VE320 – Summer 2021

Introduction to Semiconductor Devices

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Chapter 12 Bipolar Junction Transistor

Outline

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12.1 Review and example

12.2 Bipolar Junction transistor

12.3 Early Effect

12.4 Summary

12.5 Quantitative analysis of BJT gain

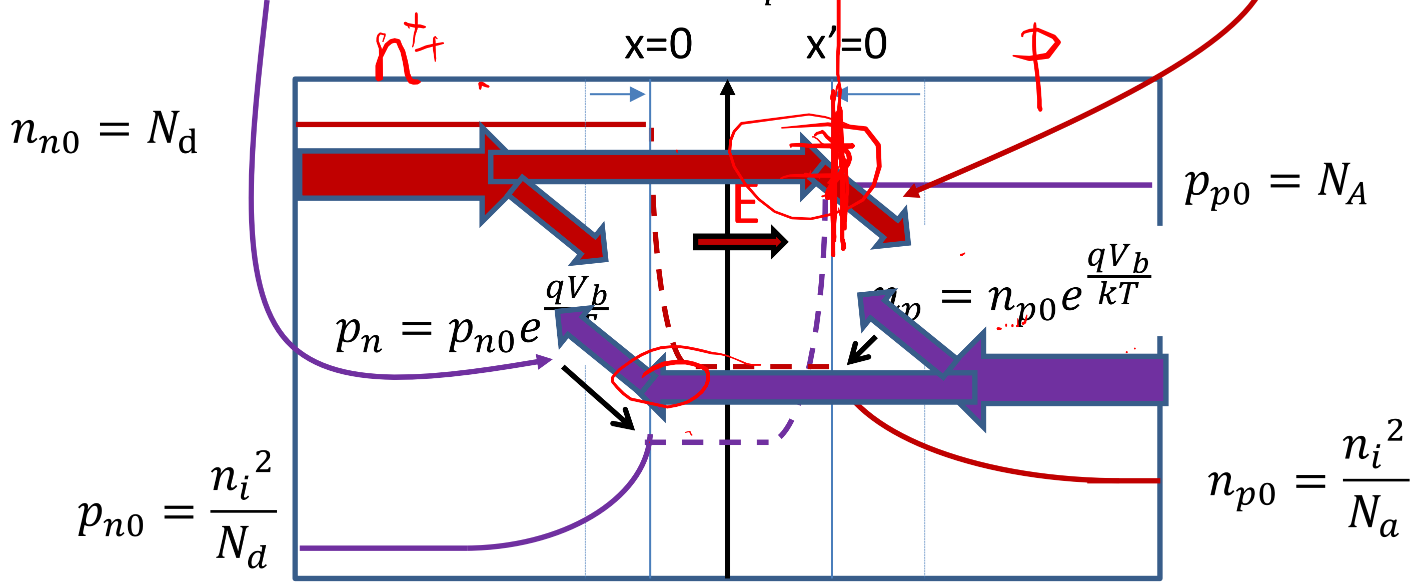
12.1 Previously: pn Junction Current

- charge carrier transport: forward bias: current ratio

$$J_n = -qD_n\frac{dn_p}{dx} = -\frac{qD_n n_{p0}}{L_n}\left(e^{\frac{qV_b}{kT}} - 1\right)e^{-x/L_n}$$

$$\boxed{\frac{J_n}{J_p} = \frac{D_n N_d/L_n}{D_p N_a/L_p}}$$

$$J_p = -qD_p\frac{dp_n}{dx} = -\frac{qD_p p_{n0}}{L_p}\left(e^{\frac{qV_b}{kT}} - 1\right)e^{x/L_p}$$



Assumption: No recombination-generation in depletion region.

12.1 Example: pn Junction Current

Finding L_n, τ_n in **p-type** region because electrons are minority carriers.

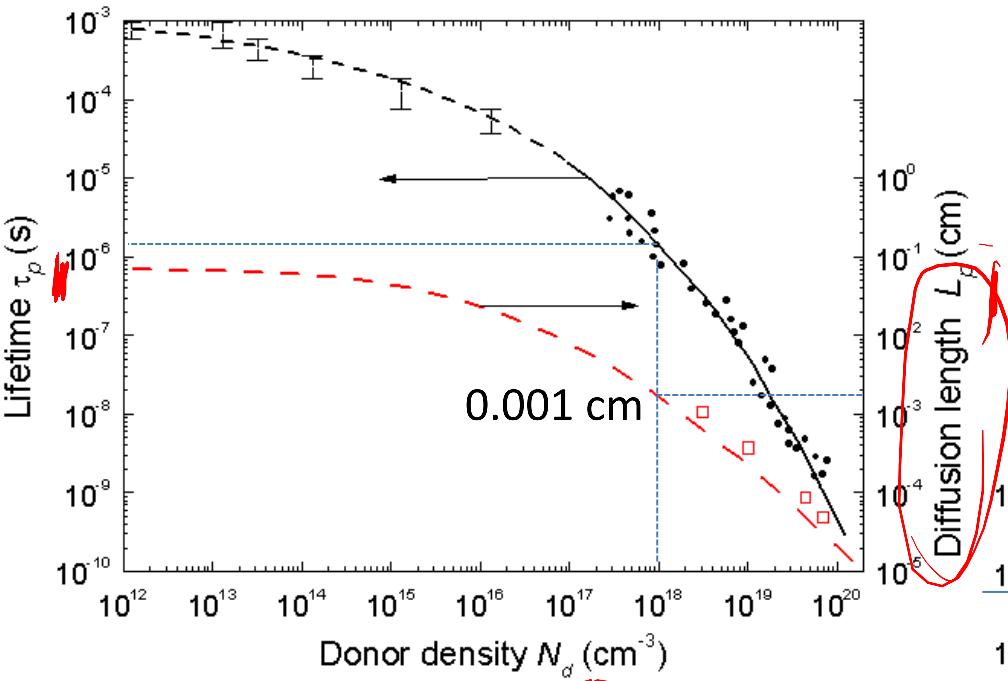
For $N_a = 10^{16}\ cm^{-3}$ $L_n = 0.04cm$ $\tau_n = 5\times10^{-5} s$

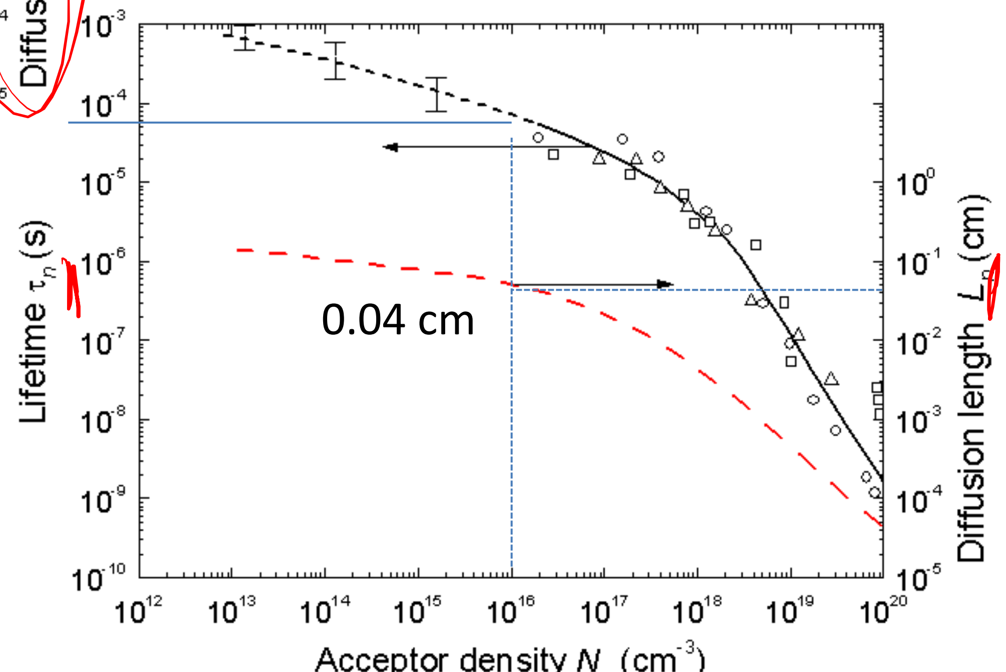
Finding L_p, τ_p in **n-type** region because holes are minority carriers.

For $N_d = 10^{18}\ cm^{-3}$ $L_p = 0.0015cm$ $\tau_p = 1.5\times10^{-6} s$

$$\boxed{\frac{J_n}{J_p} = \frac{D_n N_d / L_n}{D_p N_a / L_p} = \frac{L_n/\tau_n}{L_p/\tau_p}\frac{N_d}{N_a} \approx \frac{\dfrac{4\times10^{-2}}{5\times10^{-5}}}{\dfrac{1.5\times10^{-3}}{1.5\times10^{-6}}} \times \frac{10^{18}}{10^{16}} = 80}$$

