# Section 25
# Bipolar Junction Transistor – Design

## 25.5 Poly-Si emitter

Gerhard Klimeck
gekco@purdue.edu

PURDUE UNIVERSITY

School of Electrical and Computer Engineering

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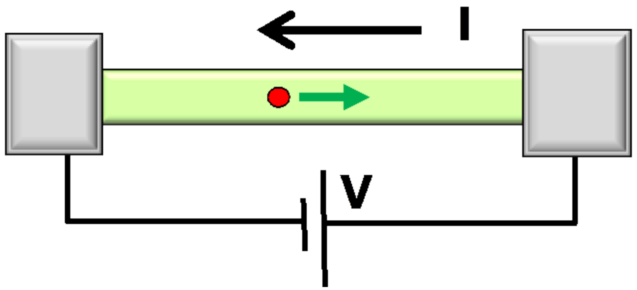
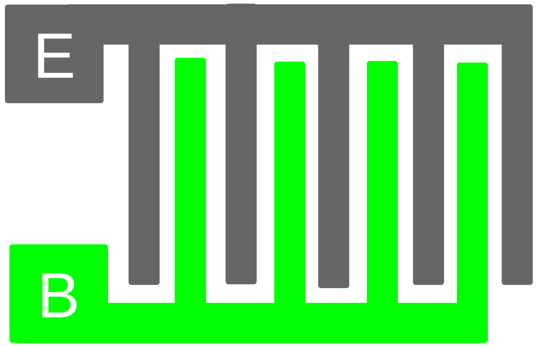



I = G × V

= q × n × v × A

charge density velocity area

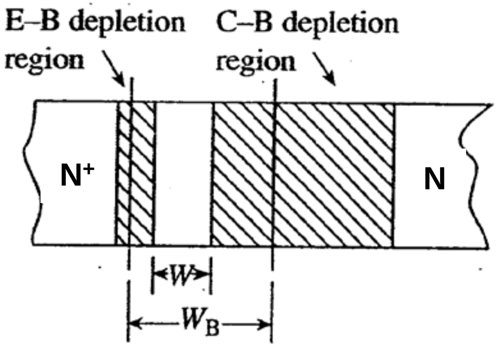



- > 25.1 Current gain in BJTs
- > 25.2 Base Doping Design
  - » Current Crowding – Non-Uniform Turn-On
  - » Punch-through
  - » Base Width Modulation
- > 25.3 Collector Doping Design (Kirk Effect, Base Pushout)
- > 25.4 Emitter Doping Design
- > 25.5 Poly-Si emitter
- > 25.6

