Section 27
Heterojunction Bipolar Transistor

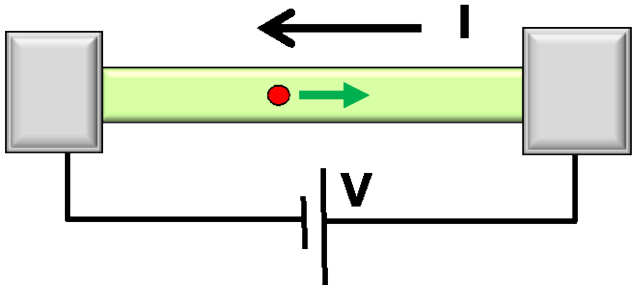
27.5 Graded Junction HBTs

Gerhard Klimeck
gekco@purdue.edu

PURDUE UNIVERSITY

School of Electrical and Computer Engineering

Section 27
Heterojunction Bipolar Transistor



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

charge density velocity area

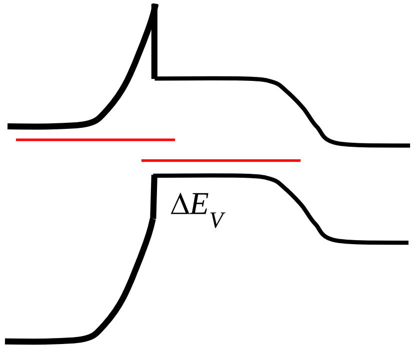
$$\beta_{poly,ballistic} \to \frac{n_{i,B}^2}{n_{i,E}^2} \times \frac{N_E}{N_B} \times \frac{\upsilon_{th}}{\upsilon_s}$$

$$\frac{n_{i,B}^2}{n_{i,E}^2} = \frac{N_{C,B} N_{V,B} e^{-E_{g,B}\beta}}{N_{C,E} N_{V,E} e^{-E_{g,E}\beta}} \approx e^{\left(E_{g,E} - E_{g,B}\right)\beta}$$

1 2 3 4 5 6 7 8

- 27.1 Applications, Concept, Innovation, Nobel Prize
- 27.2 Heterojunction Equilibrium Solution
- 27.3 Types of heterojunctions
- 27.4 Abrupt junction HBTs
- 27.5 Graded junction HBTs
- 27.6 Graded base HBTs
- 27.7 Double heterojunction HBTs
- 27.8 Modern Designs