12.1 Example: pn Junction Current





http://www.ioffe.ru/SVA/NSM/Semicond/Si/

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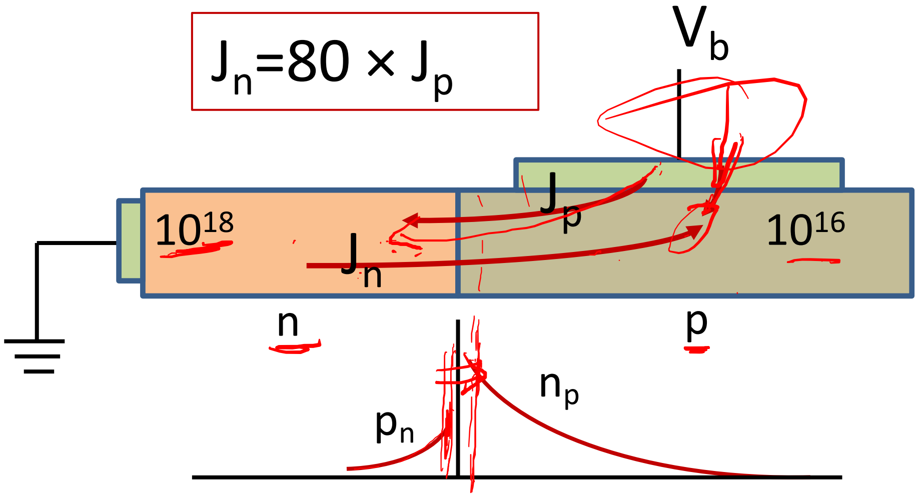
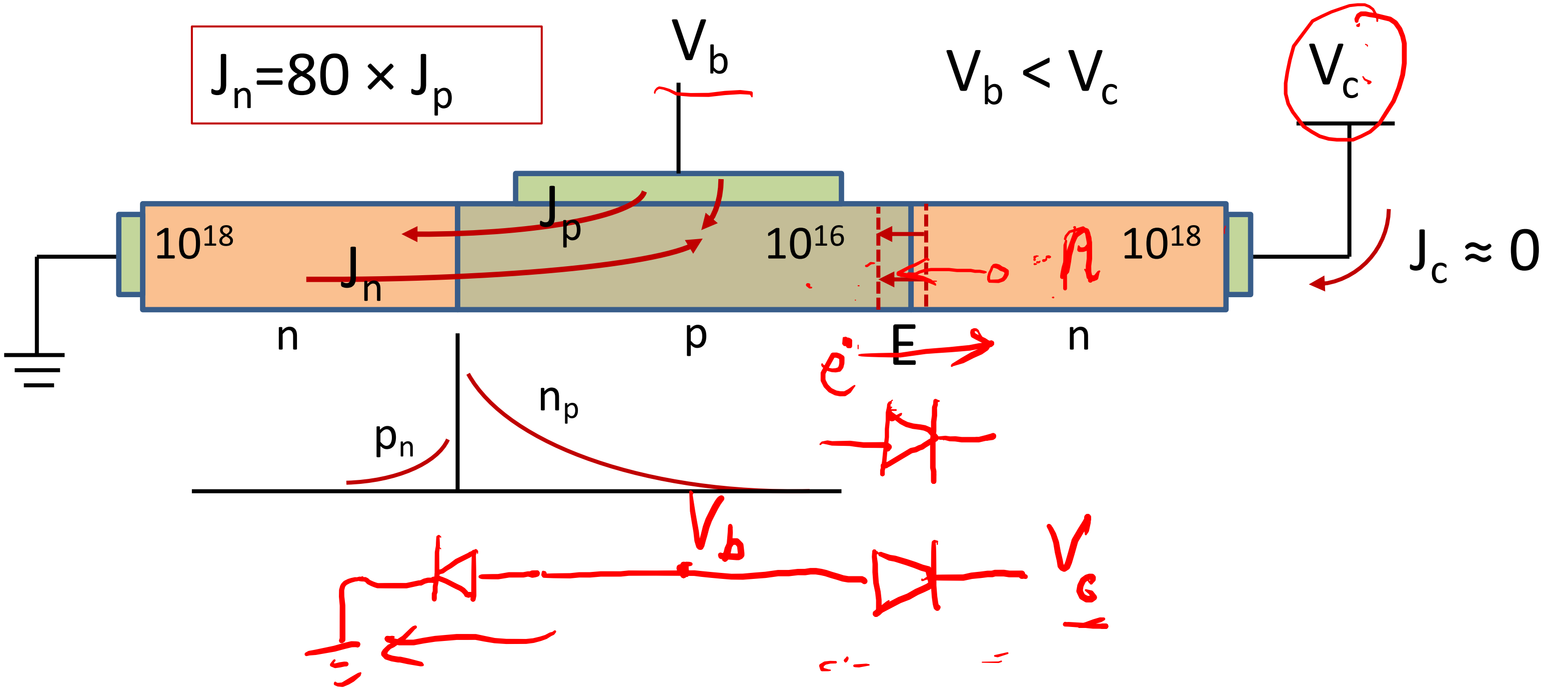
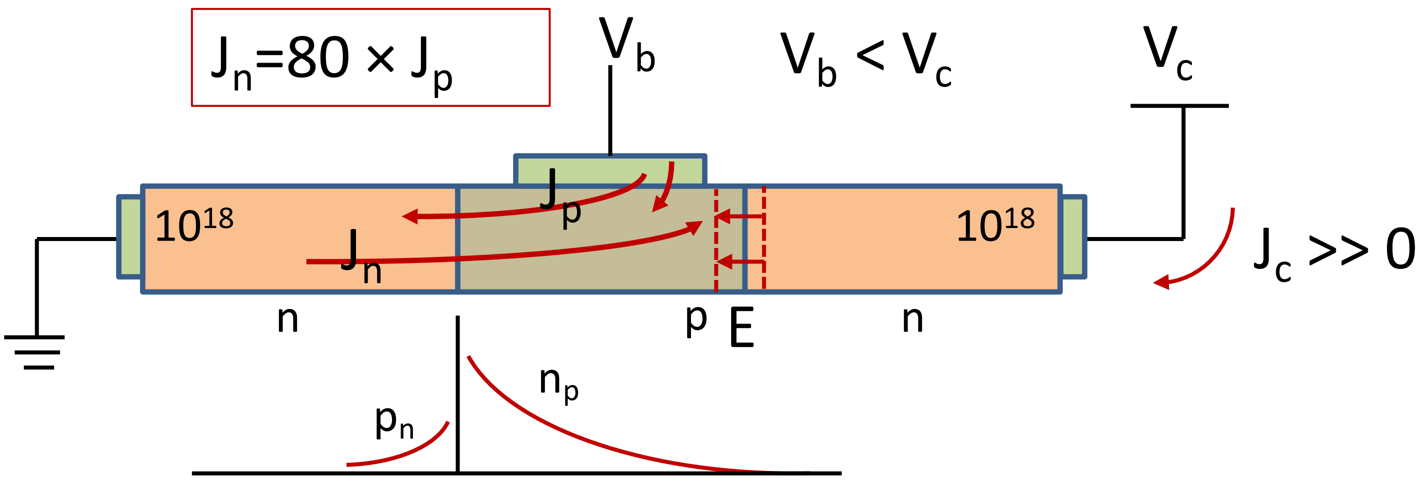
12.2 Bipolar Junction transistor



12.2 Bipolar Junction transistor



12.2 Bipolar Junction transistor



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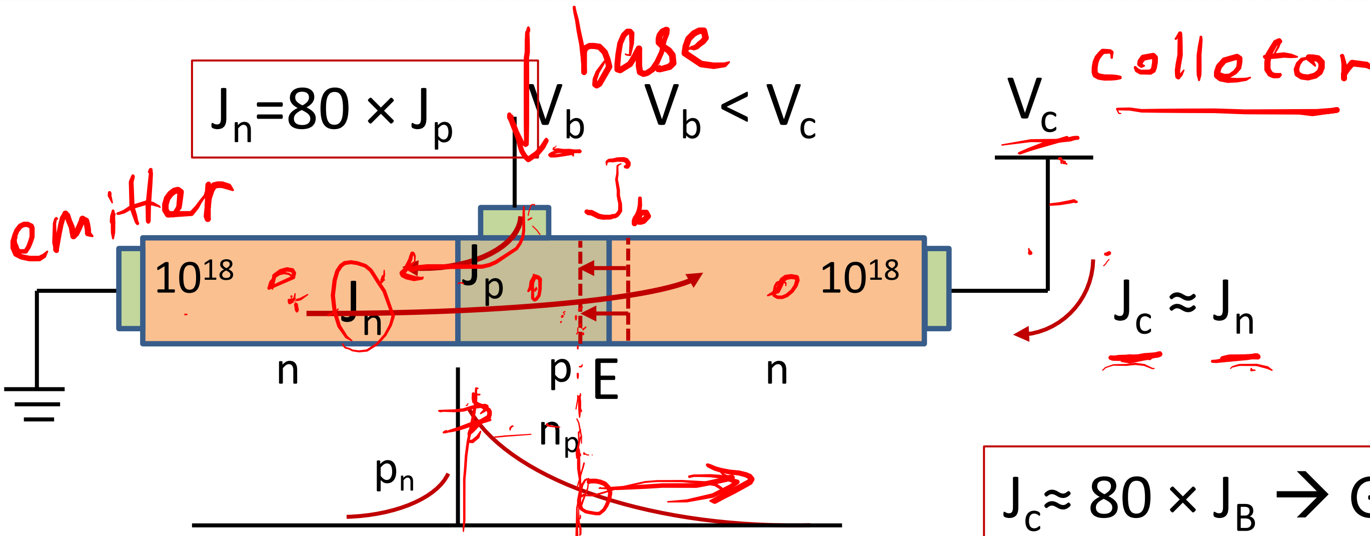
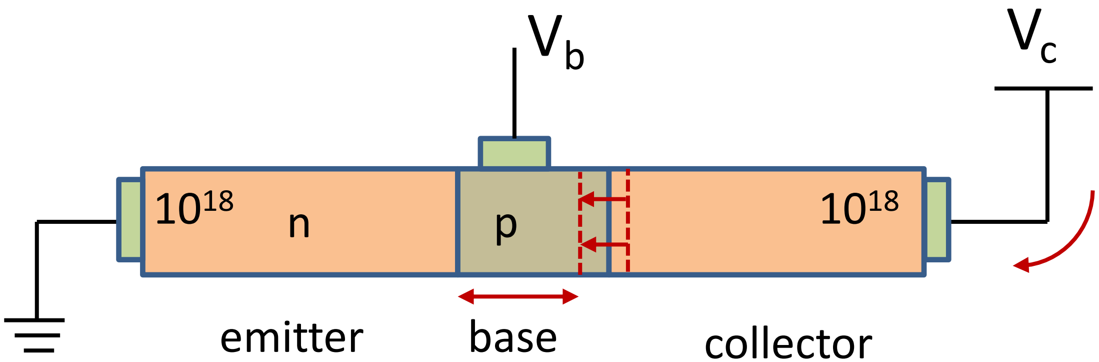


