Section 25
Bipolar Junction Transistor – Design

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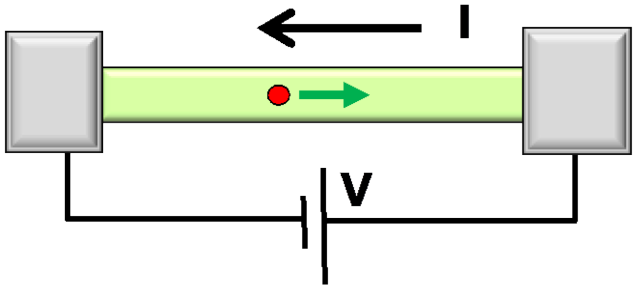
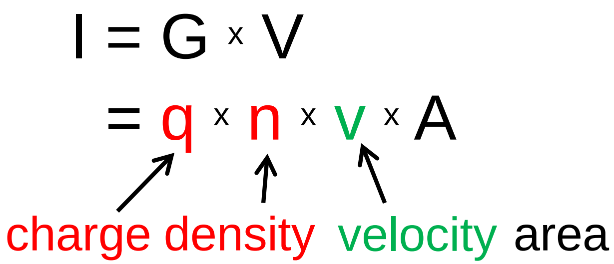
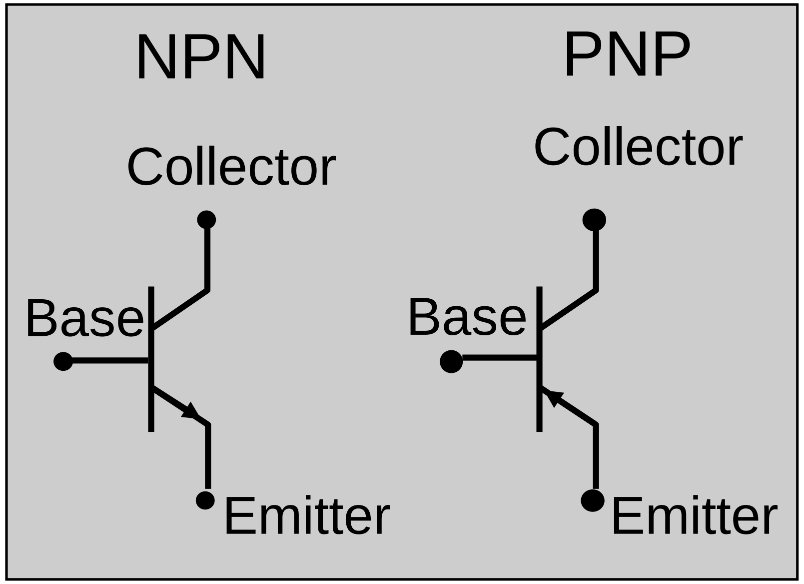
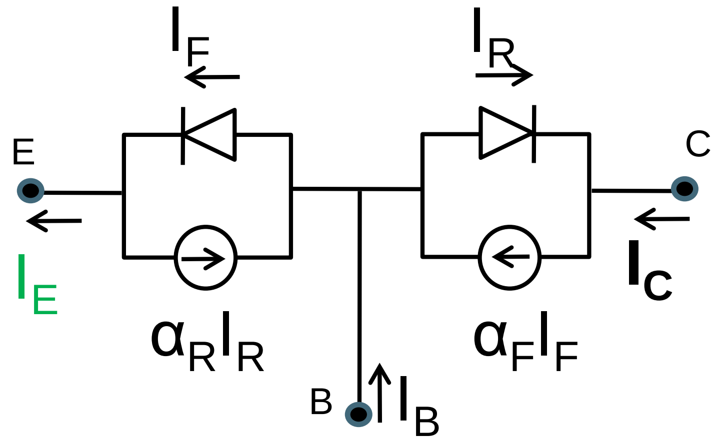
School of Electrical and Computer Engineering


I
V


I = G x V
= q x n x v x A
charge density
velocity
area


NPN
PNP
Collector
Collector
Base
Base
Emitter
Emitter


I_F
I_R
E
C
I_E
I_C
α_R I_R
α_F I_F
B
I_B

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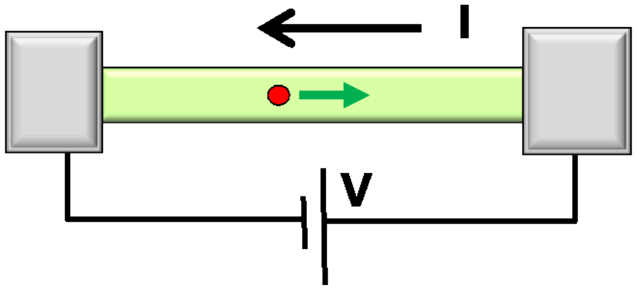
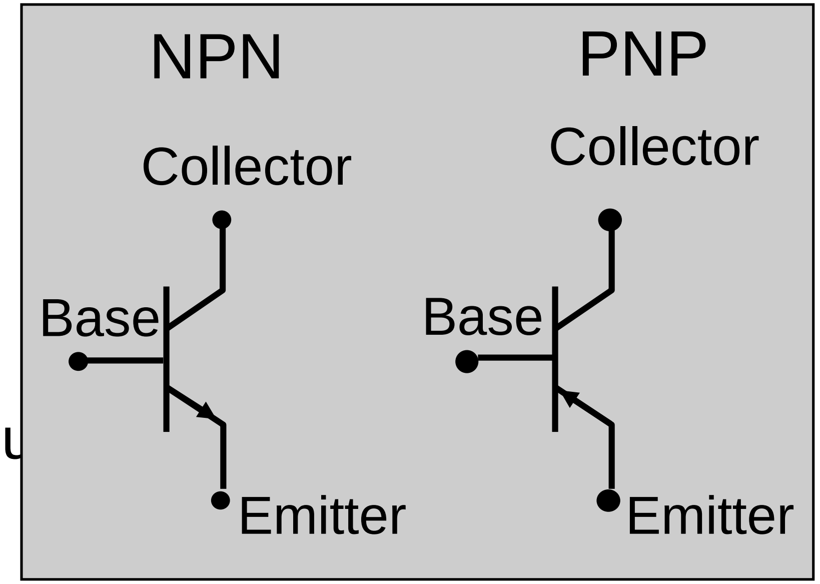
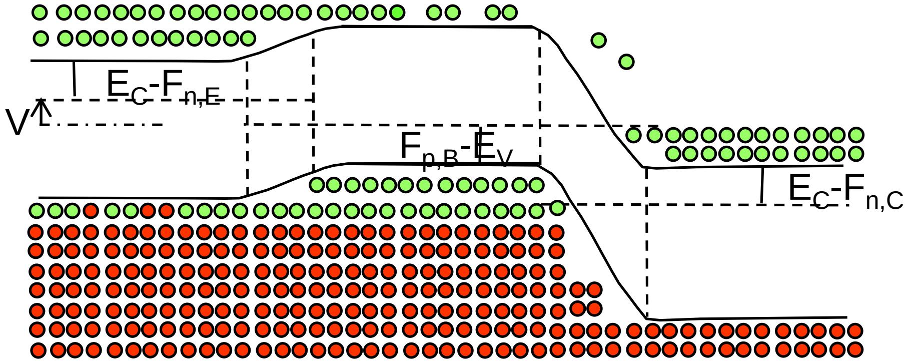


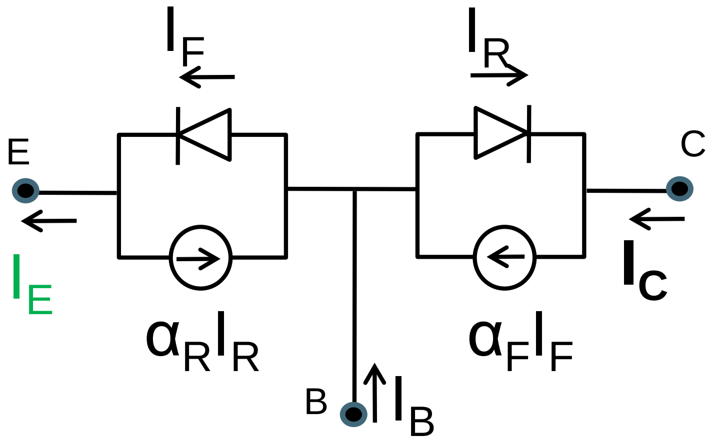
$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area