status



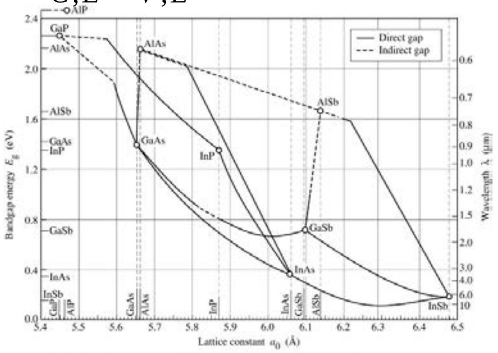
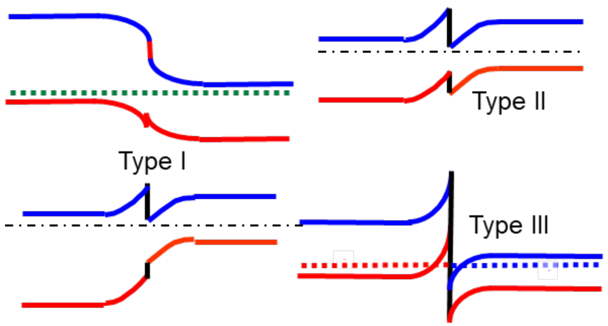
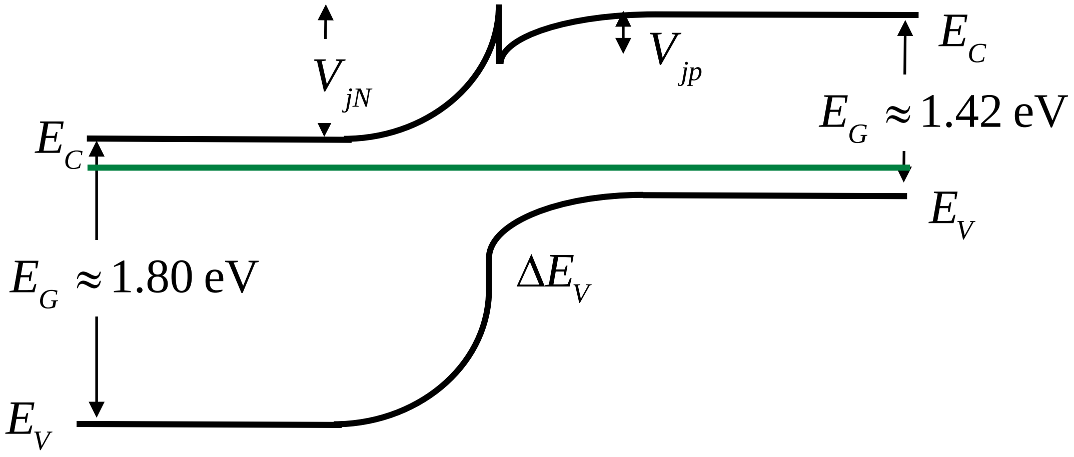
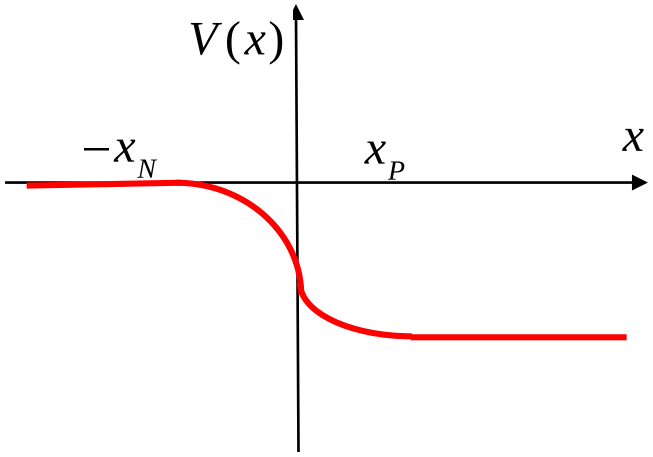


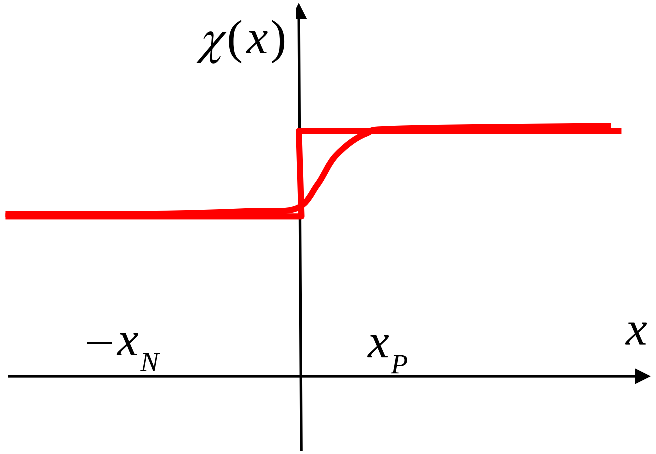
Fig. 7.6. Bandgap energy and lattice constant of various III-V semiconductors at room temperature (adopted from Tien, 1988).



Mark Lundstrom, “Heterostructure Fundamentals,” Purdue University, 1995.
Herbert Kroemer, “Heterostructure bipolar transistors and integrated circuits,” Proc. *IEEE* , **70**, pp. 13-25, 1982.