$J_c \approx 80 \times J_B \rightarrow$ Gain $\beta=80$

$J_B \approx J_p$

12.2 Bipolar Junction transistor



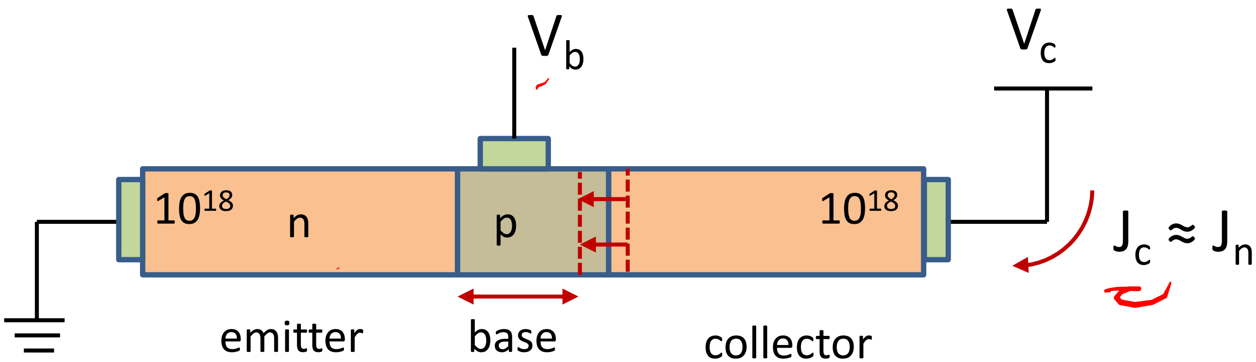
$J_c \approx J_n$

$\boxed{J_c \approx 80 \times J_B \rightarrow \text{Gain } \beta = 80}$

BJT Charateristics:

1. Base width smaller → higher gain
2. Larger emitter-base concentration ratio → higher gain

12.2 Bipolar Junction transistor: I-V



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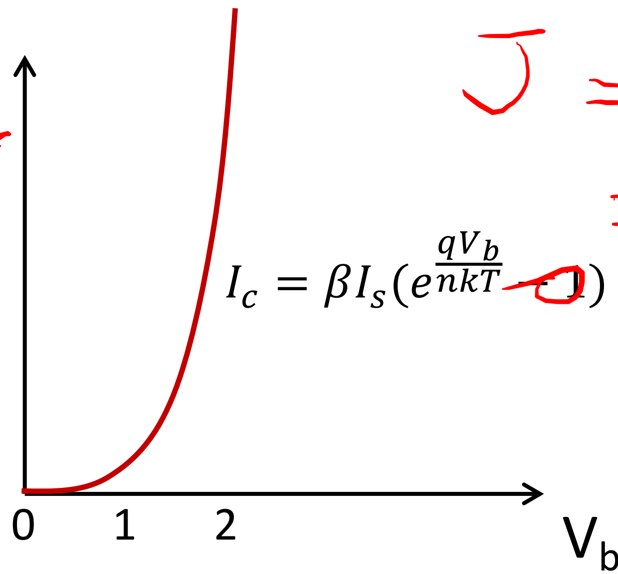


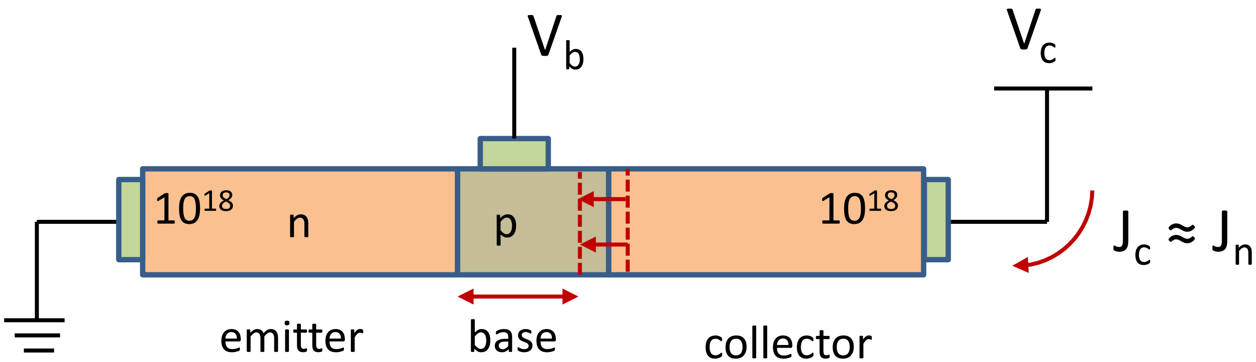
$J_n \approx I_c$

$$J = J_s\left(\exp\left(\frac{qV_b}{kT}\right) - 1\right)$$

$$= \left(\frac{D_n \cdot n_{po}}{L_n} + \frac{D_p \cdot p_{no}}{L_p}\right) e^{\frac{qV_b}{kT}}$$

$$= \underbrace{\frac{D_n n_{po}}{L_n} e^{\frac{qV_b}{kT}}}_{J_n} + \underbrace{\frac{D_p p_{no}}{L_p} e^{\frac{qV_b}{kT}}}_{J_p}$$

12.2 Bipolar Junction transistor: I-V



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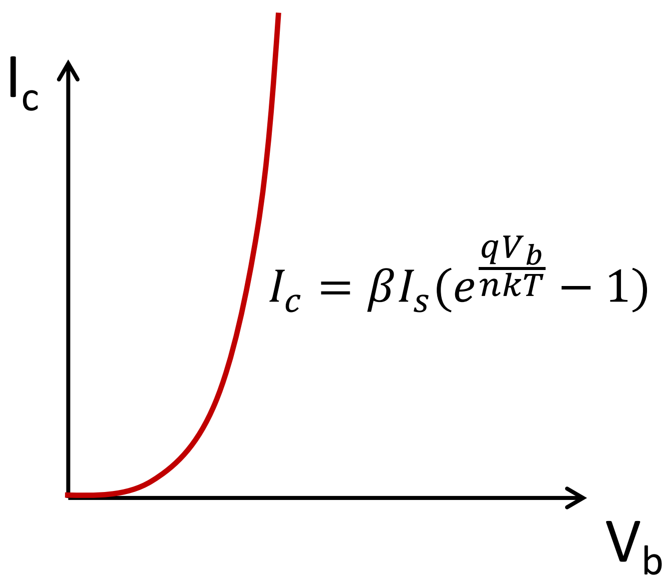
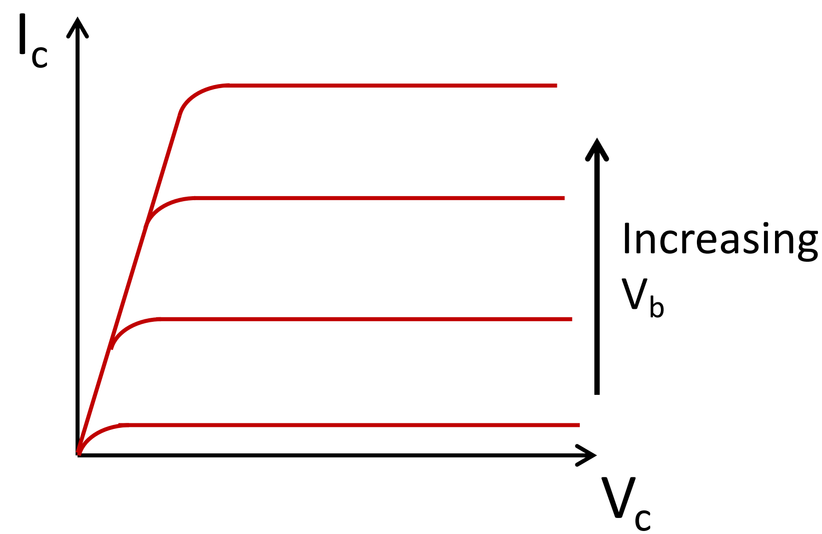
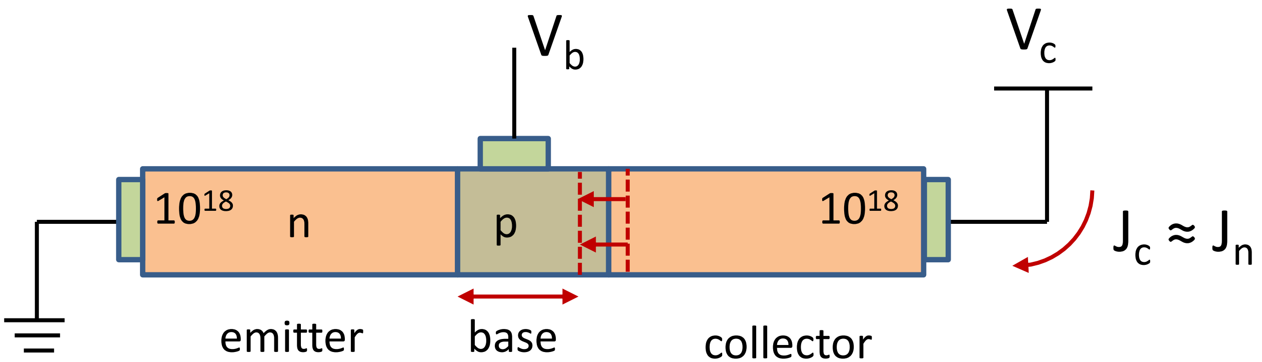
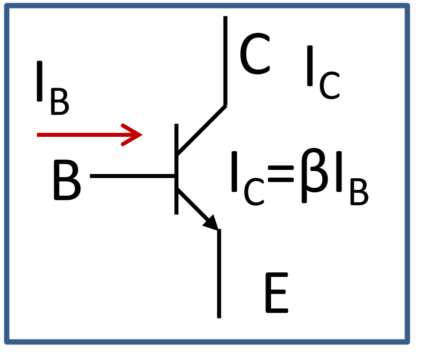




12.2 Bipolar Junction transistor: I-V

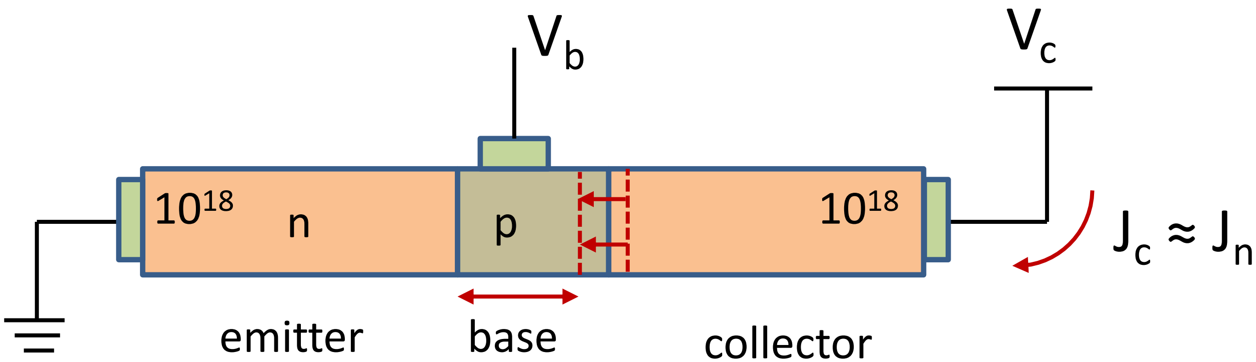


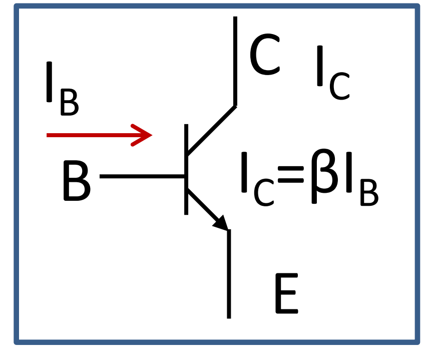
$$\boxed{J_c \approx 80 \times J_B \rightarrow \text{Gain } \beta = 80}$$