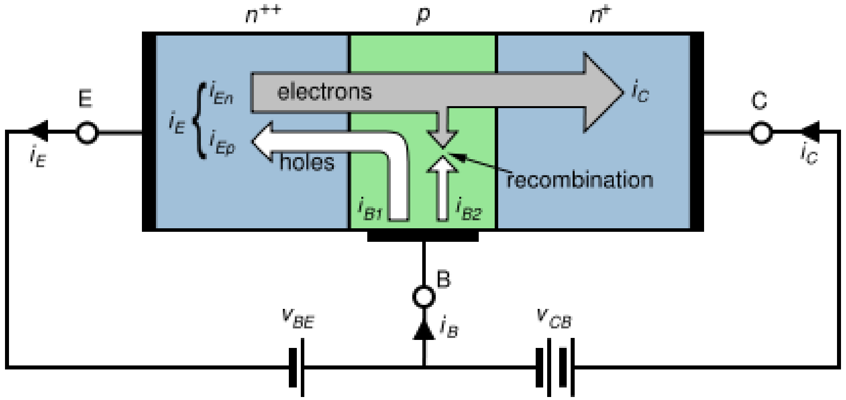
- 25.1 Current gain in BJTs
- 25.2 Base Doping Design
- 25.3 Collector Doping Design (Kirk Effect, Base Pushou
- 25.4 Emitter Doping Design
- 25.5 Poly-Si emitter
- 25.6 Short base transport

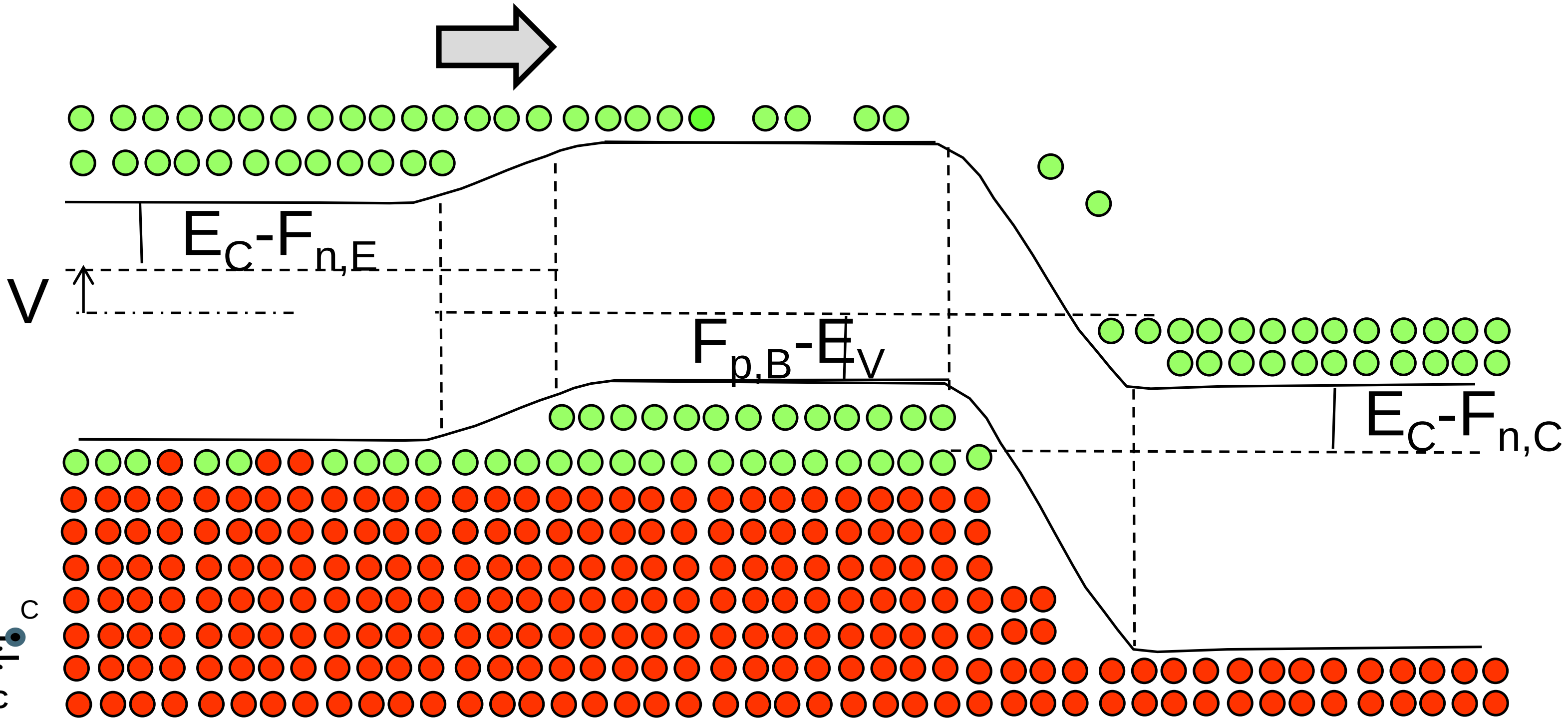


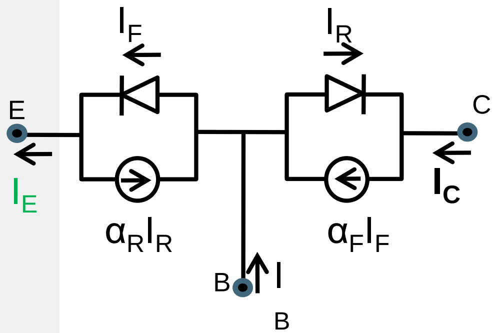


Current flow with Bias

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







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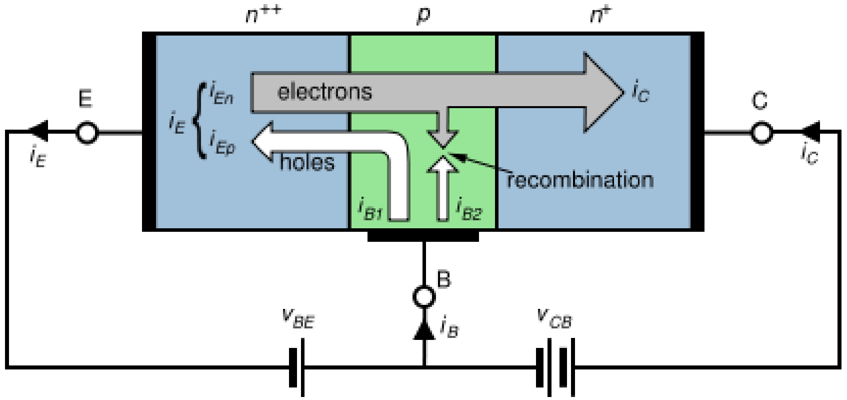
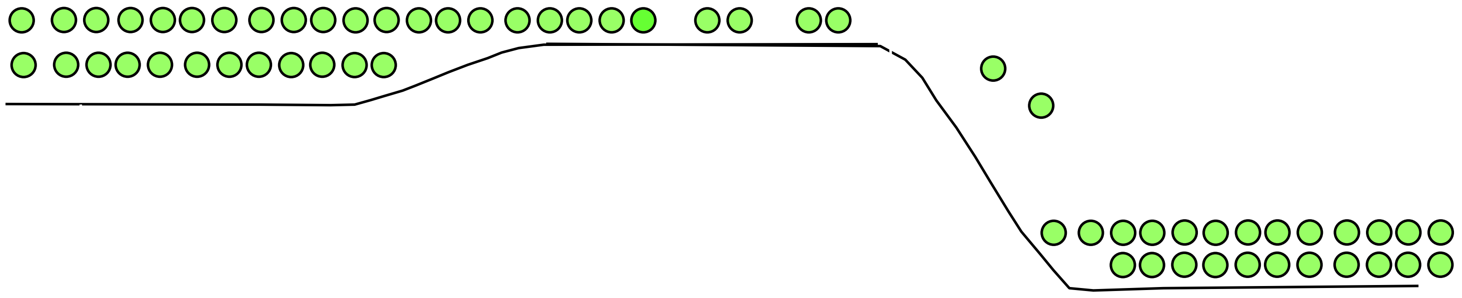
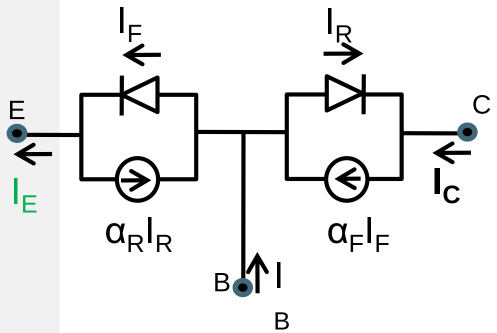
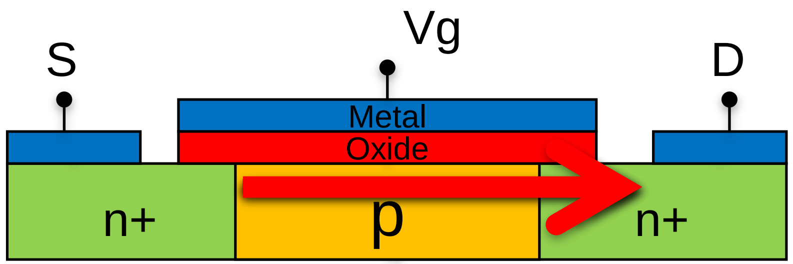
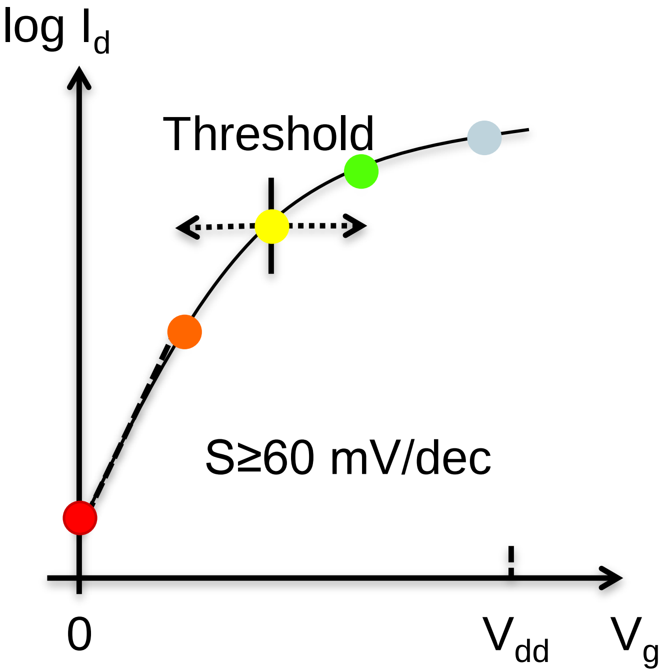


