Section 27
Heterojunction Bipolar Transistor

27.6 Graded Base HBTs

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PURDUE UNIVERSITY

School of Electrical and Computer Engineering

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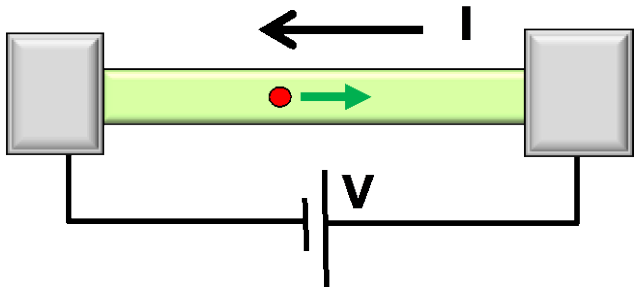


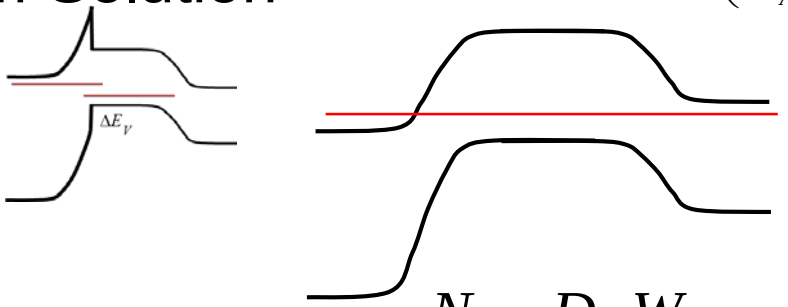
$$I = G \times V$$
$$= q \times n \times v \times A$$

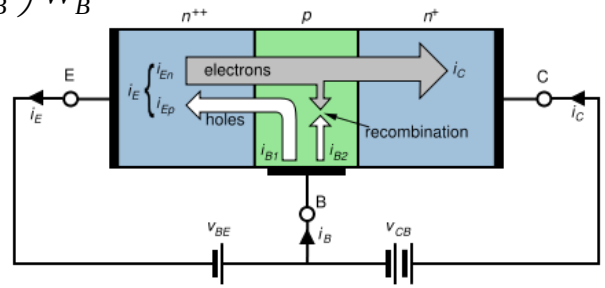
charge density velocity area

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

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

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





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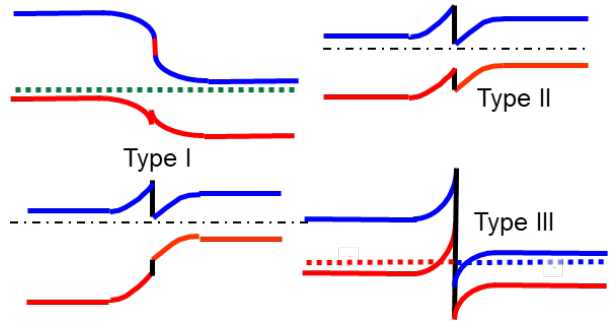
- 27.1 Applications, Concept, Innovation, Nobel Prize
- 27.2 Heterojunction Equilibrium Solution
- 27.3 Types of heterojunctions
- 27.4 Abrupt junction HBTs
- 27.5 Graded junction HBTs
- 27.6 Graded base HBTs ← status
- 27.7 Double heterojunction HBTs
- 27.8 Modern Designs