Basic facts:

12.2 Bipolar Junction transistor: I-V





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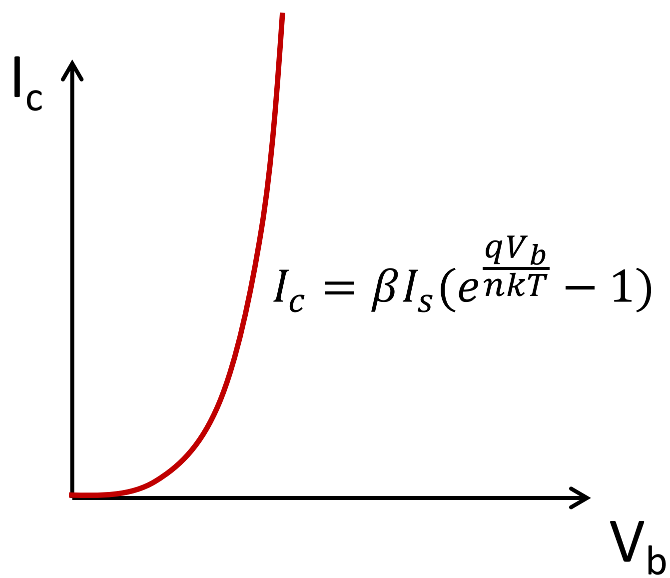

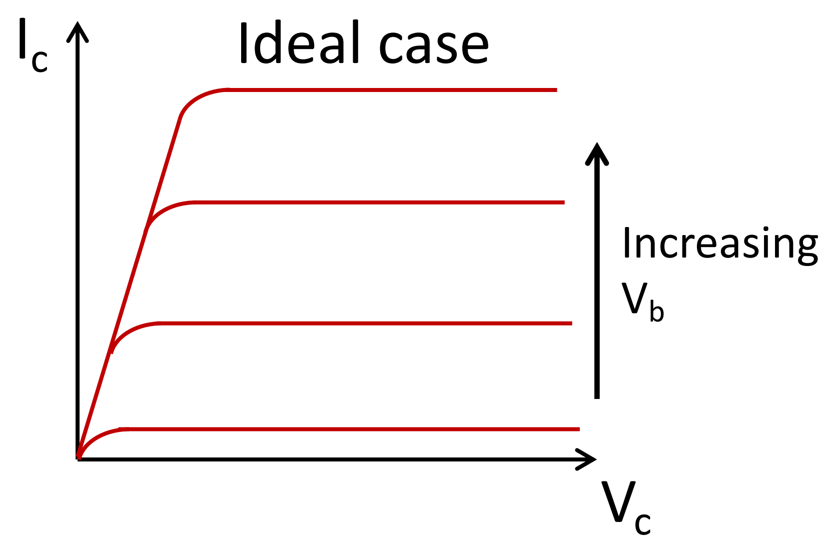

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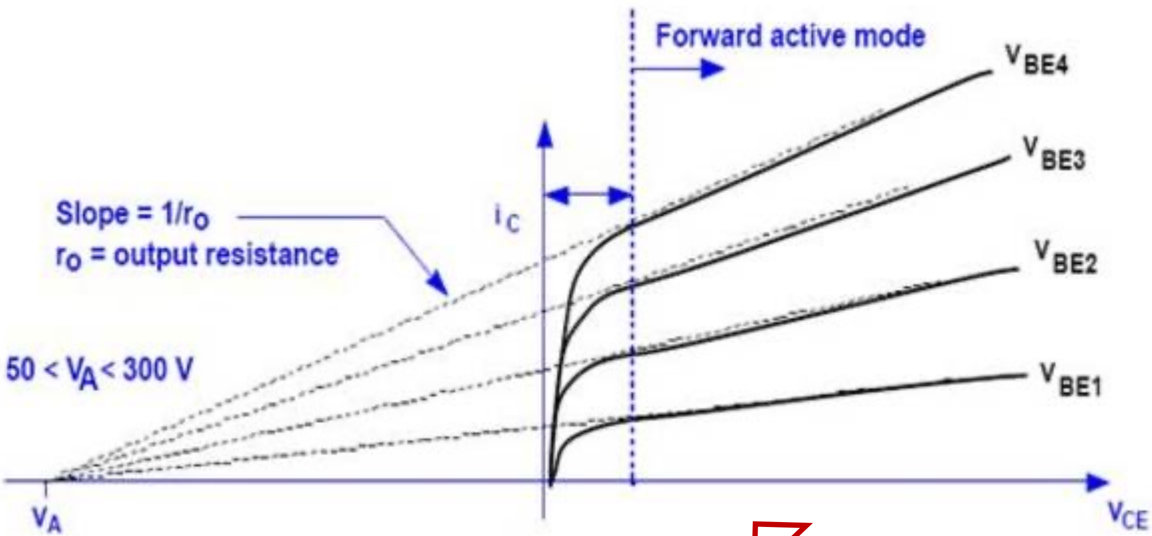
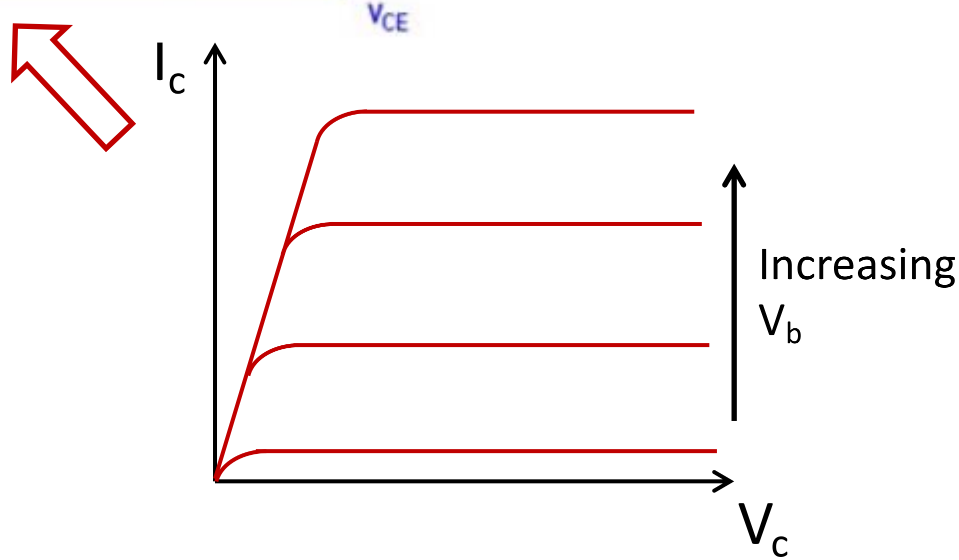
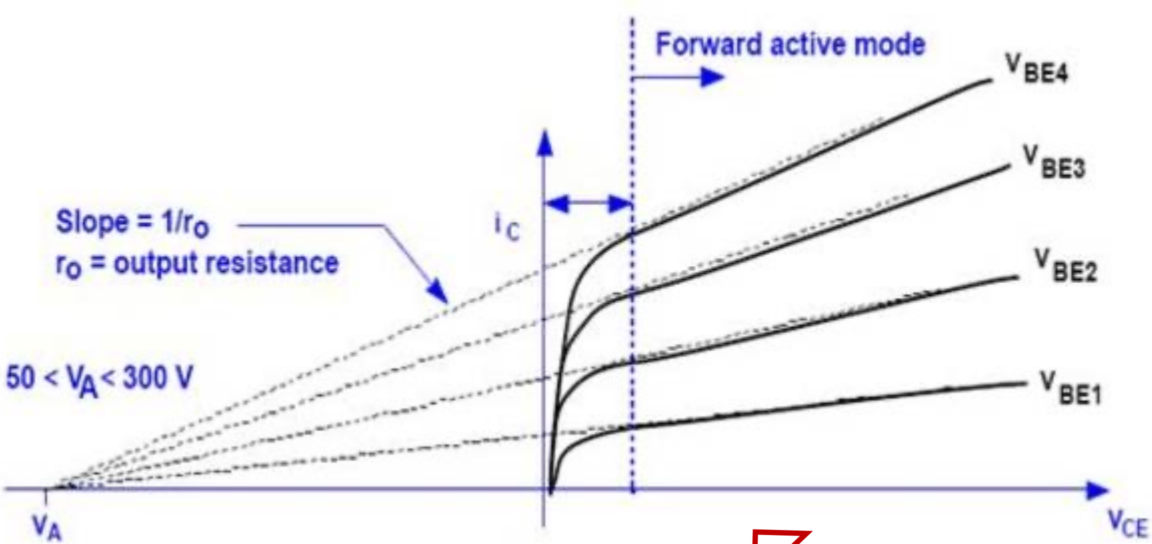
12.3 Early Effect





12.3 Early Effect



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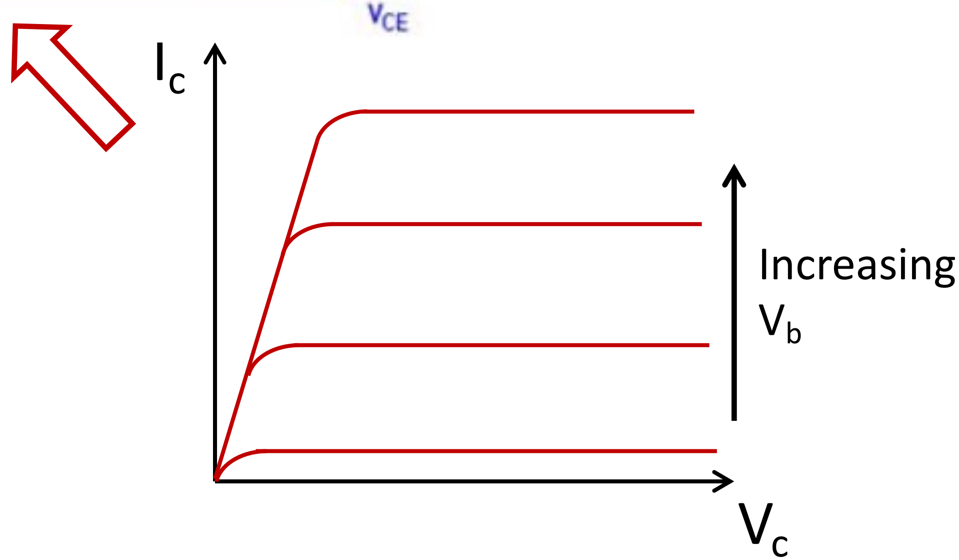