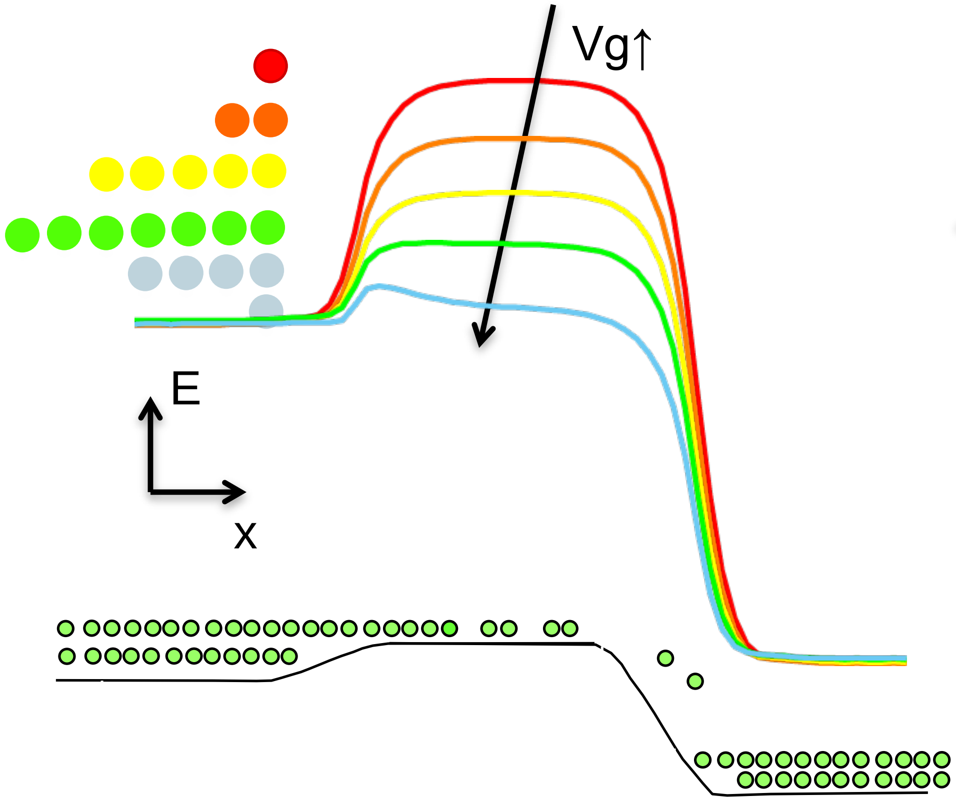


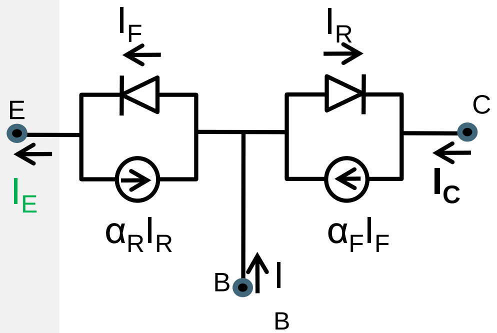


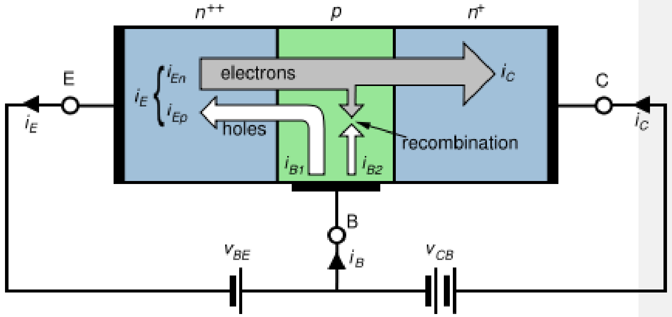
Modern MOSFET - “Fundamental” Limit
looks similar to BJT