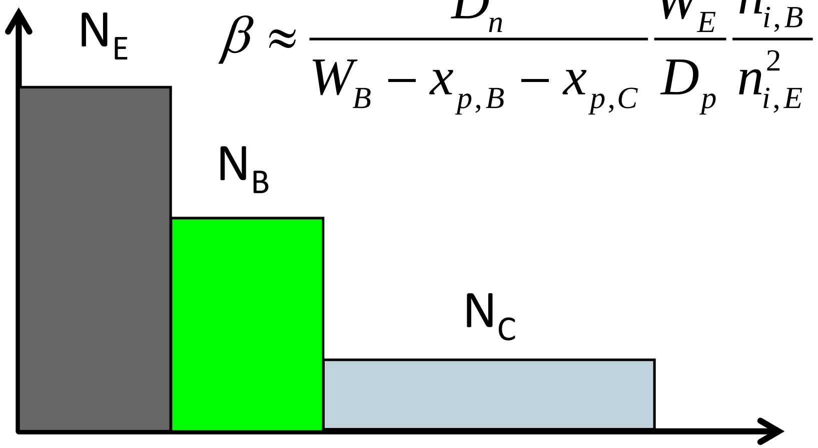
status

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

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




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




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

# Doping for Gain

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

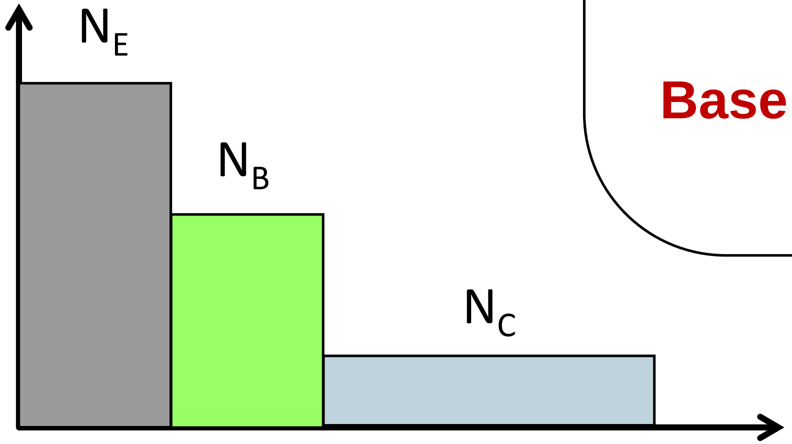
$$\beta_{dc} \approx \frac{D_n}{W_B}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}$$

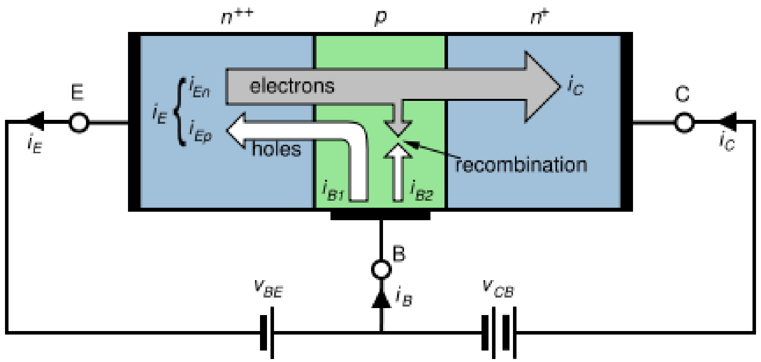
**Emitter doping:** As high as possible without *band gap narrowing*

**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*



# How to make better Transistor

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

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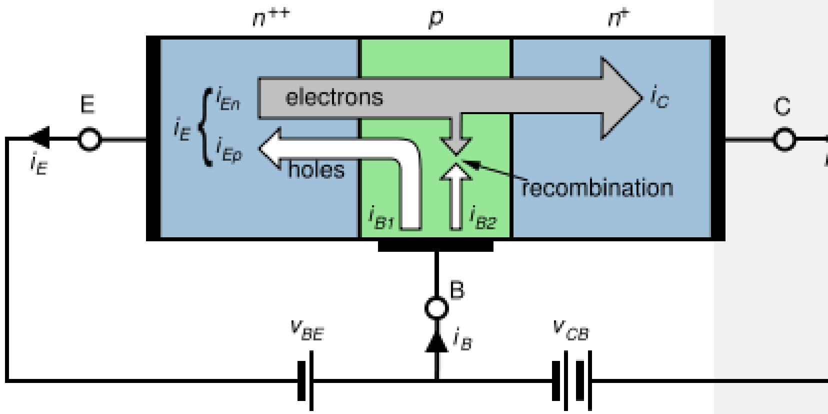



**Polysilicon Emitter**
**suppress $D_p$**
**suppress base current**

Graded Base transport
(build in electric field to accelerate el)