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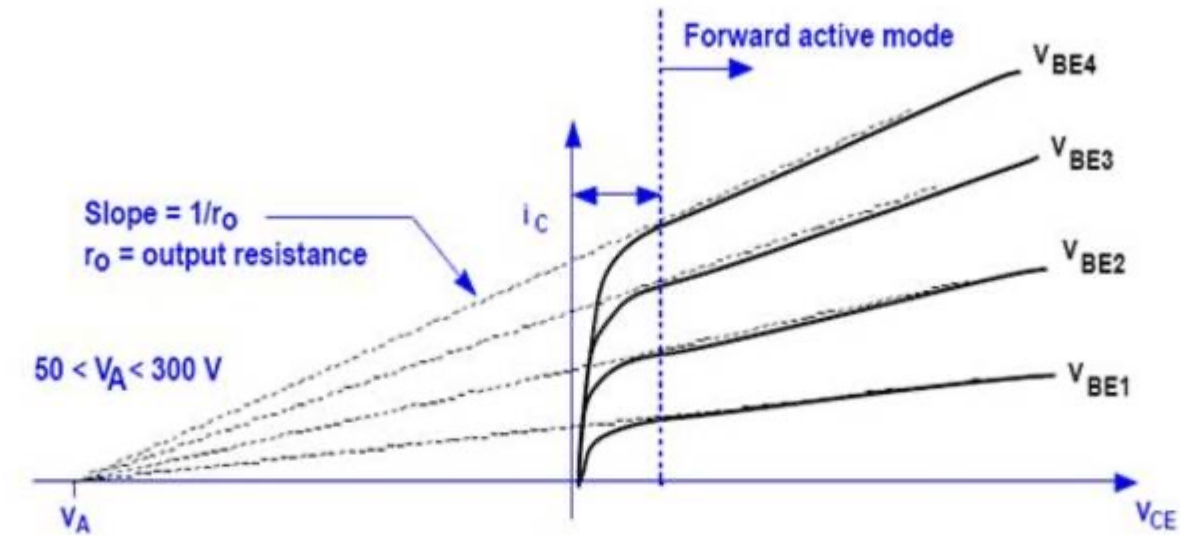

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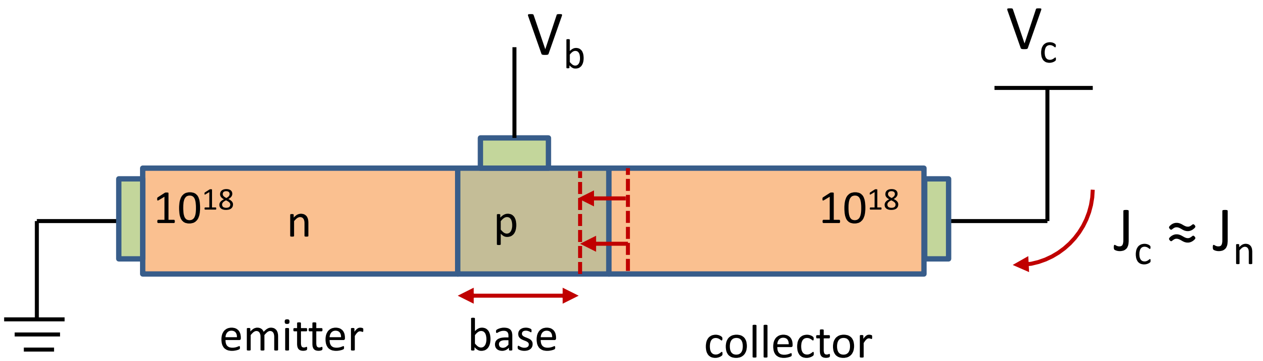

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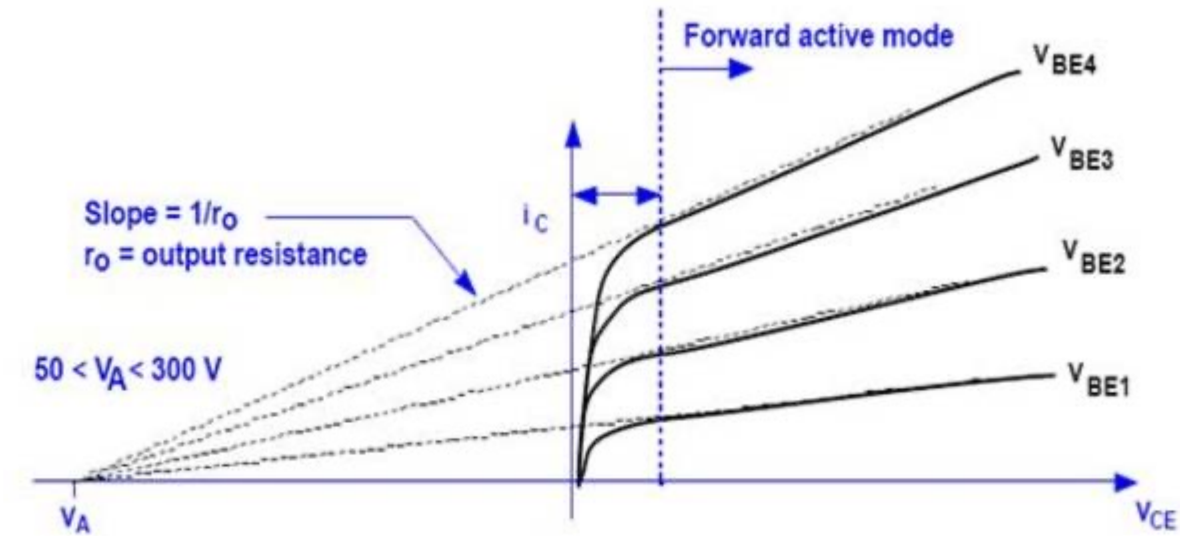

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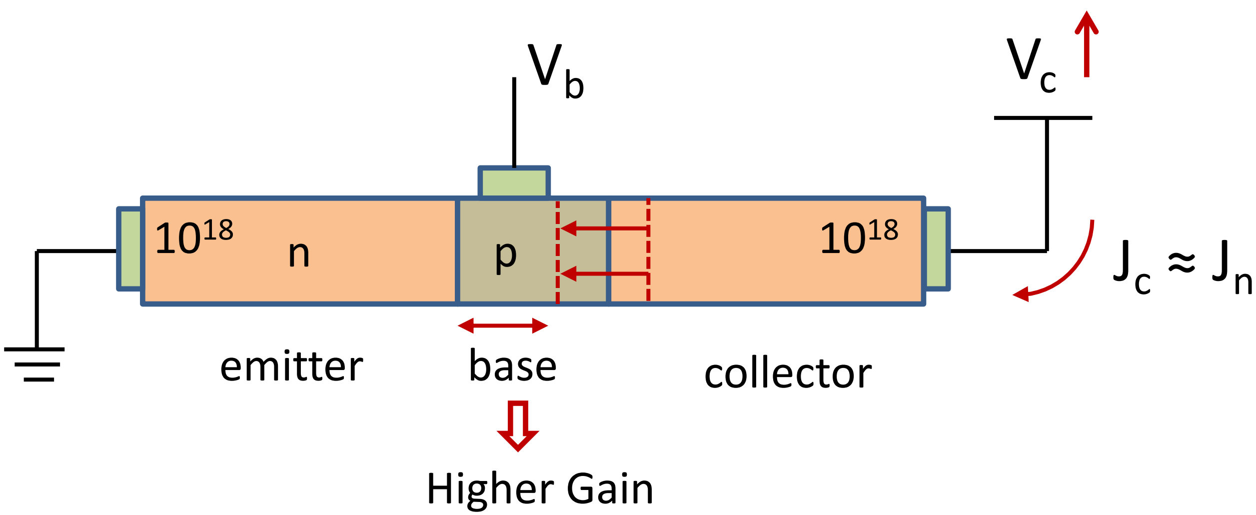
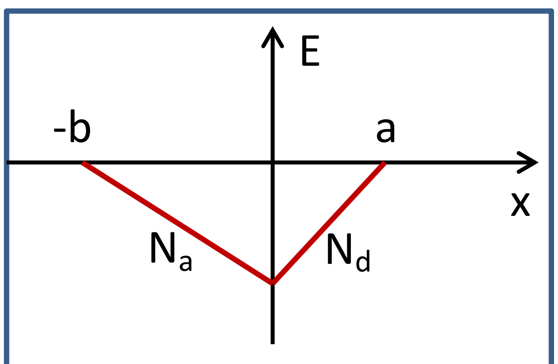
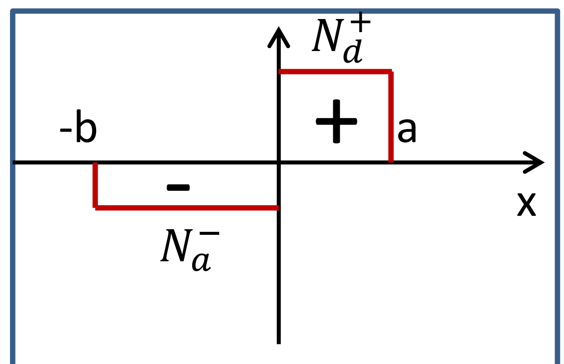


Previously…

$$a = \sqrt{\frac{2\varepsilon(V_{bi} - V_R)}{q}\frac{N_a}{N_d}\frac{1}{N_a + N_d}}$$