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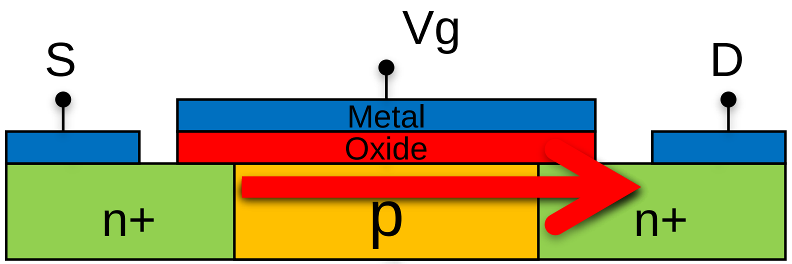
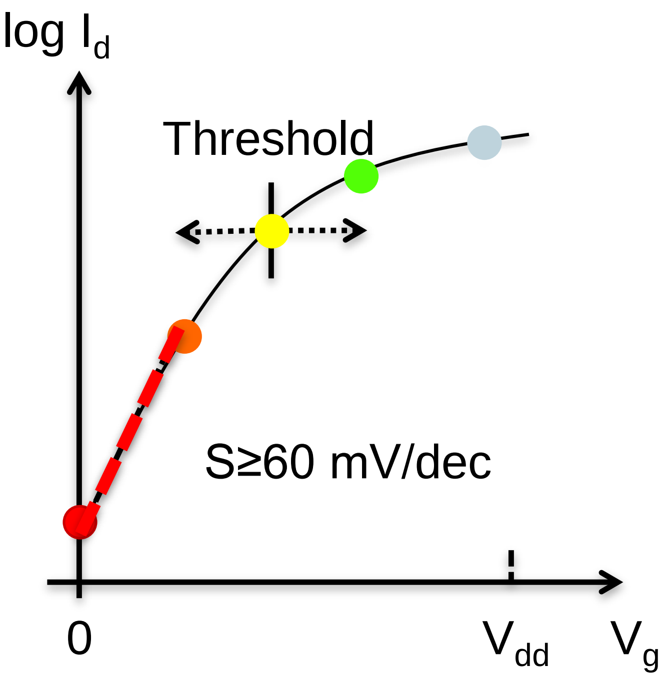
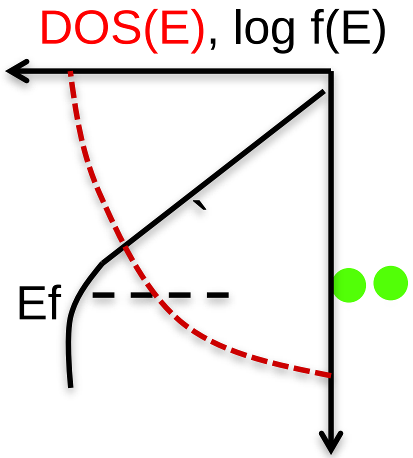
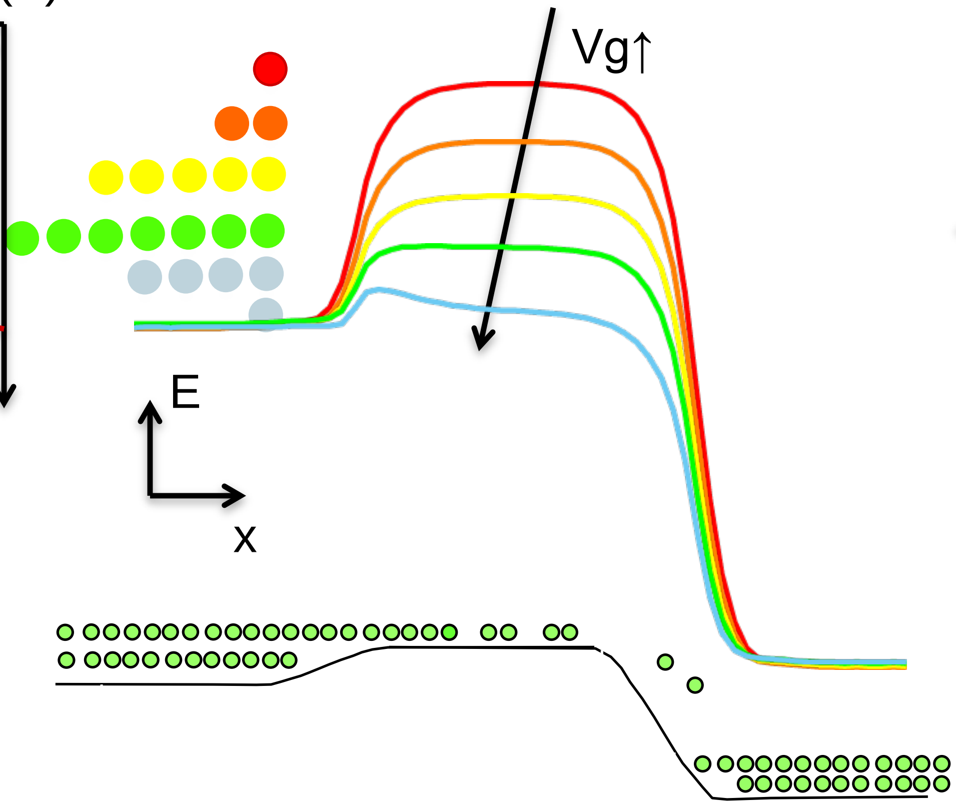
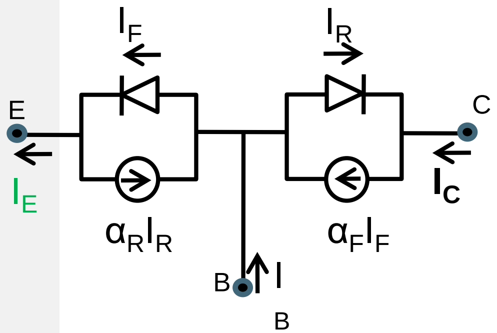
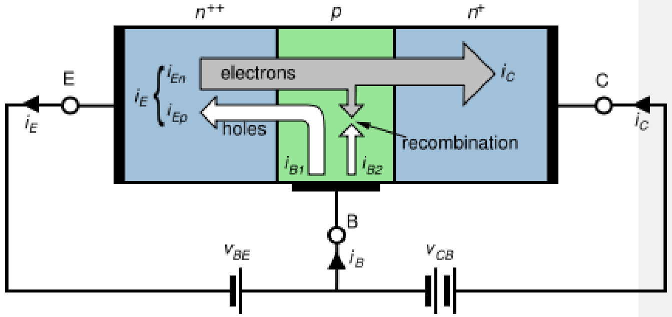








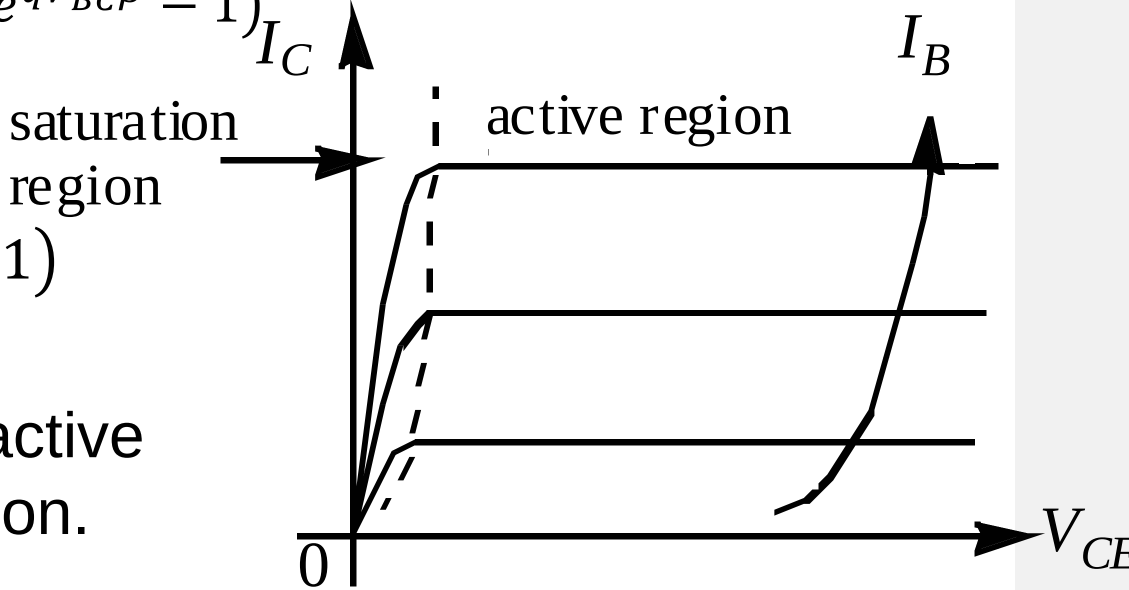




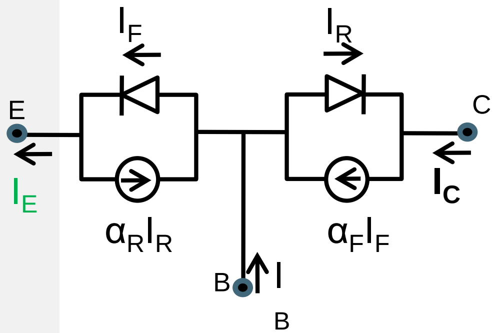
Ebers Moll Model

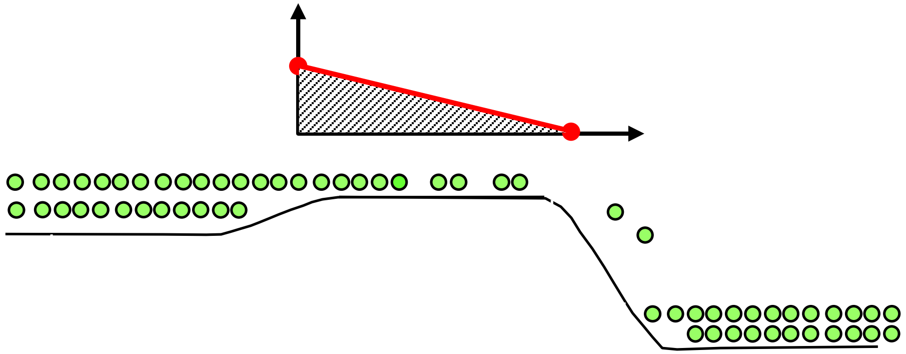
$$I_C = -A\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta}-1\right) + A\left[\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B} + \frac{qD_p}{W_C}\frac{n_{i,C}^2}{N_C}\right]\left(e^{qV_{BC}\beta}-1\right)$$