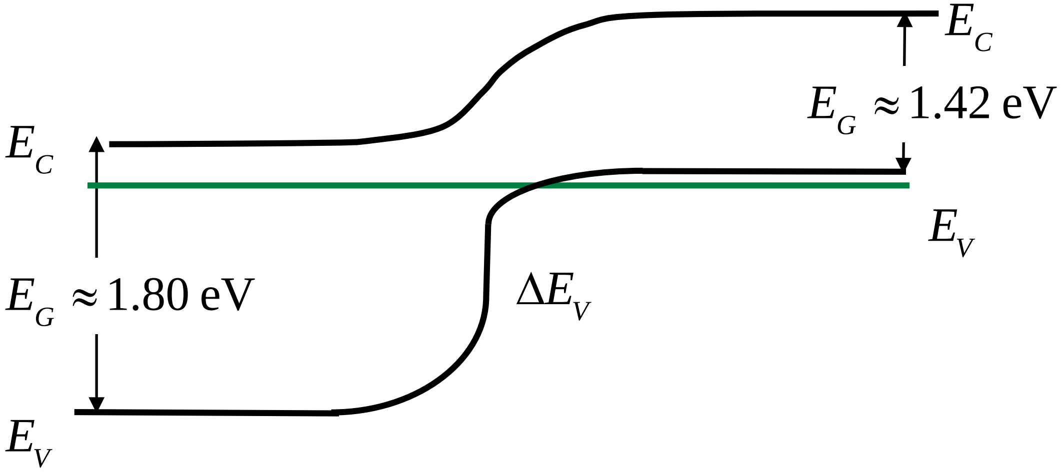




$$E_C(x) = E_0 - \chi(x) - qV(x)$$

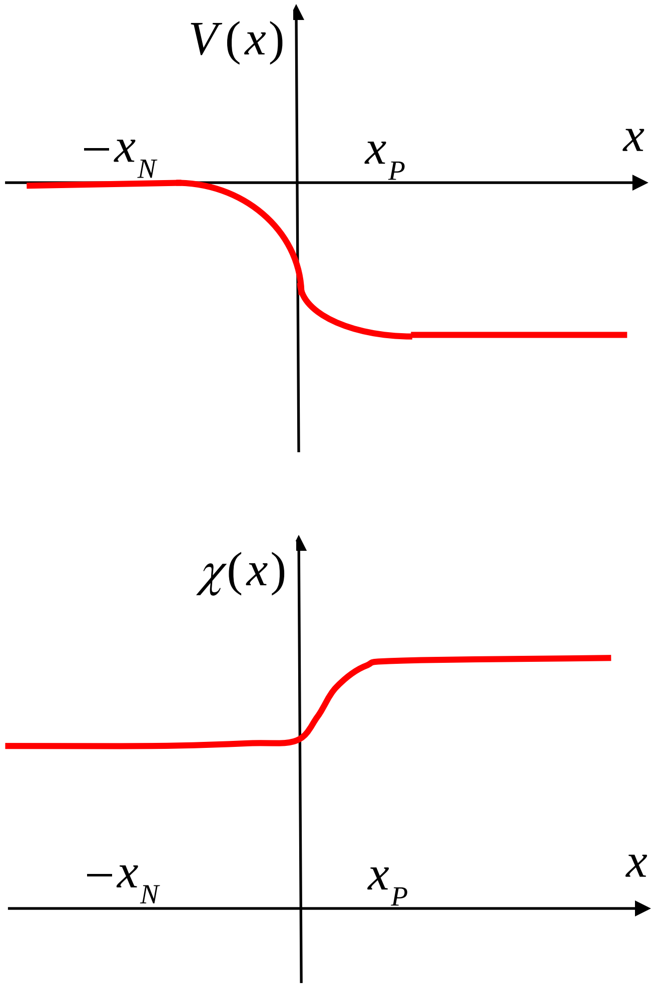
$$E_V(x) = E_C(x) - E_G(x)$$

Graded Base-Emitter Junction

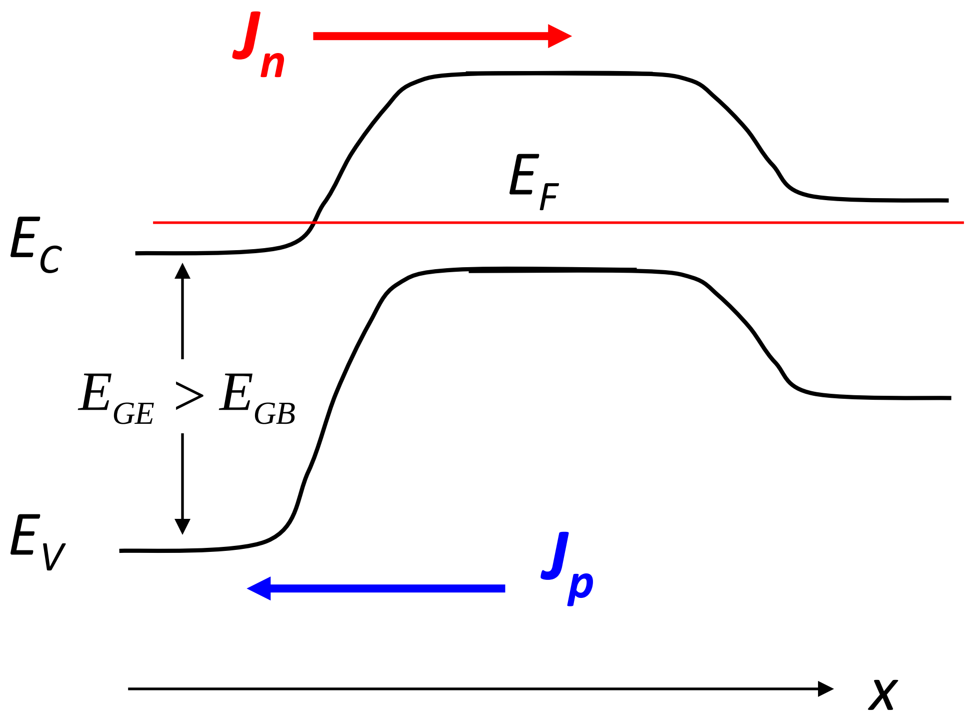


$$E_C(x) = E_0 - \chi(x) - qV(x)$$

$$E_V(x) = E_C(x) - E_G(x)$$



Current Gain



No exponential Suppression!

$$J_n = q\left(\frac{n_{iB}^2}{N_{AB}}\right)\frac{D_n}{W_B}e^{qV_{BE}/k_BT}$$