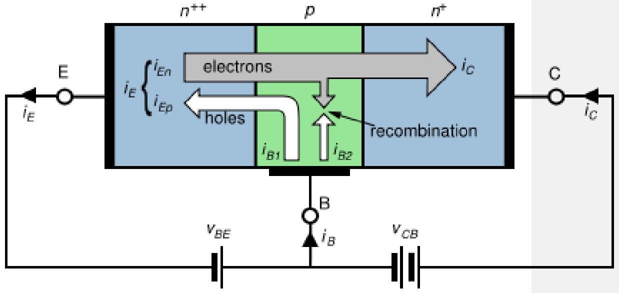
Classical Shockley Transistor

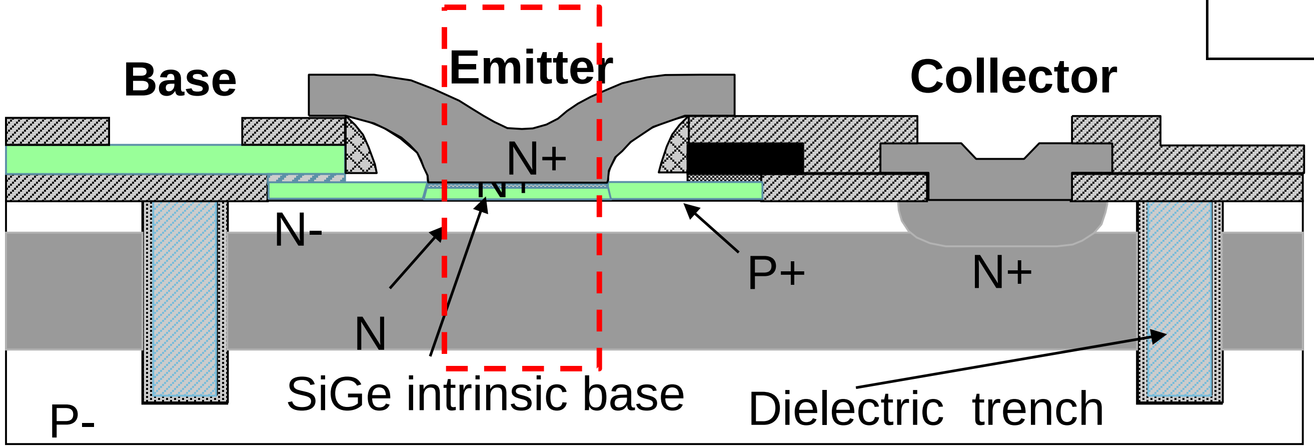
Hetero-junction Bipolar Transistor
Nobel Prize Kroemer/Alferov