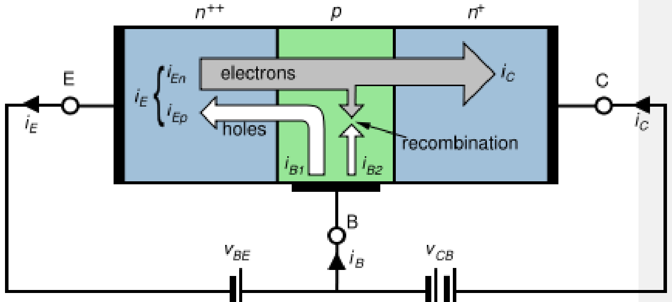
$$I_B = A\frac{qD_p}{W_E}\frac{n_{i,E}^2}{N_E}\left(e^{qV_{BE}\beta}-1\right) + A\frac{qD_p}{W_C}\frac{n_{i,C}^2}{N_C}\left(e^{qV_{BC}\beta}-1\right)$$



The Ebers-Moll model describes both the active and the saturation regions of BJT operation.







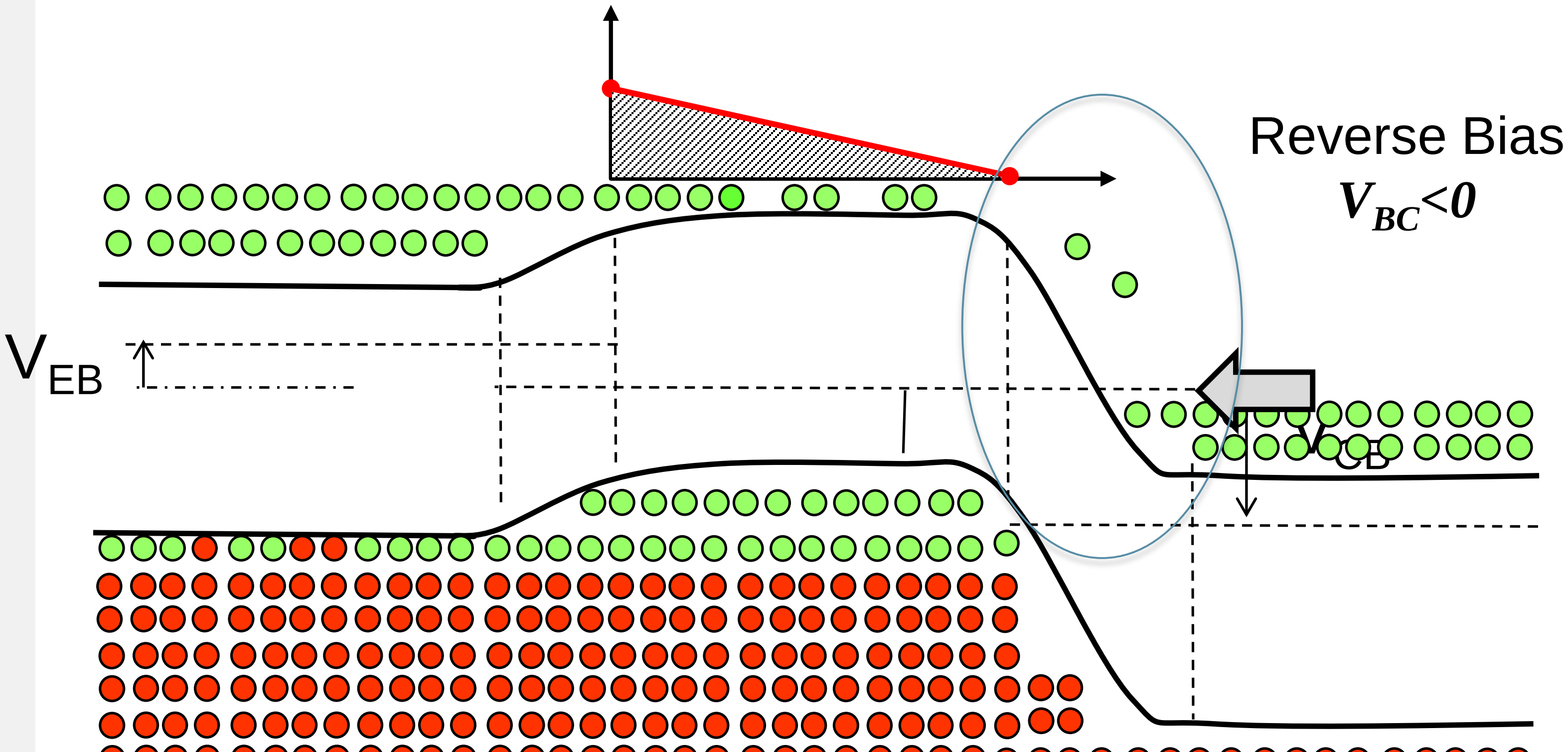
Ebers Moll Model

$$I_C = -A\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta}-1\right) + A\left[\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B} + \frac{qD_p}{W_C}\frac{n_{i,C}^2}{N_C}\right]\left(e^{qV_{BC}\beta}-1\right)$$

$$\frac{I_C}{A} \approx -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta}-1\right)$$

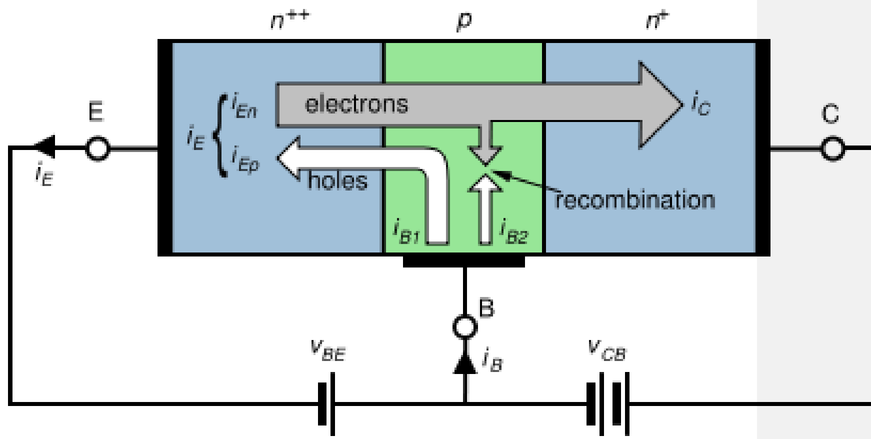
$$I_B = A\frac{qD_p}{W_E}\frac{n_{i,E}^2}{N_E}\left(e^{qV_{BE}\beta}-1\right) + A\frac{qD_p}{W_C}\frac{n_{i,C}^2}{N_C}\left(e^{qV_{BC}\beta}-1\right)$$

$$\frac{I_B}{A} \approx \frac{qD_p}{W_E}\frac{n_{i,E}^2}{N_E}\left(e^{qV_{BE}\beta}-1\right)$$

