Section 25
Bipolar Junction Transistor – Design

25.3 Collector Doping Design (Kirk Effect, Base Pushout)

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PURDUE UNIVERSITY

School of Electrical and Computer Engineering

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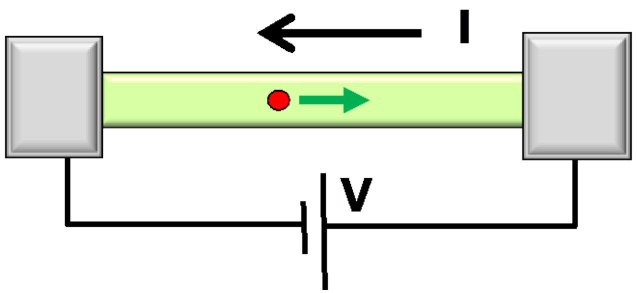
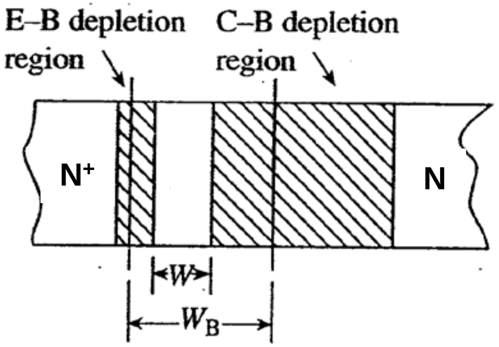


$I = G \times V$

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

charge density velocity area

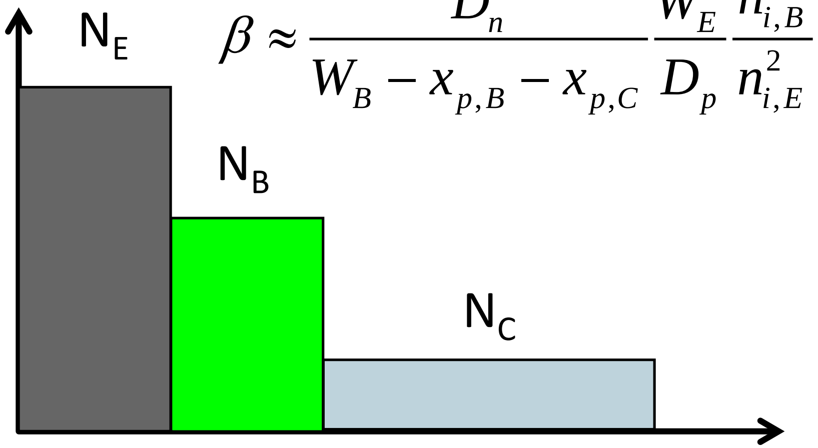
- 25.1 Current gain in BJTs
- 25.2 Base Doping Design
  - » Current Crowding – Non-Uniform Turn-On
  - » Punch-through
  - » Base Width Modulation
- 25.3 Collector Doping Design (Kirk Effect, Base Pushout)
- 25.4
- 25.5
- 25.6



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

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

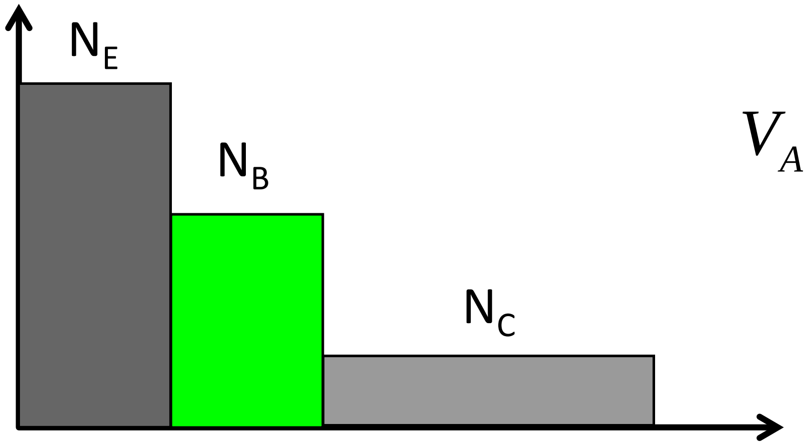
$$\beta \approx \frac{D_n}{W_B - x_{p,B} - x_{p,C}}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}$$