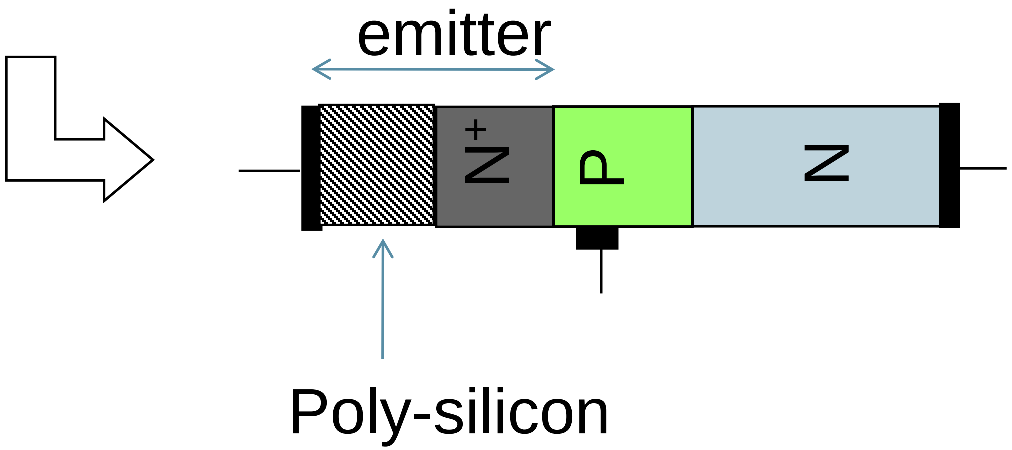
# Poly-silicon Emitter

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

**Polysilicon Emitter suppress $D_p$ suppress base current**



# Poly-silicon Emitter

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

**Polysilicon Emitter**
**suppress $D_p$**
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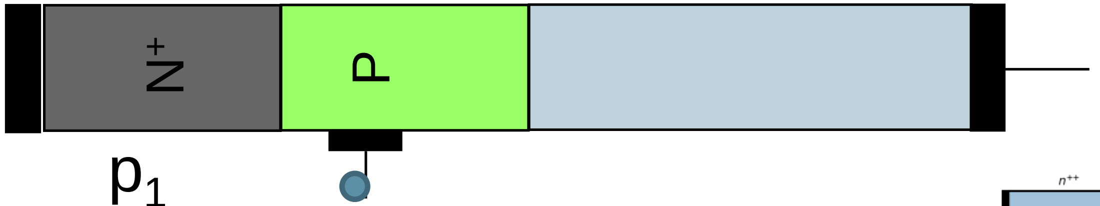
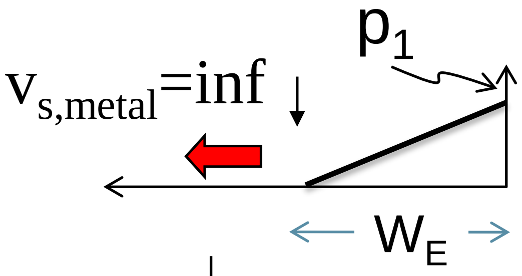
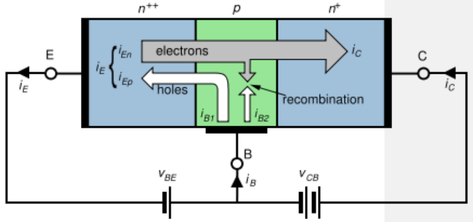
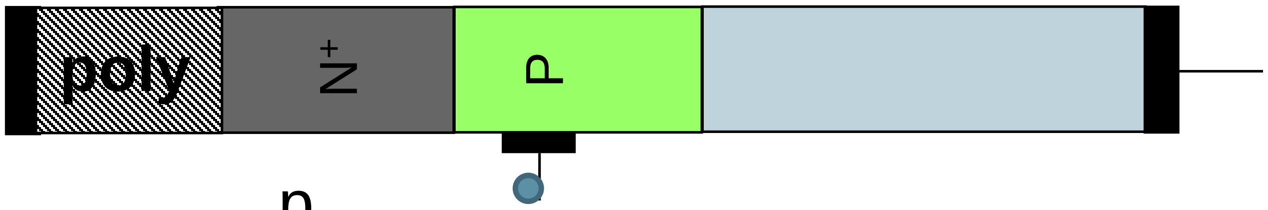



$$I_{p,E,si} = -qD_p \frac{dp}{dx}$$

$$I_{p,E,si} = -q\left(D_p / W_E\right) p_1$$

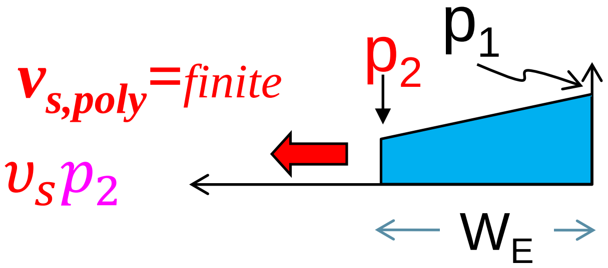



$$I_{p,E,poly} = -qD_p \frac{dp}{dx}$$

$$I_{p,E,poly} = -qD_p \frac{p_1 - p_2}{W_E}$$




$$I_{p,E,poly} = -q\upsilon_s p_2$$

$v_{s,poly}$=*finite* reduces $I_{p,E,poly}$

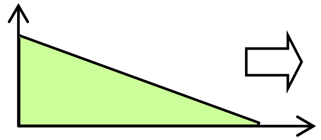
$$p_2 = p_1 \frac{\frac{D_p}{W_E}}{\frac{D_p}{W_E} + \upsilon_s}$$

$$\frac{I_{p,E,poly}}{I_{p,E,Si}} = \frac{q\upsilon_s p_2}{q\left(\frac{D_p}{W_E}\right)} \qquad \frac{I_{p,E,poly}}{I_{p,E,Si}} = \frac{\upsilon_s}{\frac{D_p}{W_E} + \upsilon_s} \qquad \frac{I_{p,E,poly}}{I_{p,E,Si}} = \frac{1}{1 + \frac{D_p}{W_E}\frac{1}{\upsilon_s}}$$