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



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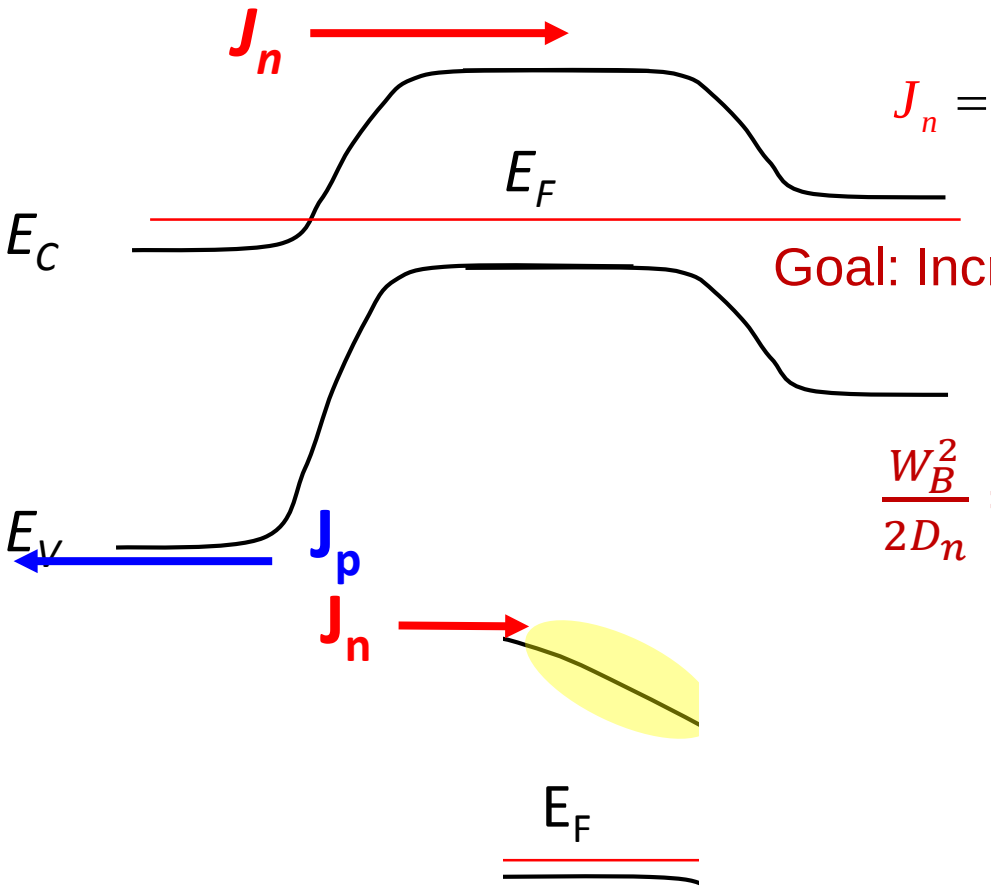
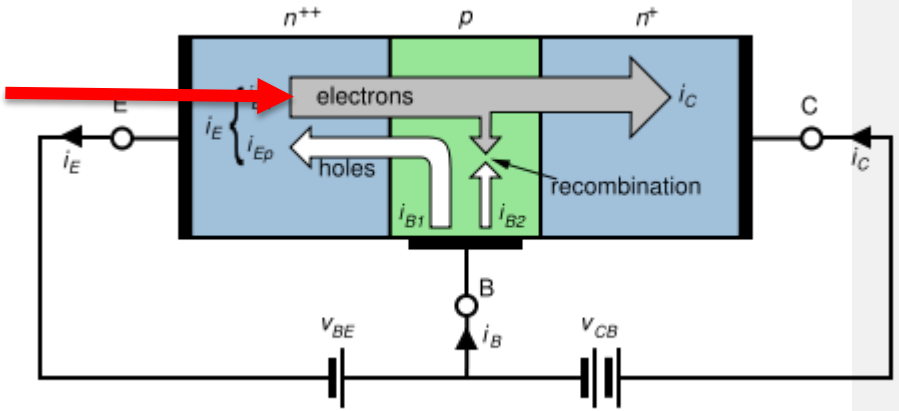
HBT Opportunities