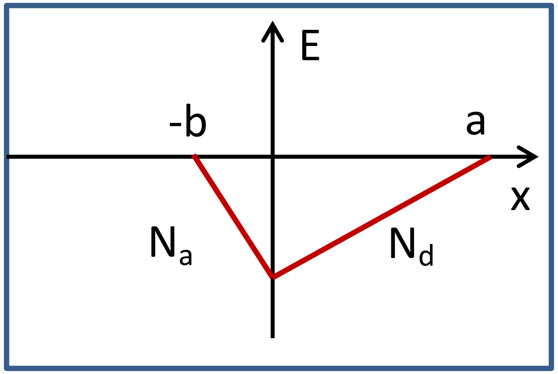
$$N_A^- b = N_D^+ a \Rightarrow b = \sqrt{\frac{2\varepsilon(V_{bi} - V_R)}{q}\frac{N_d}{N_a}\frac{1}{N_a + N_d}}$$

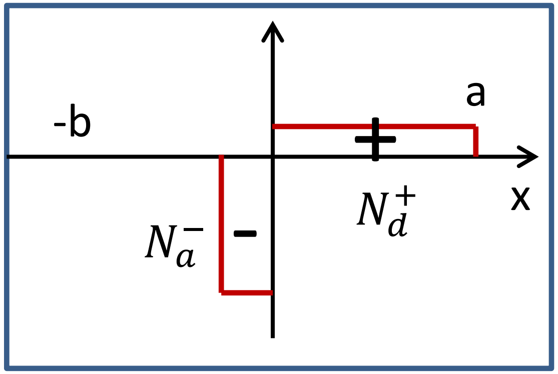




Previously…

Depletion region width W = a + b





12.3 Early Effect

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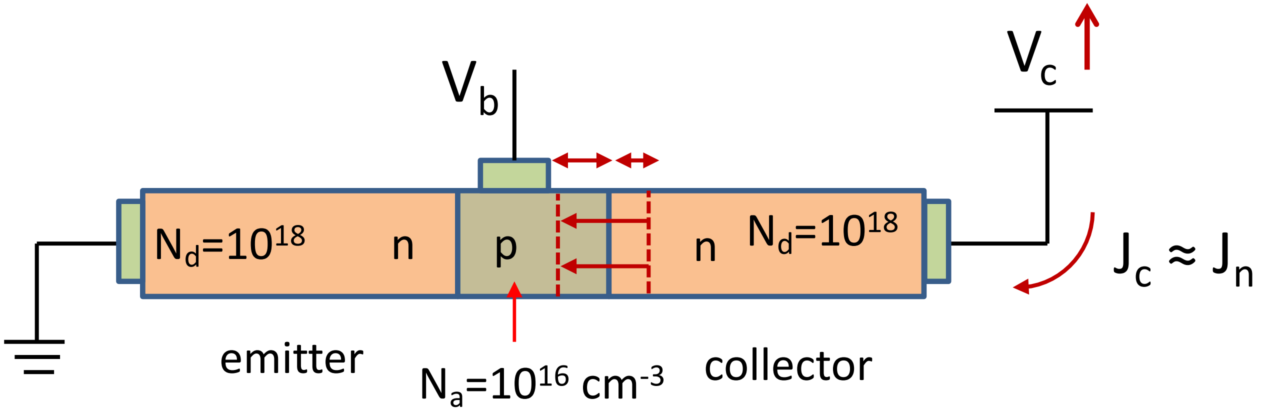

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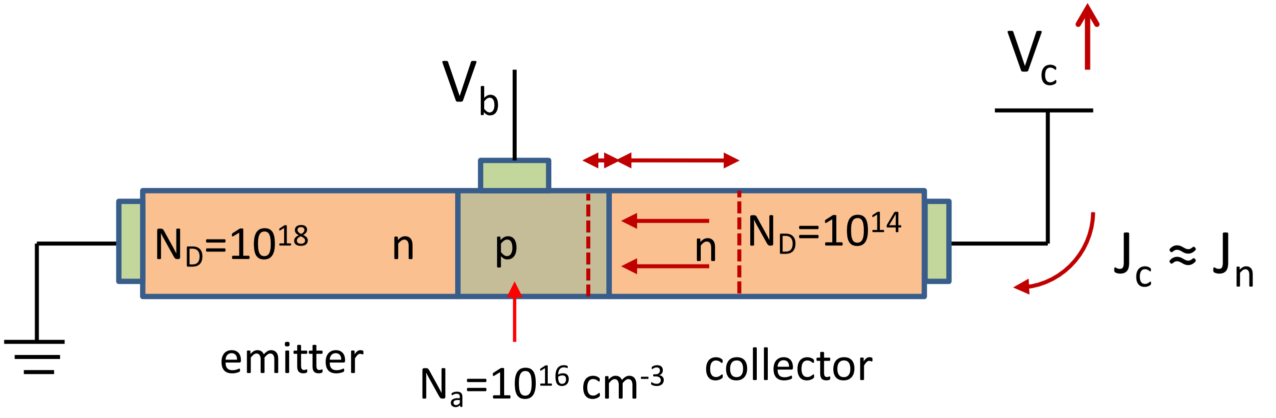

12.3 Early Effect

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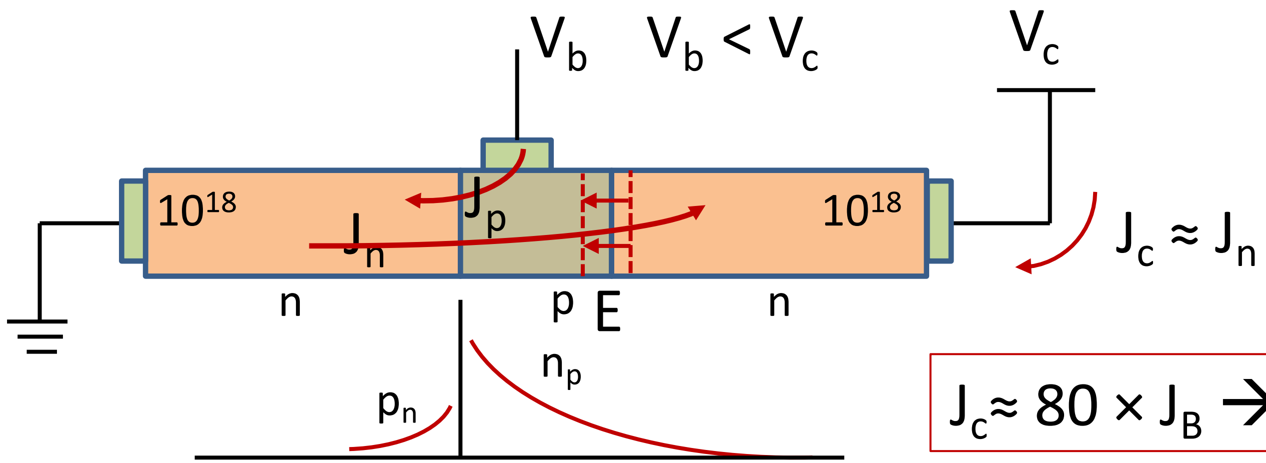

$J_c \approx 80 \times J_B \rightarrow$ Gain $\beta=80$

1. highest doping concentration is limited by solubility ($<10^{20}$)
2. Lowest doping concentration is limited by n_i and fabrication process

Basic facts:

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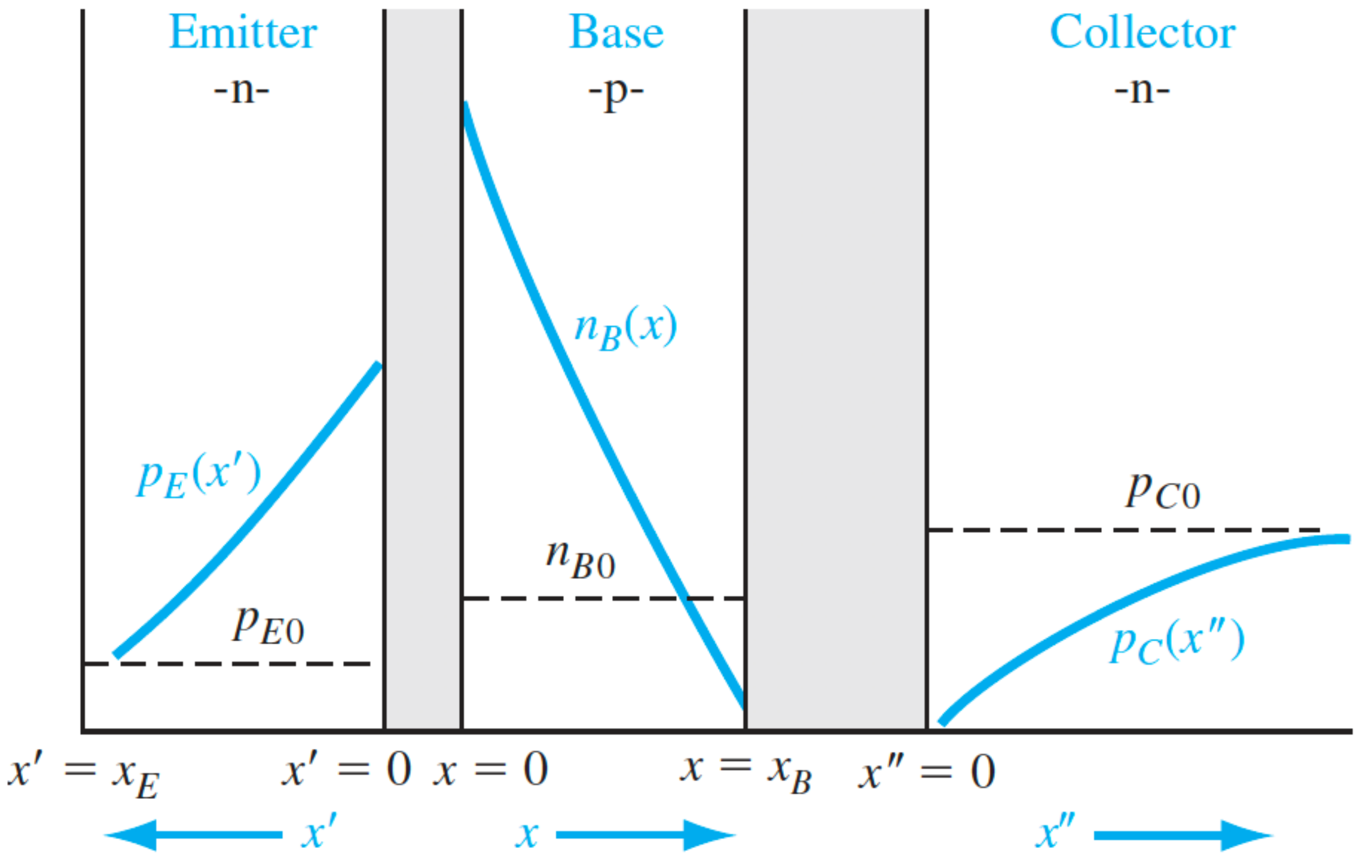
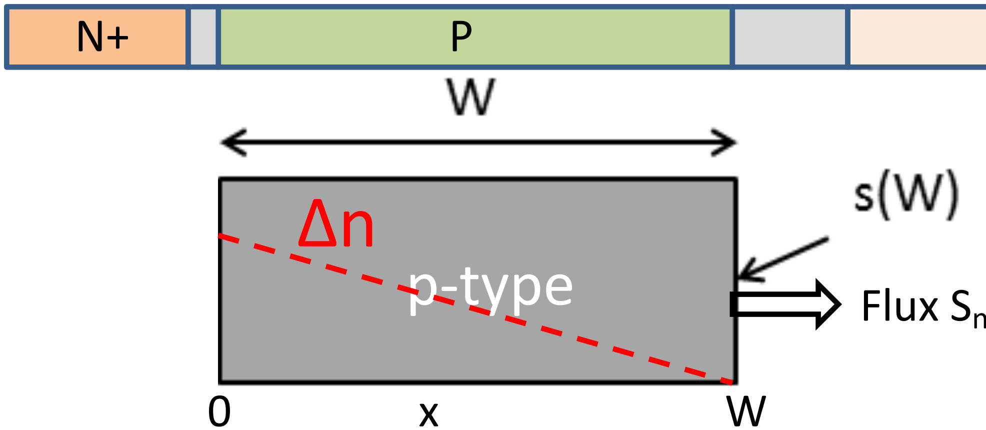