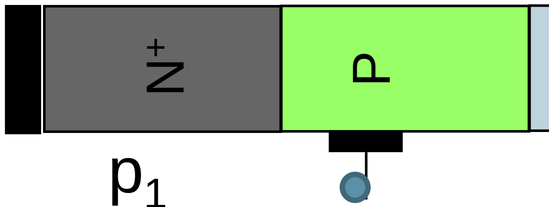
# Poly-silicon Emitter

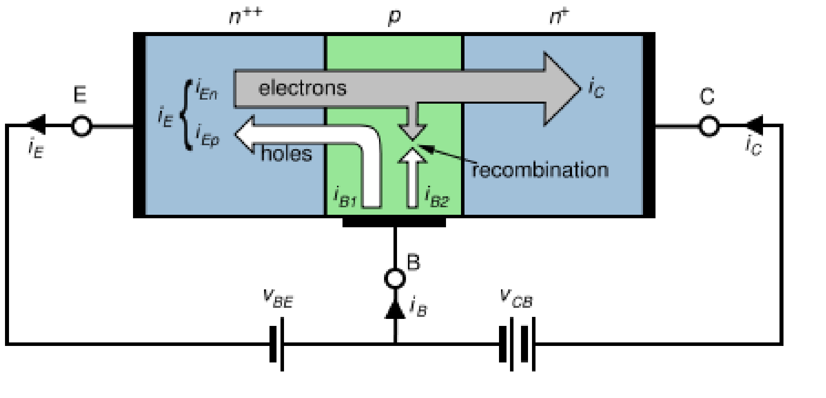
$$\beta_{DC} = \frac{I_C}{I_B}$$

**Polysilicon Emitter**
**suppress $D_p$**
**suppress base current**



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




$$I_{p,E,si} = -qD_p \frac{dp}{dx}$$

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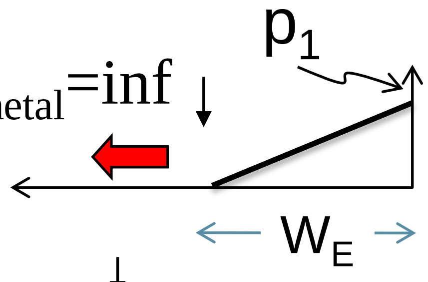
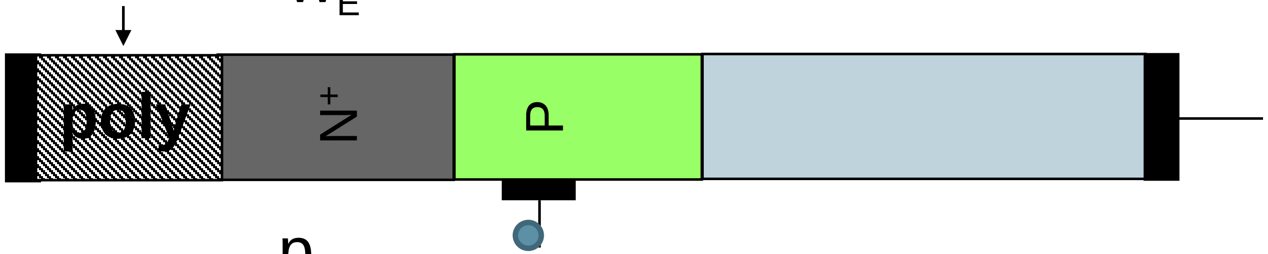
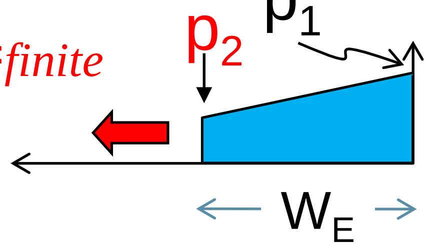