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

Collector Doping

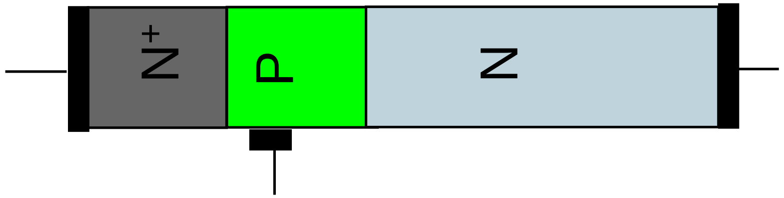
$$\beta \approx \frac{D_n}{W_B - x_{p,B} - x_{p,C}} \frac{W_E}{D_p} \frac{n_{i,B}^2}{n_{i,E}^2} \frac{N_E}{N_B}$$



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

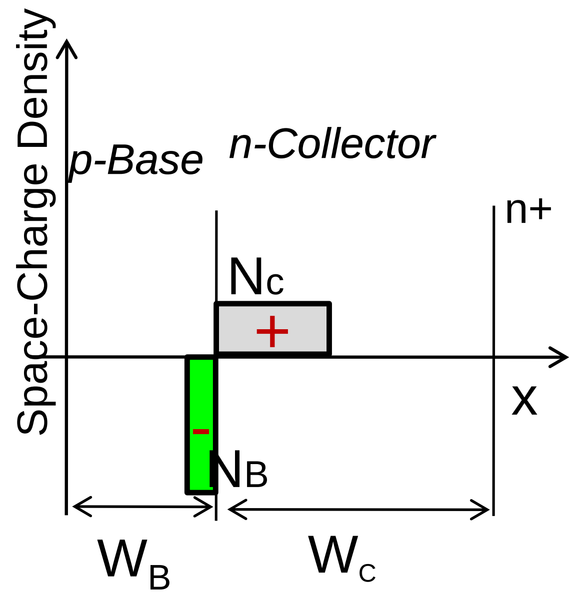
Base-Collector in reverse bias
⇒Majority carriers only
⇒No diffusion capacitance

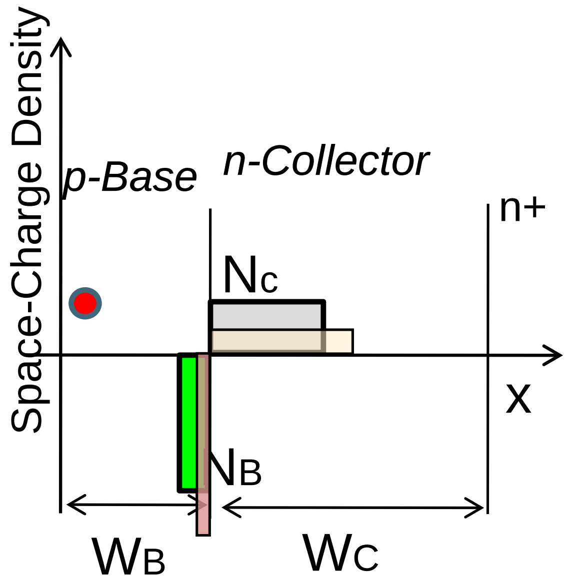
⇒Reduce capacitance
⇒Increase x_{nC}



If you want low base doping then reduce collector doping even more to increase Collector depletion.....