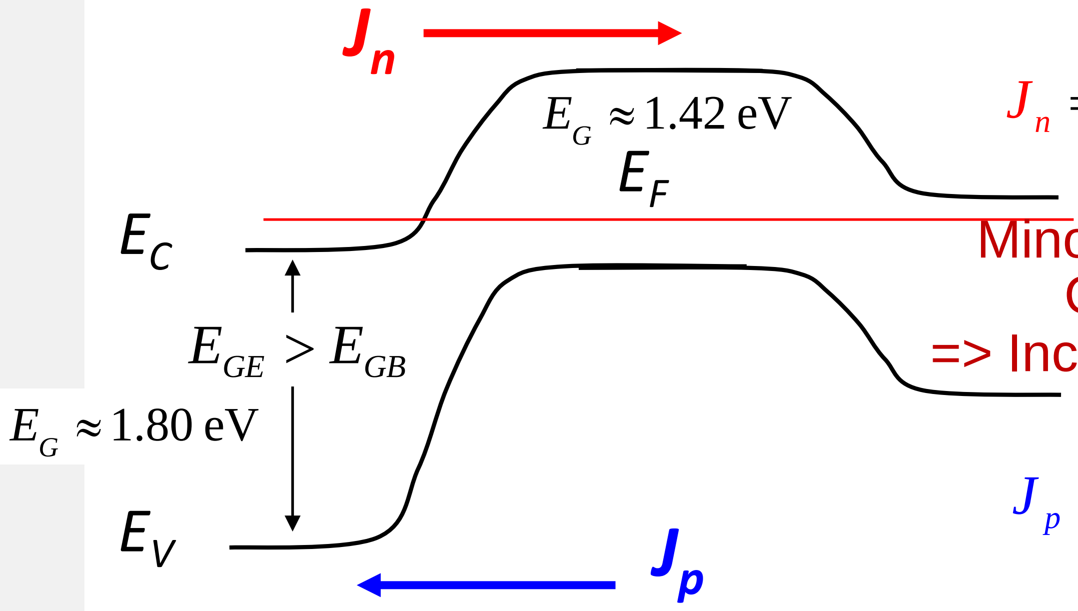
$$J_p = q\left(\frac{n_{iE}^2}{N_{DE}}\right)\frac{D_p}{W_E}e^{qV_{BE}/k_BT}$$

$$\beta = \frac{N_{DE}}{N_{AB}}\frac{D_n}{D_p}\frac{W_E}{W_B}\frac{n_{iB}^2}{n_{iE}^2}$$

$$n_i = \sqrt{N_C N_V}e^{-E_G/k_BT}$$

$$\beta_{DC} \approx \frac{N_{DE}}{N_{AB}}\frac{D_n}{D_p}\frac{W_E}{W_B}e^{\Delta E_G/k_BT}$$