$$I_{p,E,poly} = -qD_p \frac{dp}{dx}$$

$$I_{p,E,poly} = -qD_p \frac{p_1 - p_2}{W_E}$$

$v_{s,poly}$=*finite*

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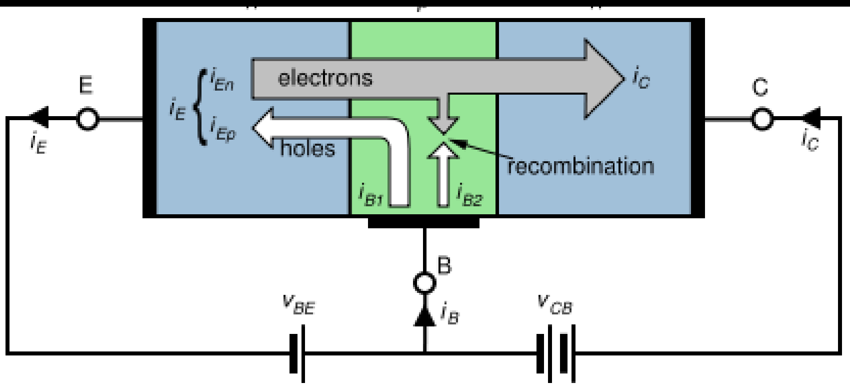
$$p_2 = p_1 \frac{\frac{D_p}{W_E}}{\frac{D_p}{W_E} + \upsilon_s}$$

$$\frac{I_{p,E,poly}}{I_{p,E,Si}} = \frac{q\upsilon_s p_2}{q\left(\frac{D_p}{W_E}\right)} \qquad \frac{I_{p,E,poly}}{I_{p,E,Si}} = \frac{\upsilon_s}{\frac{D_p}{W_E} + \upsilon_s} \qquad \frac{I_{p,E,poly}}{I_{p,E,Si}} = \frac{1}{1 + \frac{D_p}{W_E}\frac{1}{\upsilon_s}}$$

# Gain in Poly-silicon Transistor




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

$$\beta_{poly} = \frac{I_C}{I_{B,poly}} = \left(\frac{I_C}{I_{B,si}}\right) \times \left[\frac{I_{B,si}}{I_{B,poly}}\right] \approx \left(\frac{D_n}{W_B}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}\right) \times \left[\frac{D_p/W_E + \upsilon_s}{\upsilon_s}\right]$$

$$\upsilon_s << \frac{D_p}{W_E}$$

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

Poly suppresses base current, increases gain …

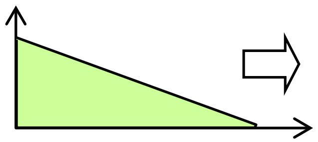
$$I_{n,E} = \frac{qD_n}{W_B} n_1 \qquad n_1 \equiv \frac{n_{i,B}^2}{N_B}\left(e^{qV_{BE}\beta} - 1\right)$$

Question: Why does poly only suppress the hole current, not electron current?

Ans. Polysilicon is not a ohmic contact and acts as rectifying contact.
It blocks the easy passage of holes but lets electrons pass through

# Poly-silicon Emitter

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



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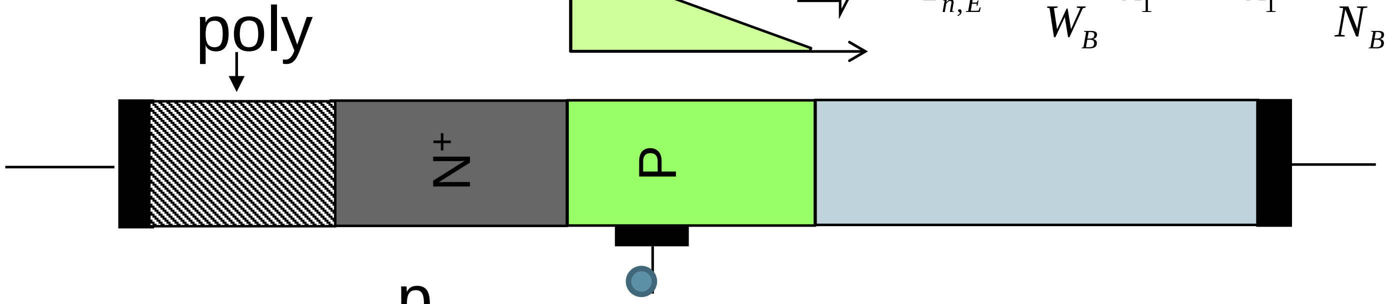