… but (!) Kirk Effect and Base Pushout





$$J_C = q\upsilon_{sat} n$$

Additional charge! Can be large compared to low doping

$$N_B x_B = N_C x_C$$

$$(N_B + n) x_B' = (N_C - n) x_C'$$

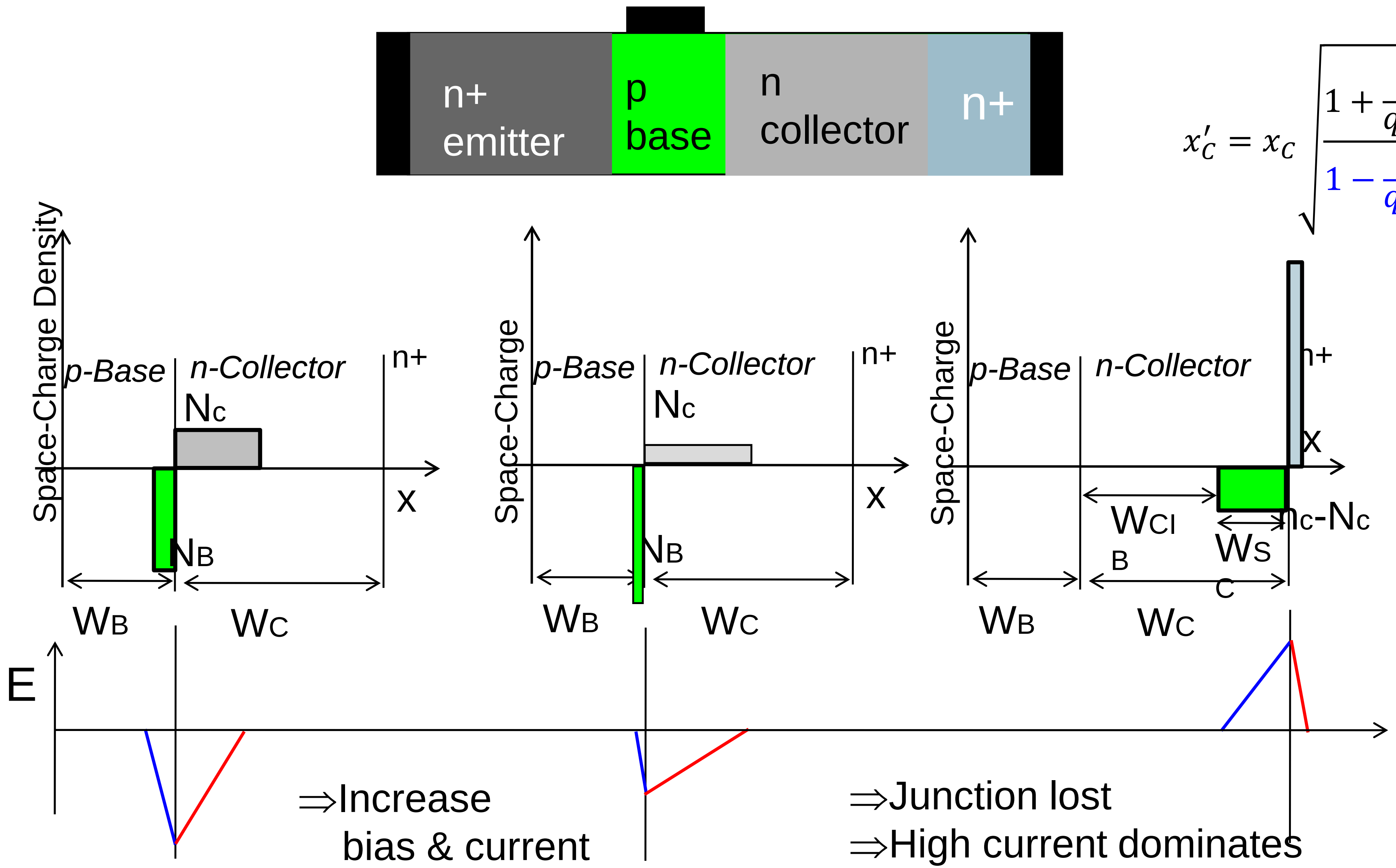
$$V_{bi} - V_{BC} = \frac{q}{2\kappa_s \varepsilon_0}\left[N_B x_B^2 + N_C x_C^2\right]$$

$$V_{bi} - V_{BC} = \frac{q}{2\kappa_s \varepsilon_0}\left[(N_B + n) x_B^2{}' + (N_C - n) x_C^2{}'\right]$$

$$x_C' = x_C \sqrt{\frac{1 + \frac{n}{N_B}}{1 - \frac{n}{N_C}}}$$

$$x_C' = x_C \sqrt{\frac{1 + \frac{J_C}{q\upsilon_{sat} N_B}}{1 - \frac{J_C}{q\upsilon_{sat} N_C}}}$$