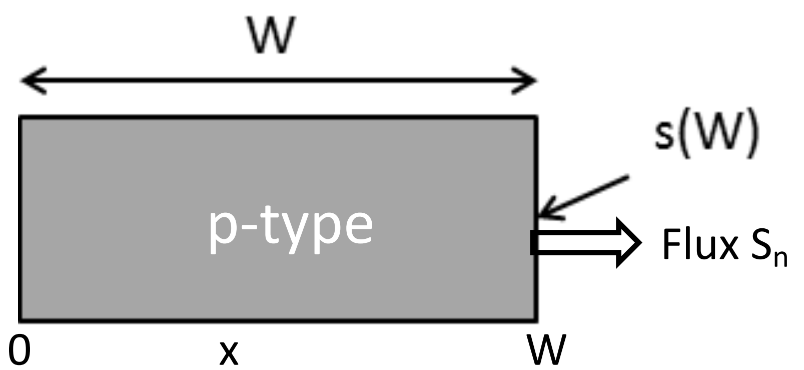
12.5 Quantitative analysis of BJT gain



$N_a = 10^{17}$ cm^{-3}, $D_n = 10$ cm^2/s, $\tau_n = 10^{-7}$ s, SRV $s(x=W) = \infty$
$\Delta n\ (x=0) = 10^{14}$ cm^{-3}

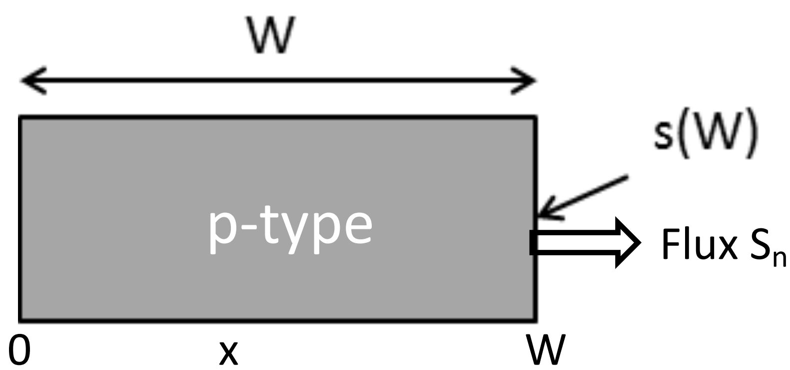
Find the electron flux Sn at x=0 and W, if
1) W=20um
2) W=2um

12.5 Quantitative analysis of BJT gain



$$0 = D_n \frac{\partial^2 \Delta n}{\partial x^2} - \frac{\Delta n}{\tau}$$

12.5 Quantitative analysis of BJT gain



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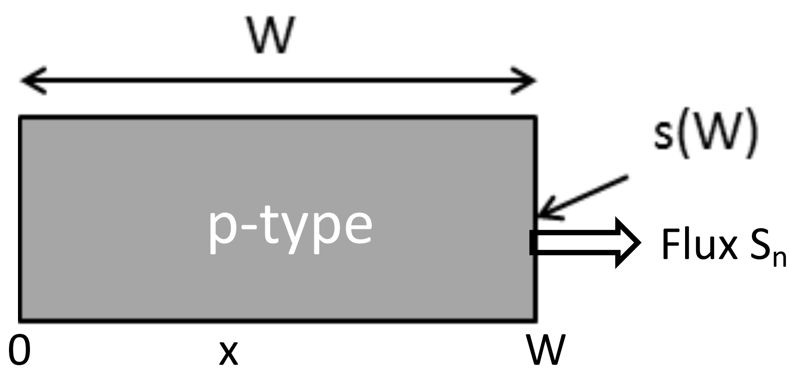

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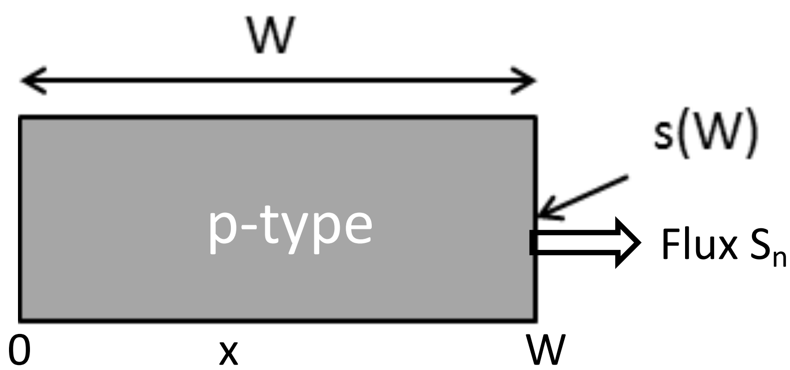

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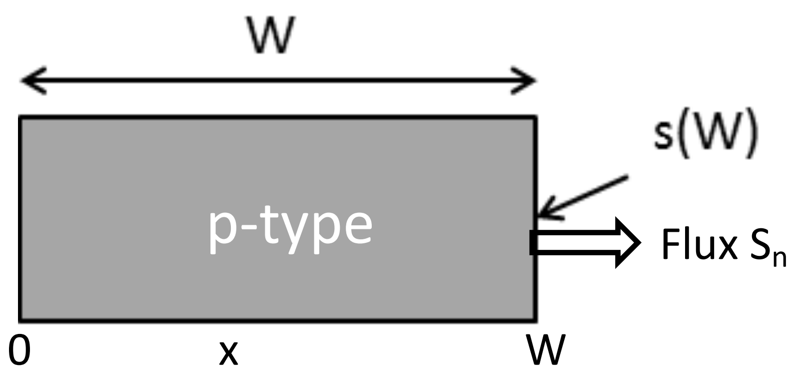

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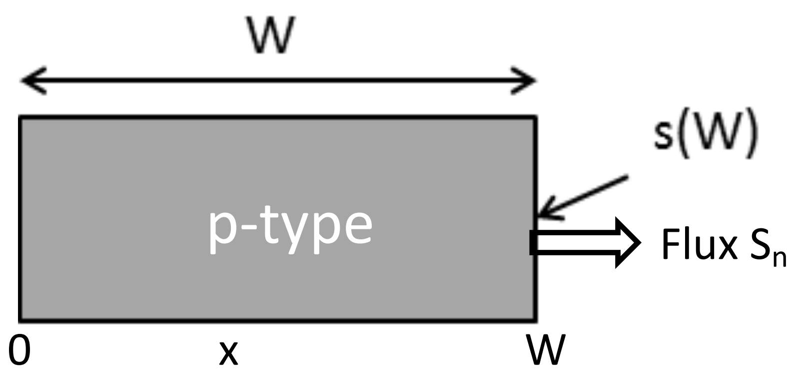