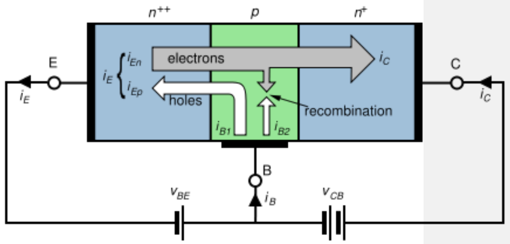


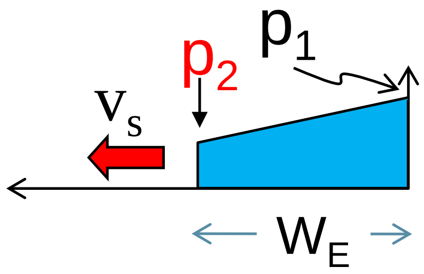


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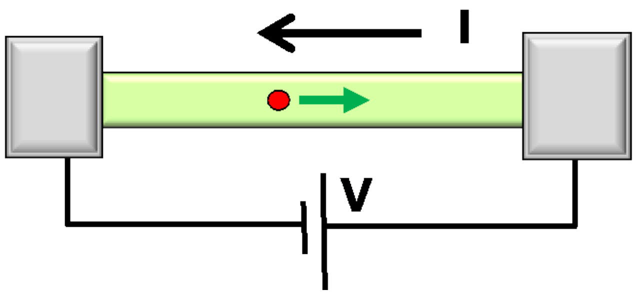
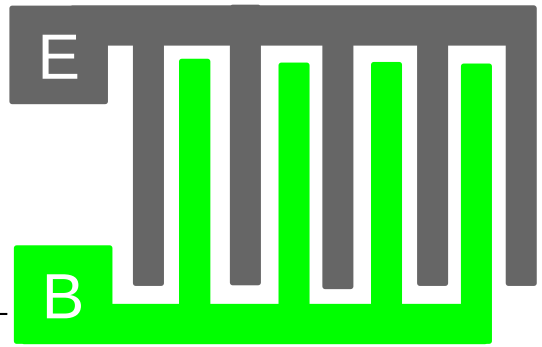



I = G x V

= q x n x v x A

charge density velocity area






status

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

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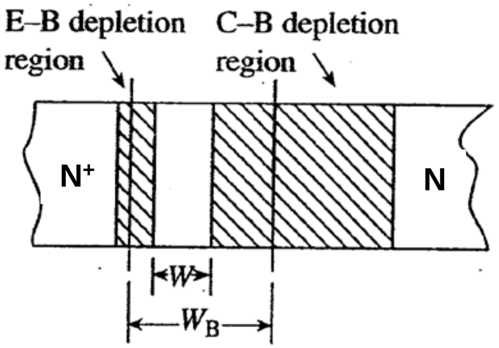
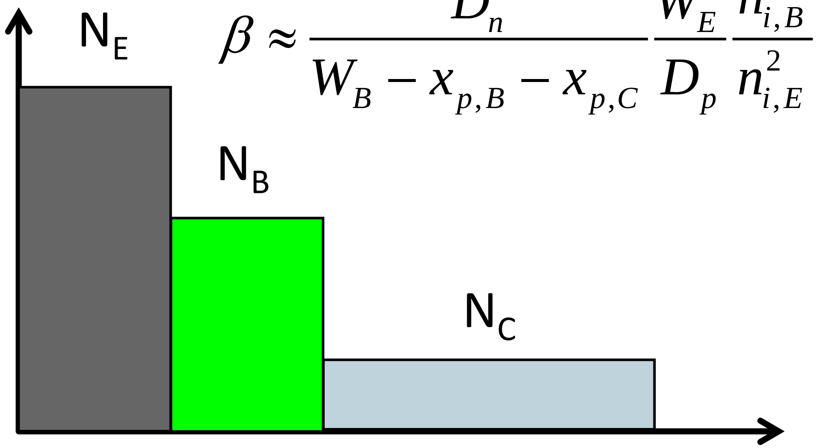