Kirk Effect and Base Pushout

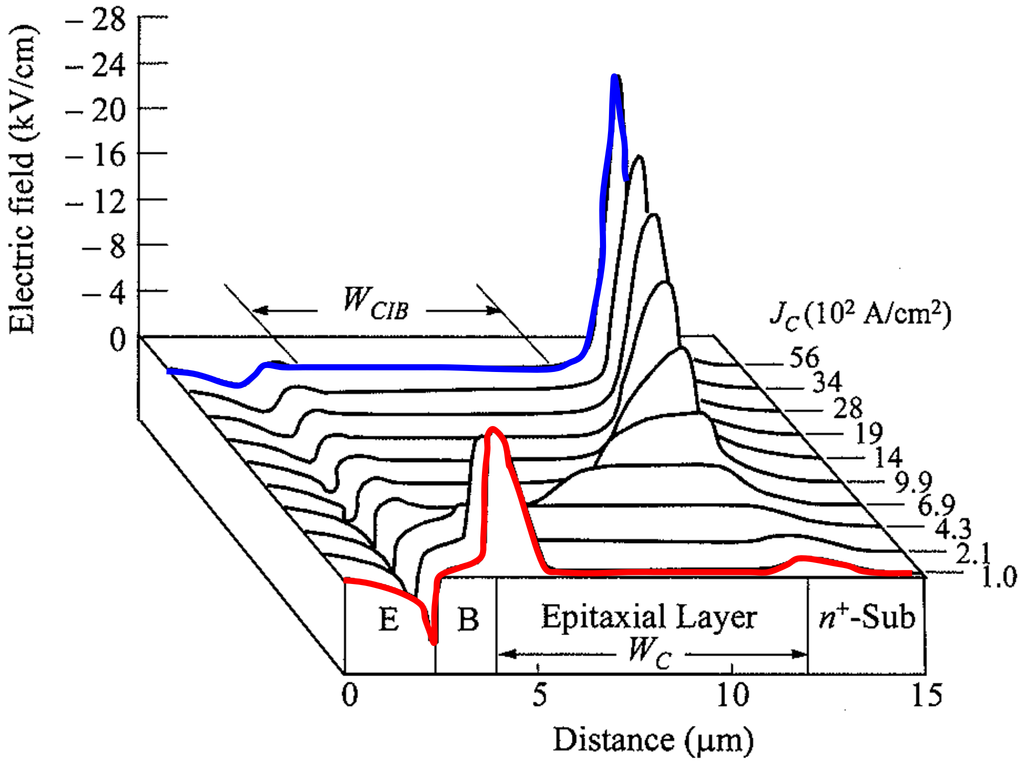


$$x'_C = x_C\sqrt{\frac{1 + \frac{J_C}{qv_{sat}N_B}}{1 - \frac{J_C}{qv_{sat}N_C}}}$$

⇒Increase
bias & current

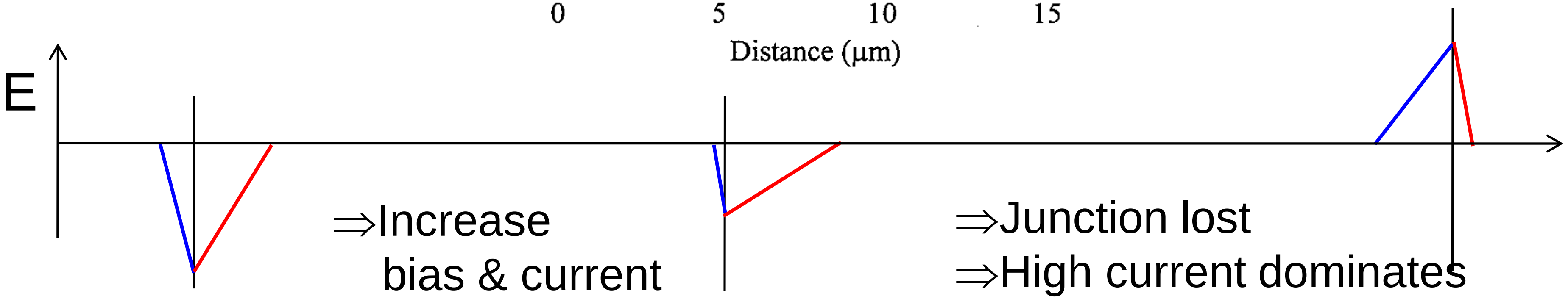
⇒Junction lost
⇒High current dominates collector doping

Key point : Under high current and low collector doping the depletion approximation is invalid in the B-C junction!



$$x'_C = x_C \sqrt{\frac{1 + \frac{J_C}{q\upsilon_{sat} N_B}}{1 - \frac{J_C}{q\upsilon_{sat} N_C}}}$$

$$J_{C,crit} = q\upsilon_{sat} N_C \equiv J_K$$



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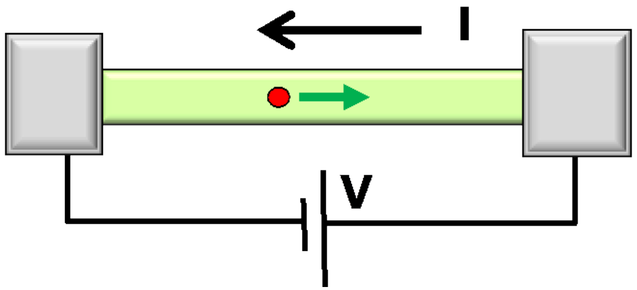