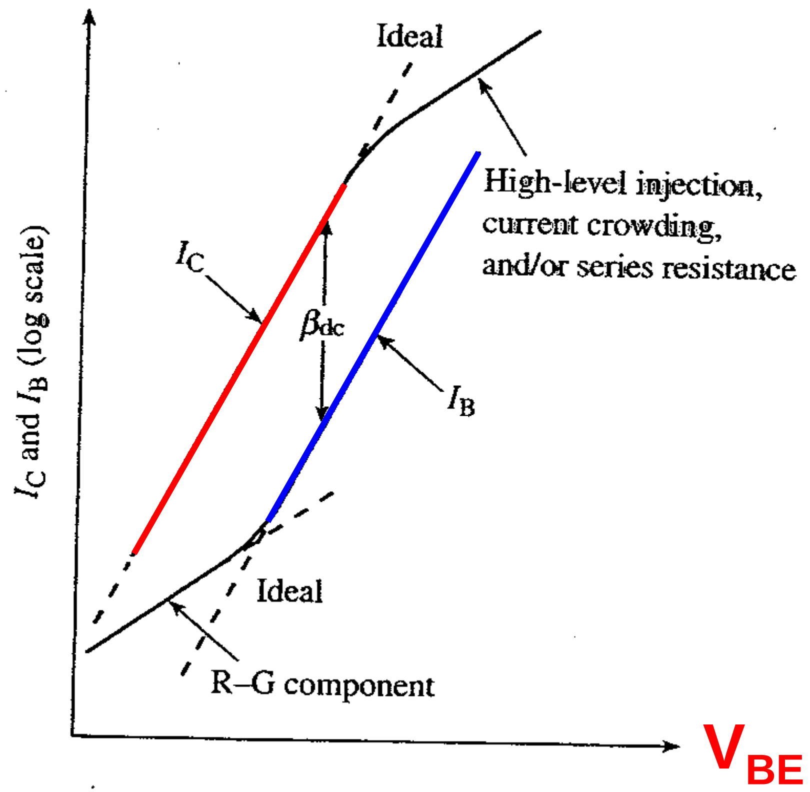


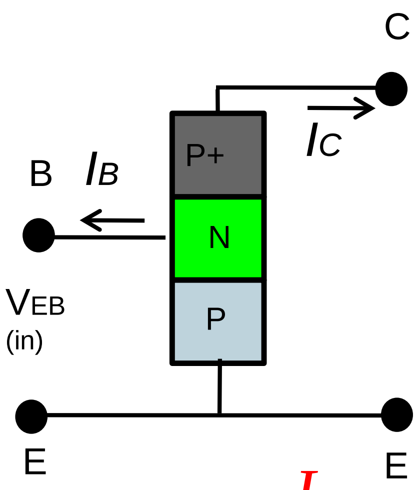
Reverse Bias

$V_{BC}<0$



Gummel Plot





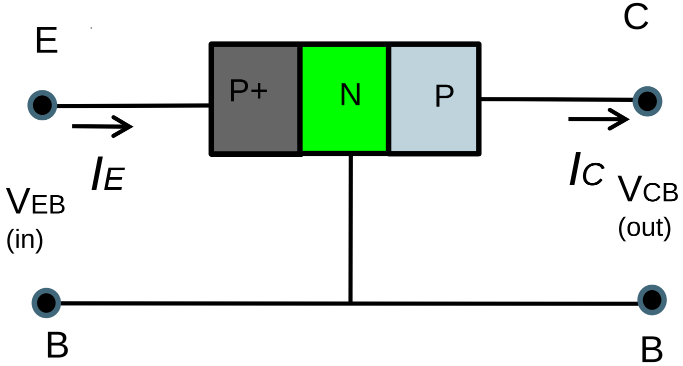
$$\frac{I_C}{A} \approx -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$

$$\frac{I_B}{A} \approx \frac{qD_p}{W_E}\frac{n_{i,E}^2}{N_E}\left(e^{qV_{BE}\beta} - 1\right)$$

$$\beta_{DC} = \frac{I_C}{I_B}$$

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

Common emitter Current Gain



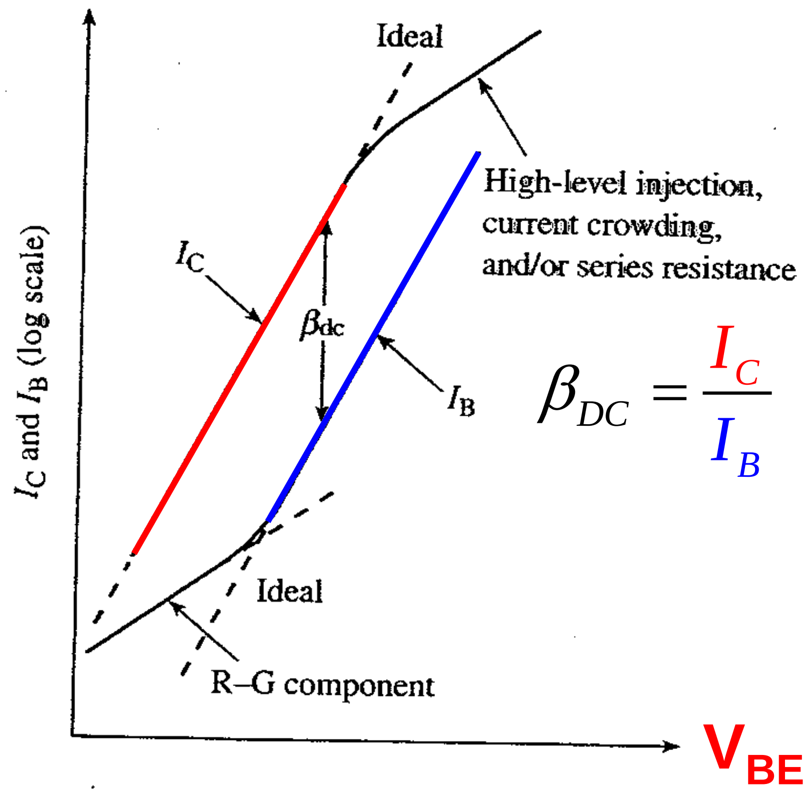
$$\alpha_{DC} = \frac{I_C}{I_E}$$

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{I_C}{I_E - I_C} = \frac{\alpha_{DC}}{1-\alpha_{DC}}$$

DC transfer gain

Properties are related – (transistor did not change)

Gummel Plot



$$\beta_{DC} = \frac{I_C}{I_B}$$

$$\frac{I_C}{A} \approx -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$

$$\frac{I_B}{A} \approx \frac{qD_p}{W_E}\frac{n_{i,E}^2}{N_E}\left(e^{qV_{BE}\beta} - 1\right)$$

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

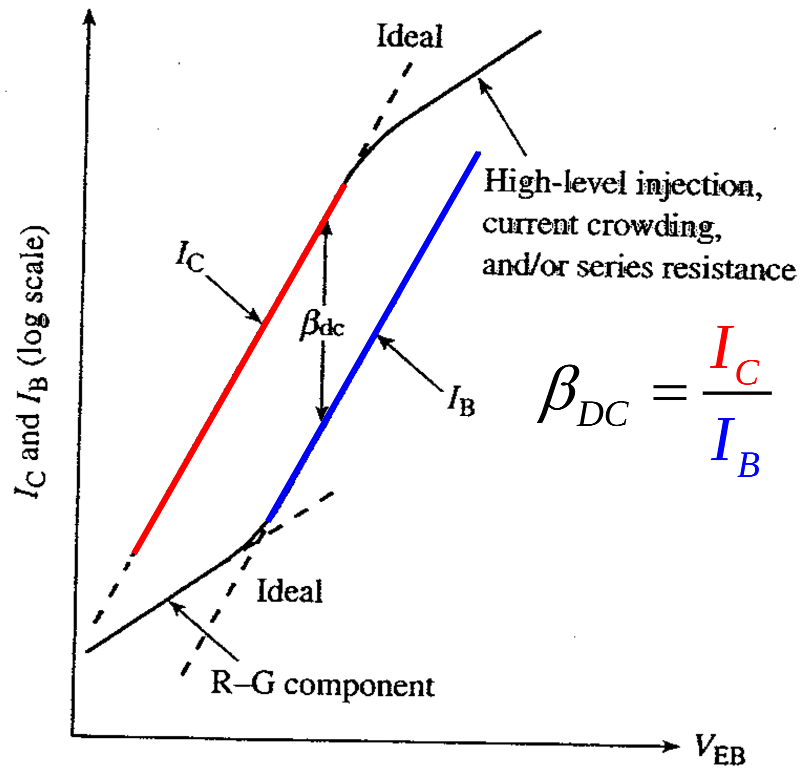
- Gummel Plot: I_C and I_B on semi-log plot

=> device characterization

=> quality of the emitter-base junction with constant base-collector bias

=> DC gain β, base and collector ideality factors, series resistances and leakage currents.