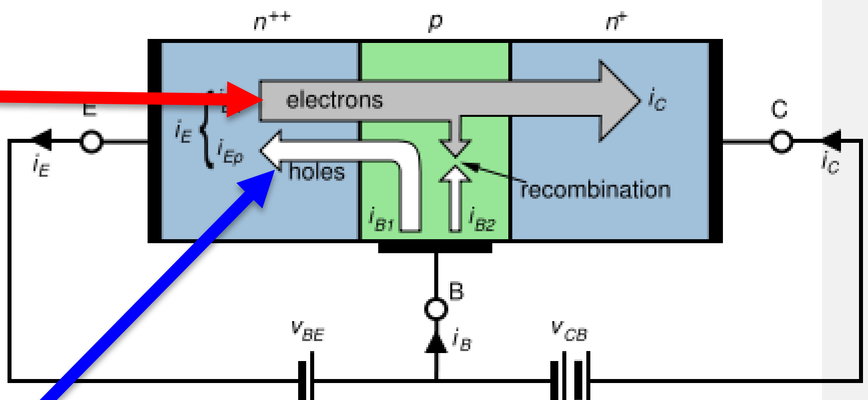
HBT Opportunities



$$J_n = q\left(\frac{n_{iB}^2}{N_{AB}}\right)\frac{D_n}{W_B}e^{qV_{BE}/k_BT}$$

Minority electrons in base
Goal: Increase I_C
=> Increase n_i decrease E_G

$$J_p = q\left(\frac{n_{iE}^2}{N_{DE}}\right)\frac{D_p}{W_E}e^{qV_{BE}/k_BT}$$



Minority holes in base
Goal: Decrease I_C
=> Decrease n_i increase E_G

Emitter bandgap > Base Bandgap

$$\beta_{DC} \approx \frac{N_{DE}}{N_{AB}}\frac{D_n}{D_p}\frac{W_E}{W_B}e^{\Delta E_G/k_BT}$$

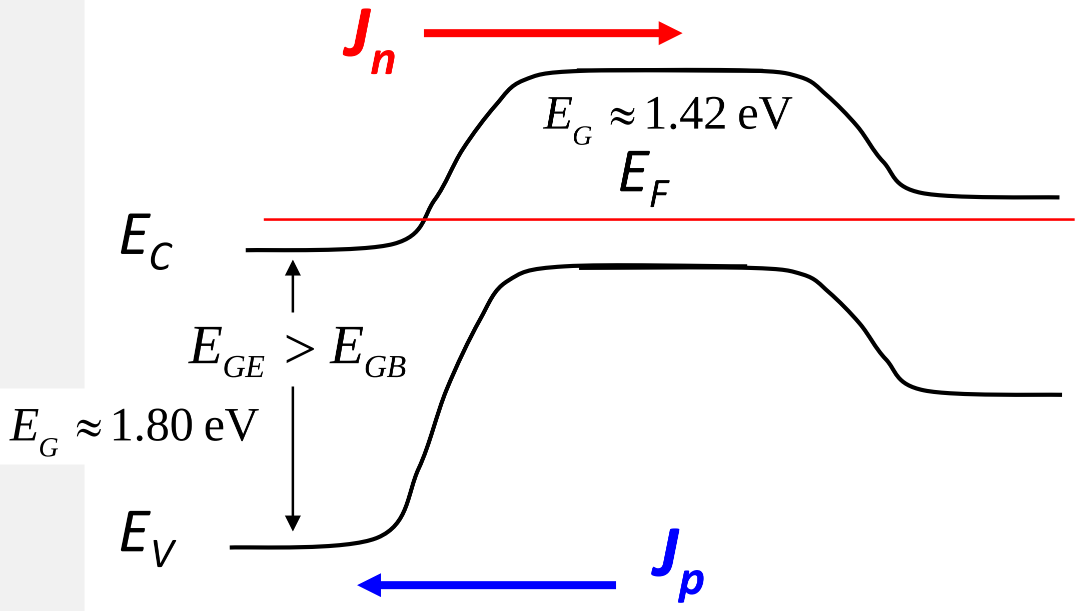
$$\Delta E_G = 1.8eV - 1.42eV = 380meV$$

$$k_BT \approx 25meV$$

$$e^{380/25} = e^{15.5} \approx 4x10^6$$

=> Opportunity for alternative thinking!