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$$= q \times n \times v \times A$$

charge density velocity area

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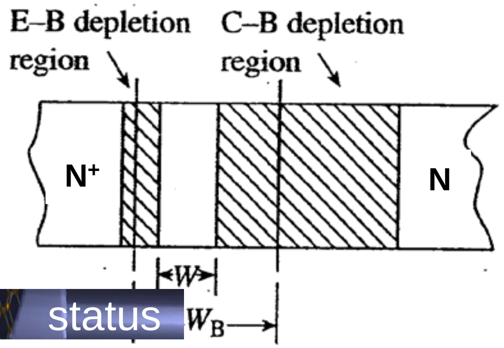

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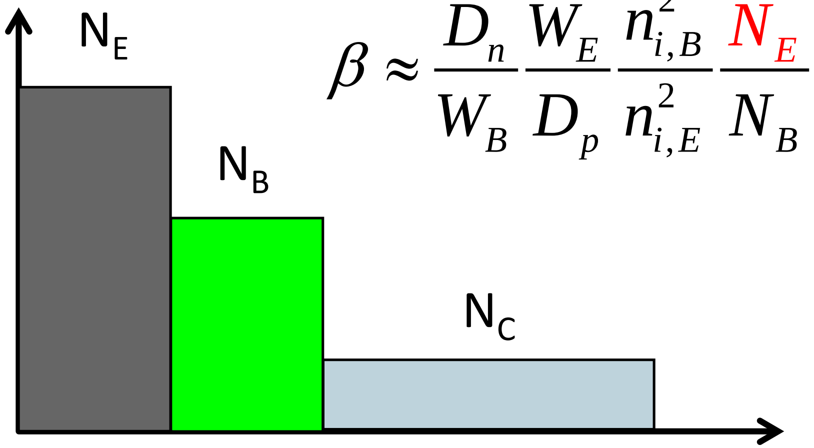
status

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



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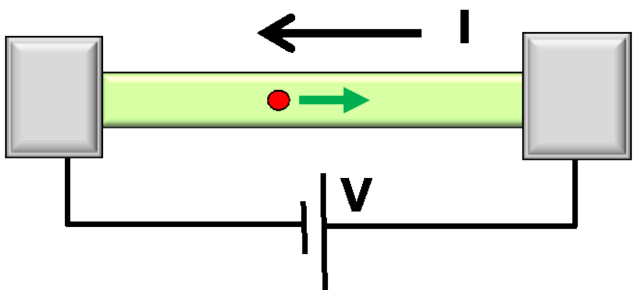

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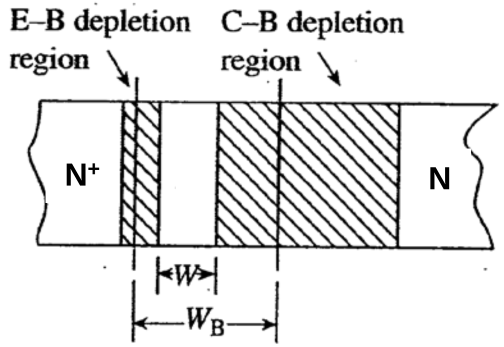

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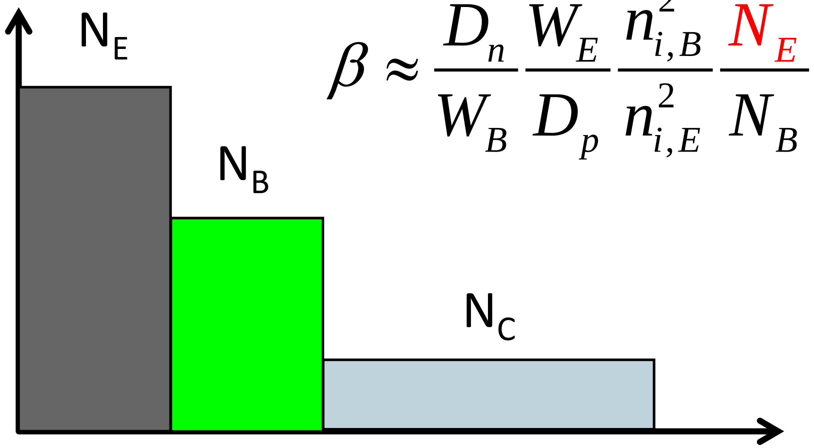

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