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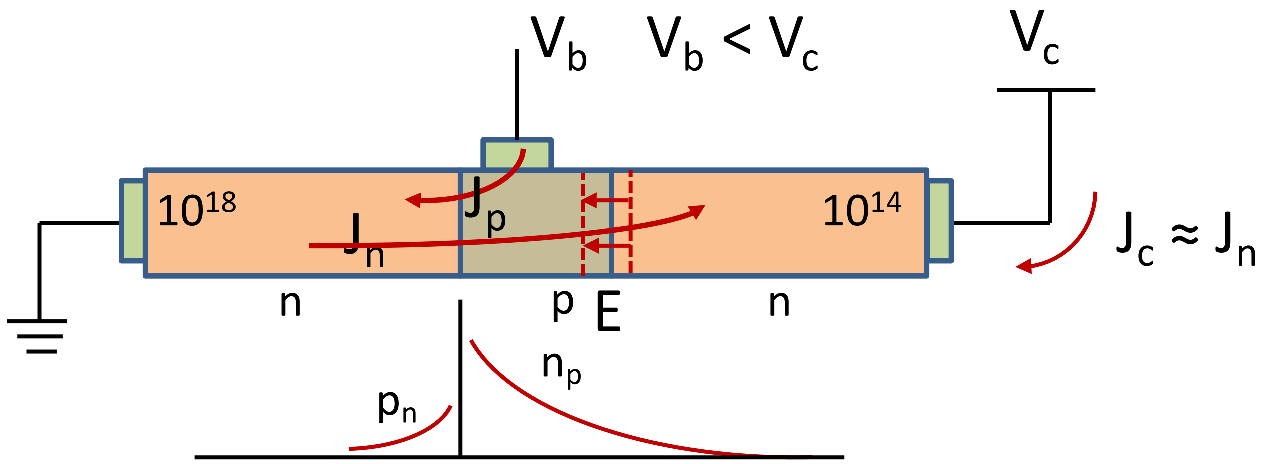
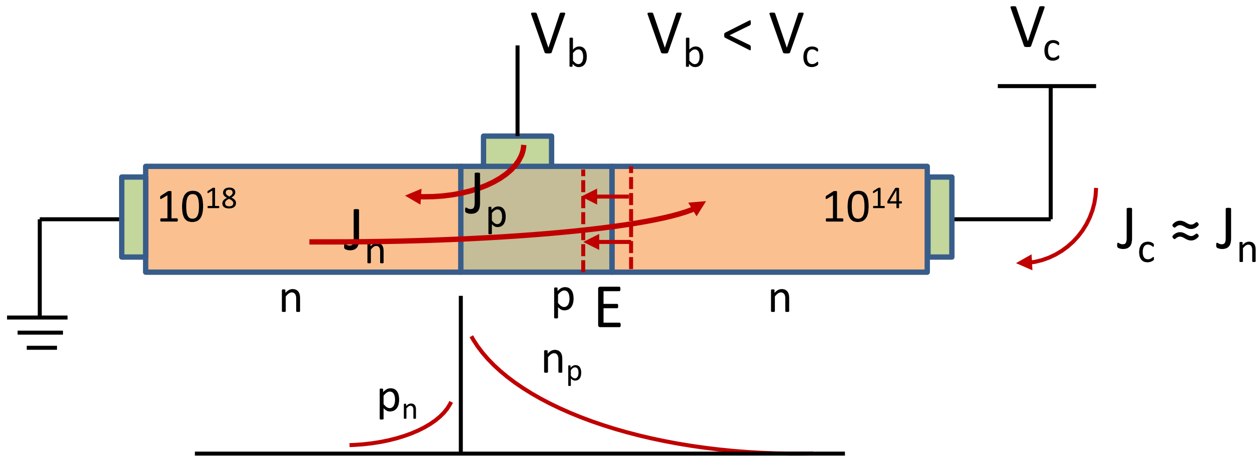


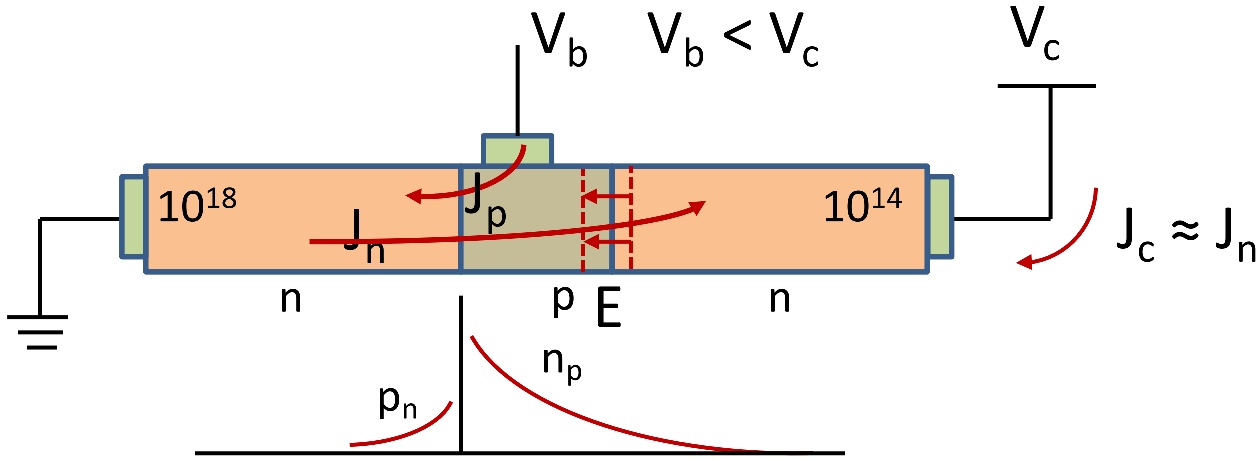
Electron flux from emitter to base: $S_n(0)$
Electron flux from base to collector: $S_n(W_b)$

12.5 Quantitative analysis of BJT gain



Electron flux from emitter to base: $S_n(0)$
Electron flux from base to collector: $S_n(W_b)$
Hole flux from base to emitter: S_p

12.5 Quantitative analysis of BJT gain



Electron flux from emitter to base: $S_n(0)$
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Hole flux from base to emitter: S_p
Base electrode flux: $S_p + S_n(0) - S_n(W_b)$

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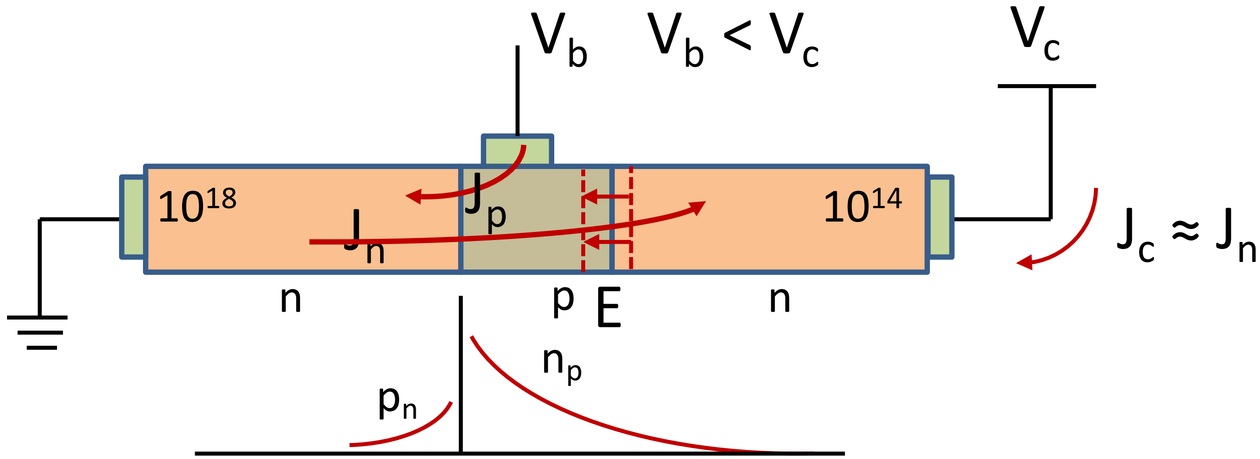

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Hole flux from base to emitter: S_p
Base electrode flux: $S_p + S_n(0) - S_n(W_b)$
Gain β = collector flux /base electrode flux $= S_n(W_b)/(S_p+S_n(0)-S_n(W_b))$

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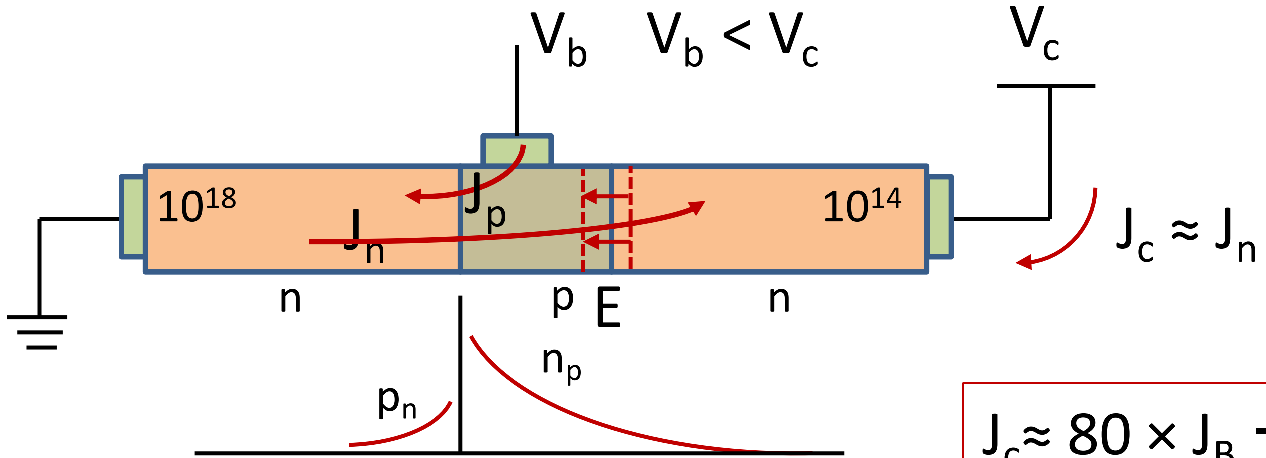

$J_c \approx 80 \times J_B \rightarrow$ Gain β=80

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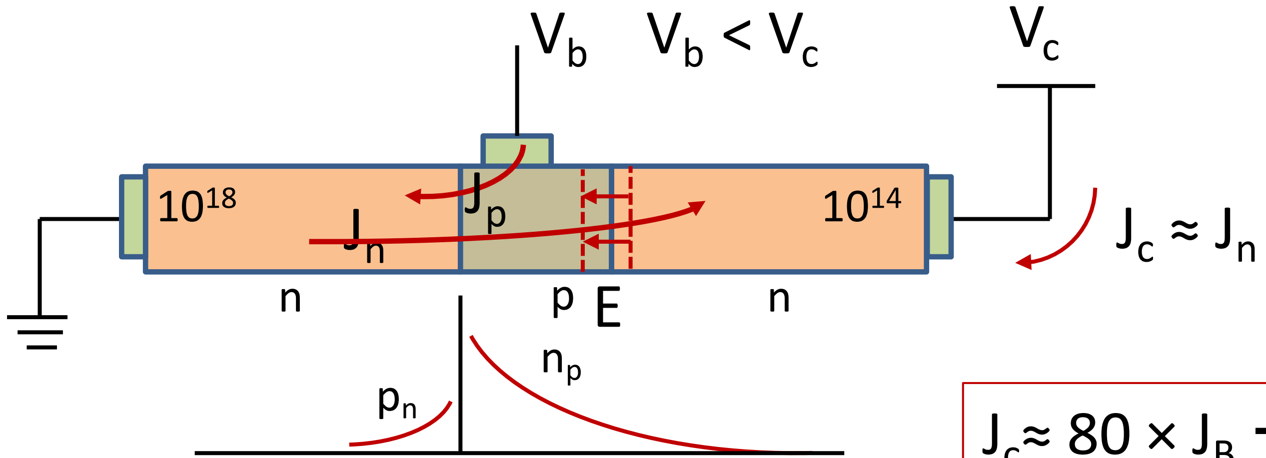

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