Advantages of HBT: Inverted Base Doping



$$\beta_{DC} \approx \frac{N_{DE}}{N_{AB}} \frac{D_n}{D_p} \frac{W_E}{W_B} e^{\Delta E_G / k_B T}$$

$$\Delta E_G = 1.8eV - 1.42eV = 380meV$$

$$k_B T \approx 25meV$$

$$e^{380/25} = e^{15.5} \approx 4x10^6$$

=> Opportunity for alternative thinking!

Thin base desired for speed and gain, but thin base was a problem (Early, Punch Through)

Increasing base doping was not an option since it lowered β_{DC}

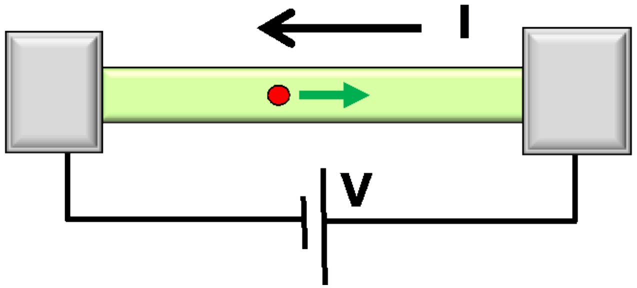
Now this is possible! => Very heavily doped base

=> prevent Punch Through, reduce Early effect, and to lower R_{ex}

Moderately doped Emitter (lower $C_{j,BE}$)

"inverted base doping" $N_{AB} >> N_{DE}$

Section 27
Heterojunction Bipolar Transistor



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

charge density velocity area

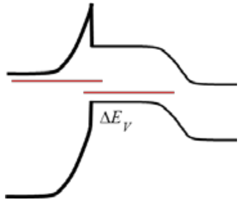
$$\beta_{poly,ballistic} \rightarrow \frac{n_{i,B}^2}{n_{i,E}^2} \times \frac{N_E}{N_B} \times \frac{\upsilon_{th}}{\upsilon_s}$$

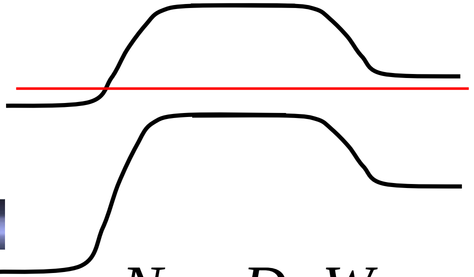
$$\frac{n_{i,B}^2}{n_{i,E}^2} = \frac{N_{C,B}N_{V,B}e^{-E_{g,B}\beta}}{N_{C,E}N_{V,E}e^{-E_{g,E}\beta}} \approx e^{(E_{g,E}-E_{g,B})\beta}$$

1
2
3
4
5
6
7
8

- 27.1 Applications, Concept, Innovation, Nobel Prize
- 27.2 Heterojunction Equilibrium Solution
- 27.3 Types of heterojunctions
- 27.4 Abrupt junction HBTs
- 27.5 Graded junction HBTs
- 27.6 Graded base HBTs
- 27.7 Double heterojunction HBTs
- 27.8 Modern Designs

status





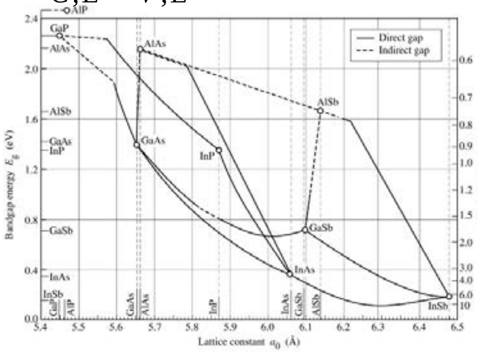
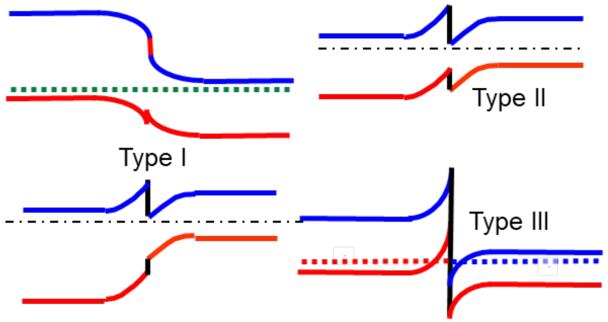