$$\beta \approx \frac{D_n}{W_B - x_{p,B} - x_{p,C}}\frac{W_E}{D_p}\frac{n_{i,B}^2}{n_{i,E}^2}\frac{N_E}{N_B}$$

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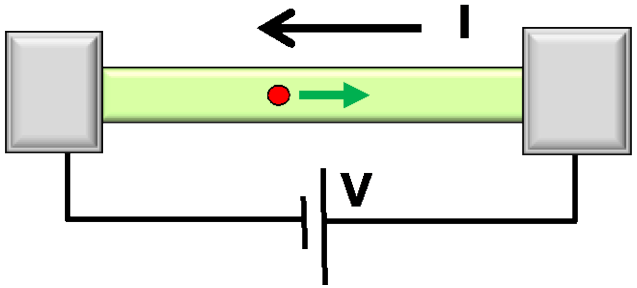


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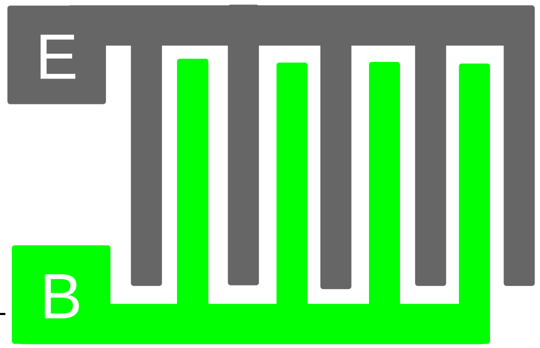
charge density velocity area

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- 25.5 Poly-Si emitter
- 25.6 Short base transport

status

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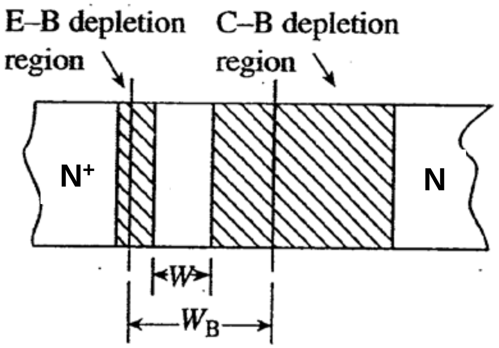


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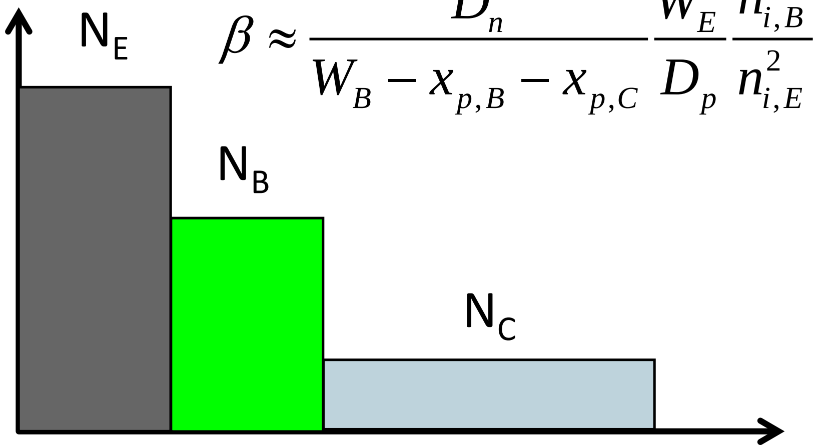


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