Gummel Plot and Current Gain



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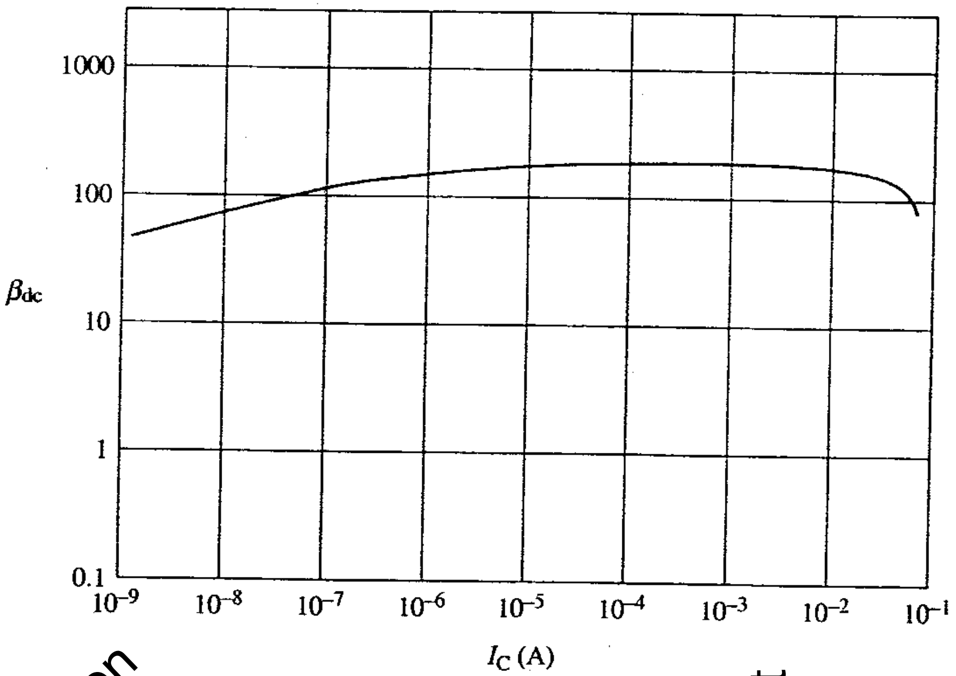


$$\frac{I_C}{A} \approx -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$

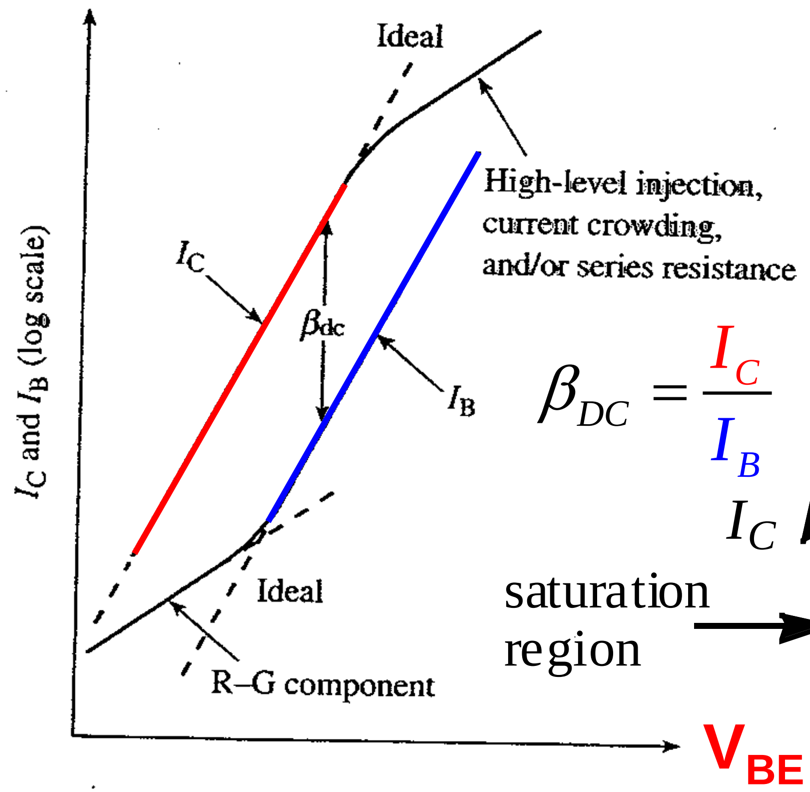
$$\frac{I_B}{A} \approx \frac{qD_p}{W_E}\frac{n_{i,E}^2}{N_E}\left(e^{qV_{BE}\beta} - 1\right)$$

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

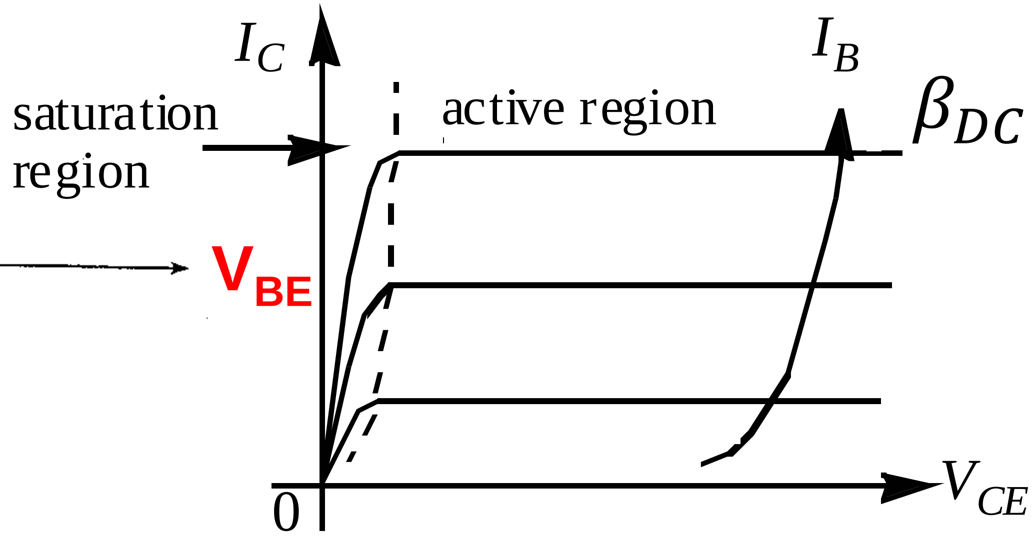
Base recombination
=> roll-off

High injection
collector current
=>roll-off
Base current
does not roll off

Gummel Plot & Output Characteristic



$$\beta_{DC} = \frac{I_C}{I_B}$$



$$\frac{I_C}{A} \approx -\frac{qD_n}{W_B}\frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$

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

How to make a Good Silicon Transistor?

For a given Emitter length

~1, same material
primarily determined
by bandgap

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

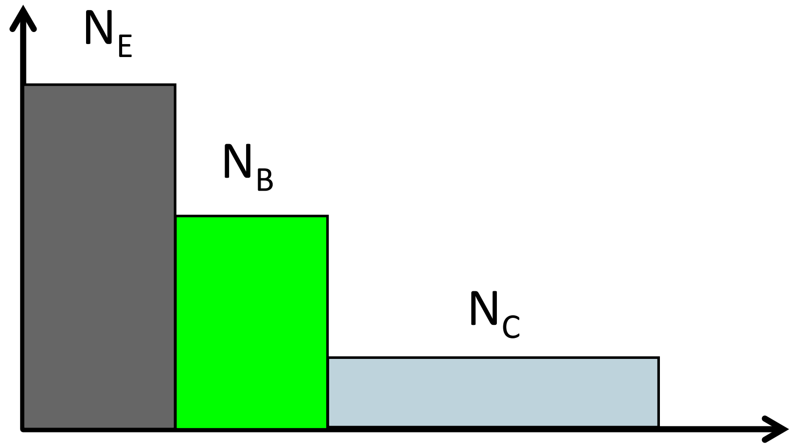
Make-Base short …
(few mm in 1950s, 200 A now)
Want high gradient of carrier density

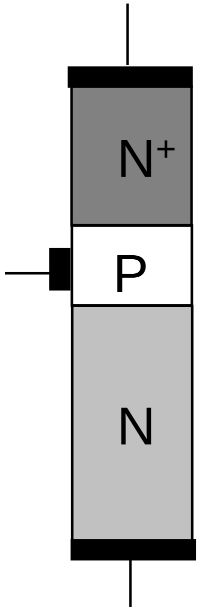
Emitter doping higher
than Base doping

Base doping hard to control
Emitter doping easier

Doping for Gain ...