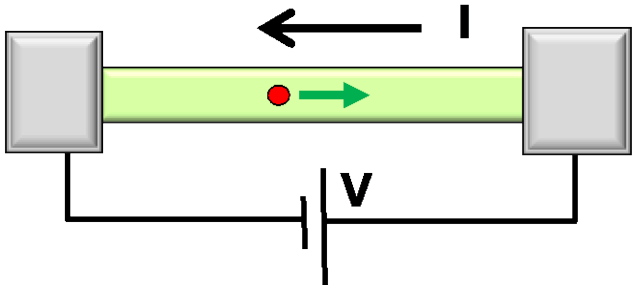
Fig. 7.6. Bandgap energy and lattice constant of various III-V semiconductors at room temperature (adopted from Tien, 1988).

$$\beta_{DC} \approx \frac{N_{DE}}{N_{AB}} \frac{D_n}{D_p} \frac{W_E}{W_B} e^{\Delta E_G / k_B T}$$



Mark Lundstrom, “Heterostructure Fundamentals,” Purdue University, 1995.
Herbert Kroemer, “Heterostructure bipolar transistors and integrated circuits,” Proc. *IEEE* , **70**, pp. 13-25, 1982.

Section 27
Heterojunction Bipolar Transistor

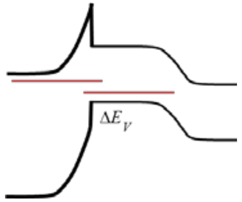


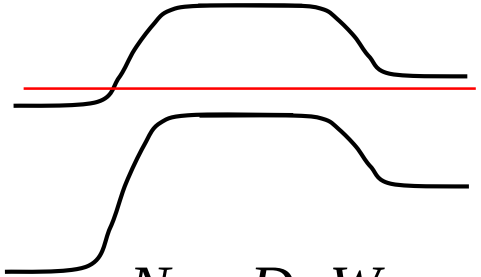
$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area

$$\beta_{poly,ballistic} \rightarrow \frac{n_{i,B}^2}{n_{i,E}^2} \times \frac{N_E}{N_B} \times \frac{\upsilon_{th}}{\upsilon_s}$$

$$\frac{n_{i,B}^2}{n_{i,E}^2} = \frac{N_{C,B} N_{V,B} e^{-E_{g,B}\beta}}{N_{C,E} N_{V,E} e^{-E_{g,E}\beta}} \approx e^{(E_{g,E} - E_{g,B})\beta}$$





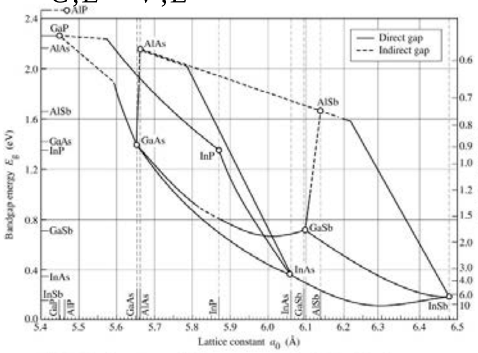
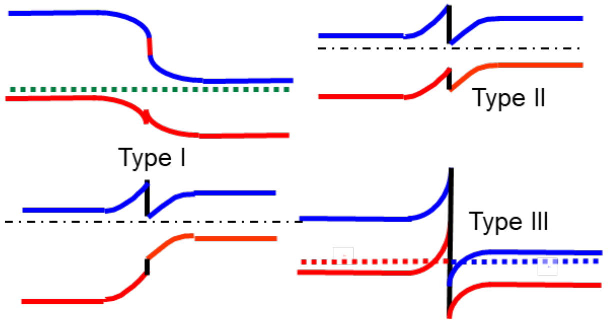


Fig. 7.6. Bandgap energy and lattice constant of various III-V semiconductors at room temperature (adopted from Tien, 1988).

$$\beta_{DC} \approx \frac{N_{DE}}{N_{AB}} \frac{D_n}{D_p} \frac{W_E}{W_B} e^{\Delta E_G / k_B T}$$



Mark Lundstrom, "Heterostructure Fundamentals," Purdue University, 1995.

Herbert Kroemer, "Heterostructure bipolar transistors and integrated circuits," Proc. *IEEE* , **70**, pp. 13-25, 1982.