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





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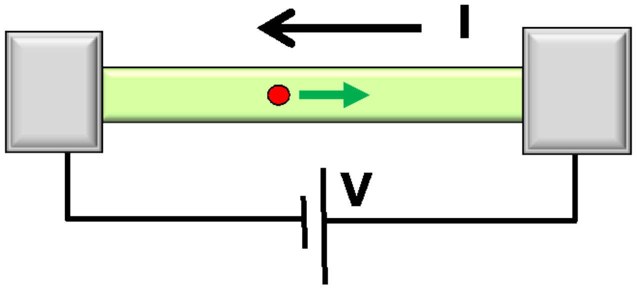

$$I = G \times V$$
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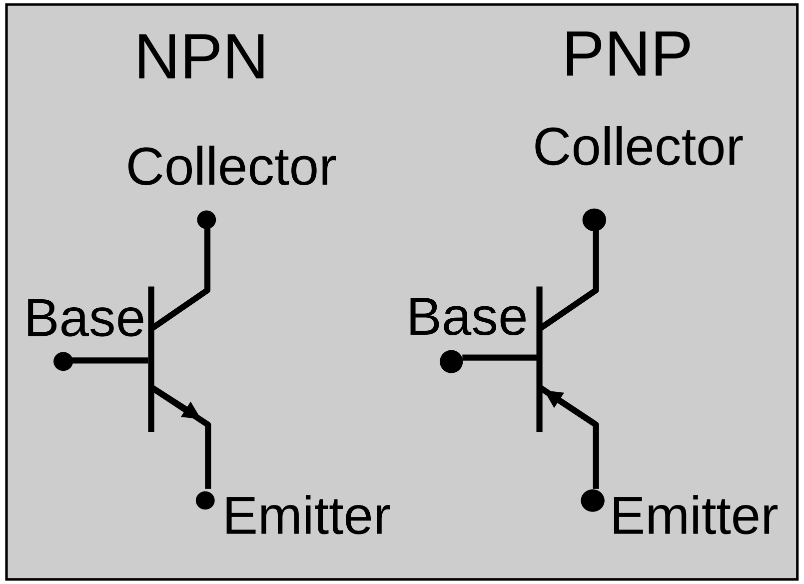
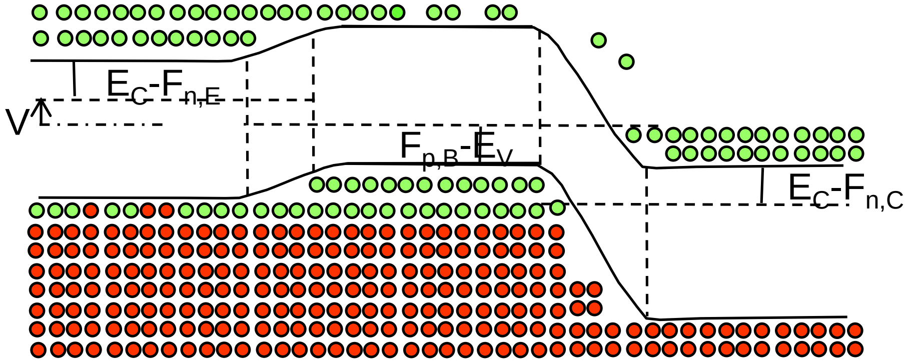
charge density velocity area

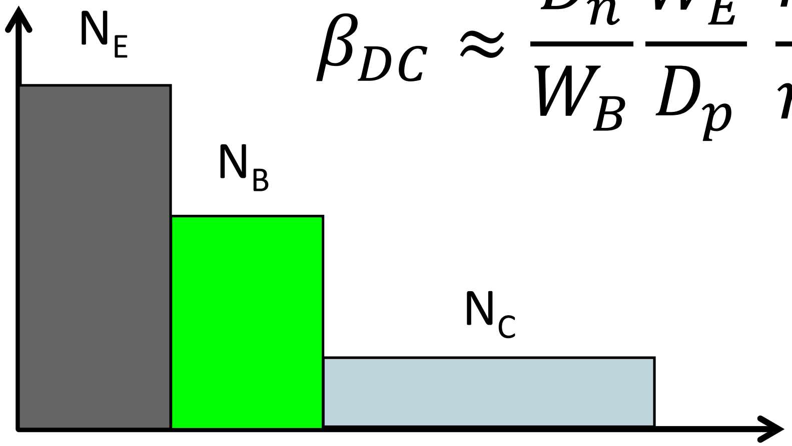


- 25.1 Current gain in BJTs

status

- 25.2
- 25.3
- 25.4
- 25.5
- 25.6





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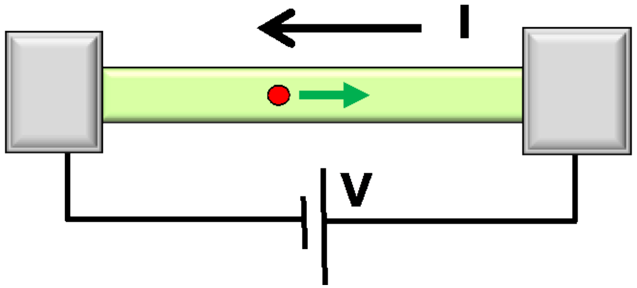

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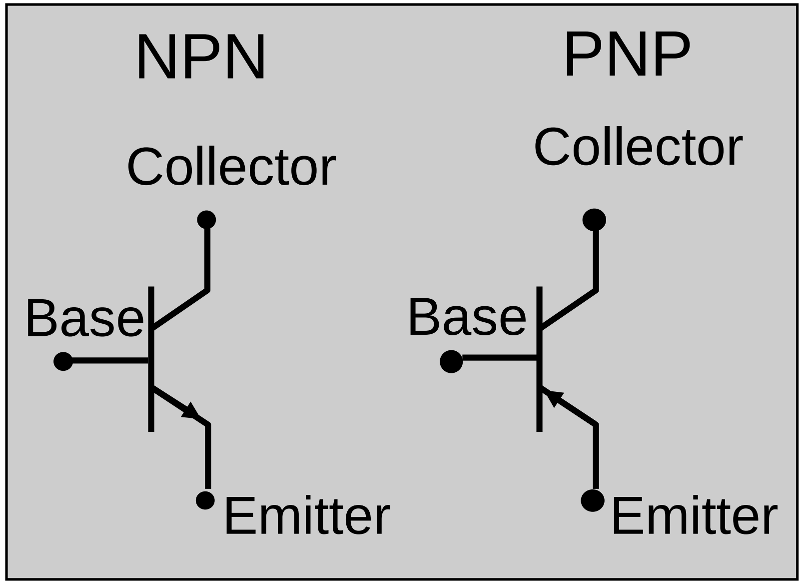
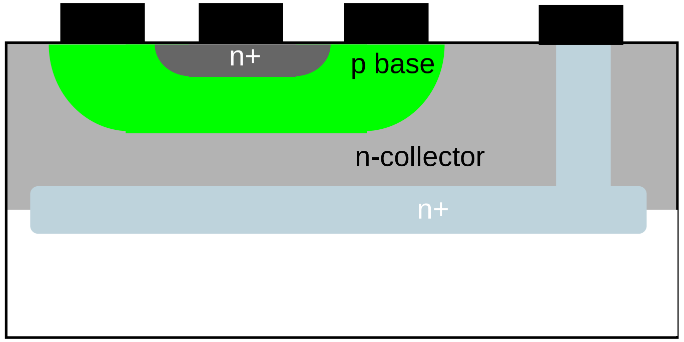
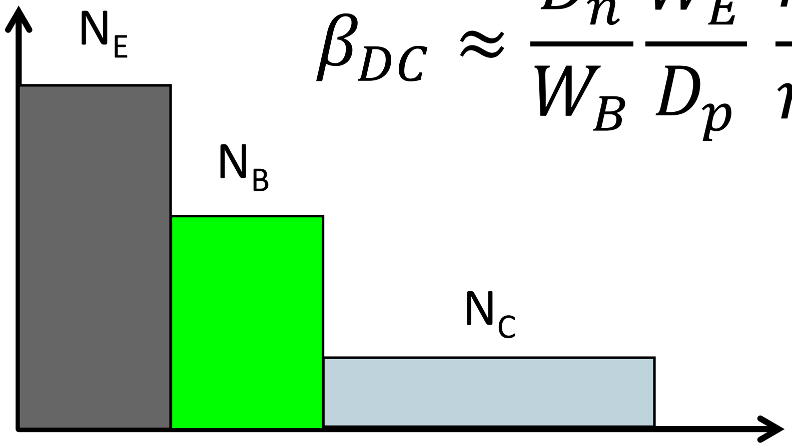


- 25.1 Current gain in BJTs
- 25.2 Base Doping Design
  - » Current Crowding – Non-Uniform Turn-On
  - » Punch-through
  - » Base Width Modulation
- 25.3
- 25.4
- 25.5
- 25.6

status



What's wrong with the recipe?



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