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

Goal: Increase I_C



$\frac{W_B^2}{2D_n} = \tau_{diff}$ transit time through base

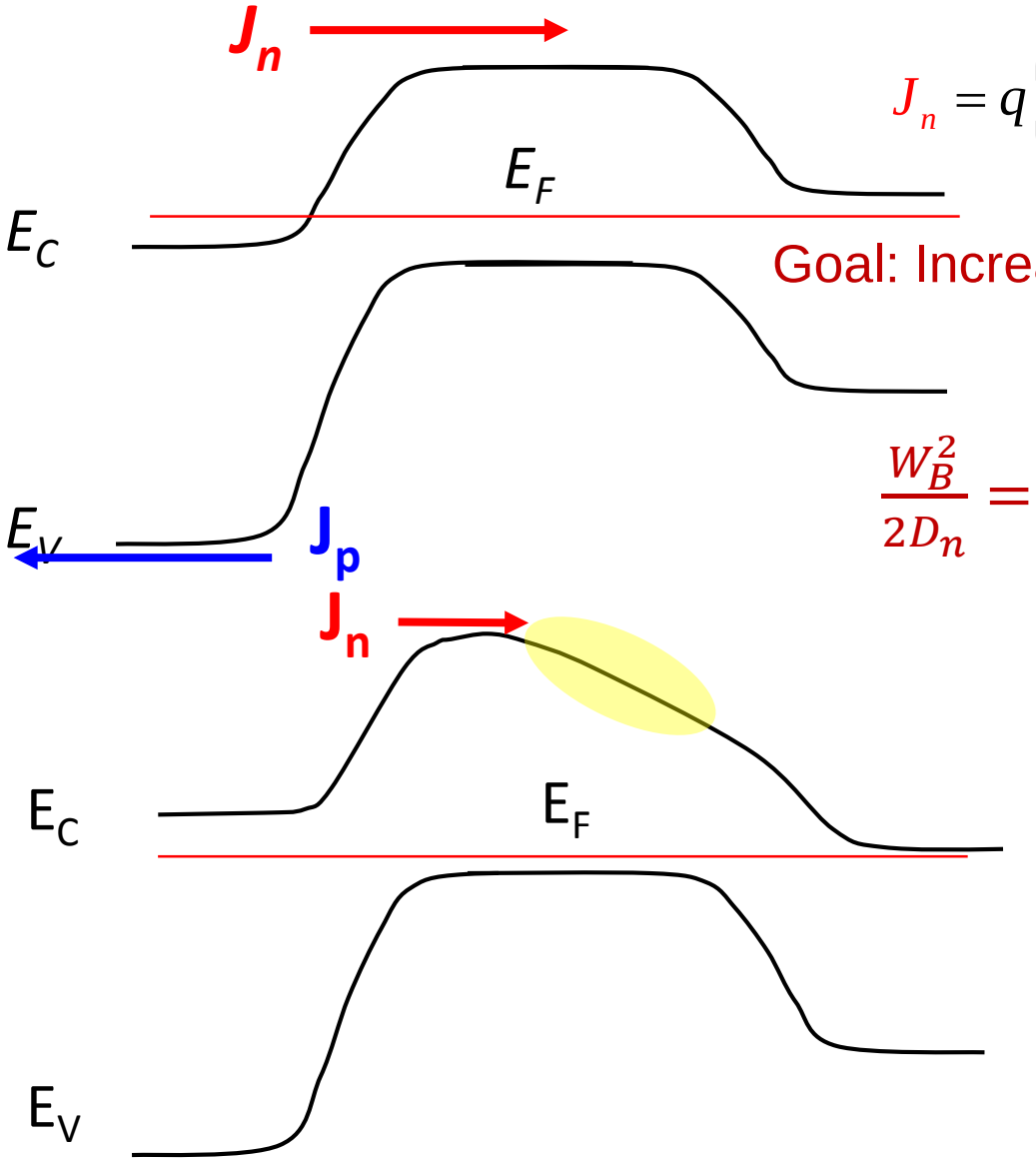
Can the base transit time be reduced?

Can the electrons be accelerated?

Can one build in an accelerating field?

Without affecting the base current?

HBT Opportunities



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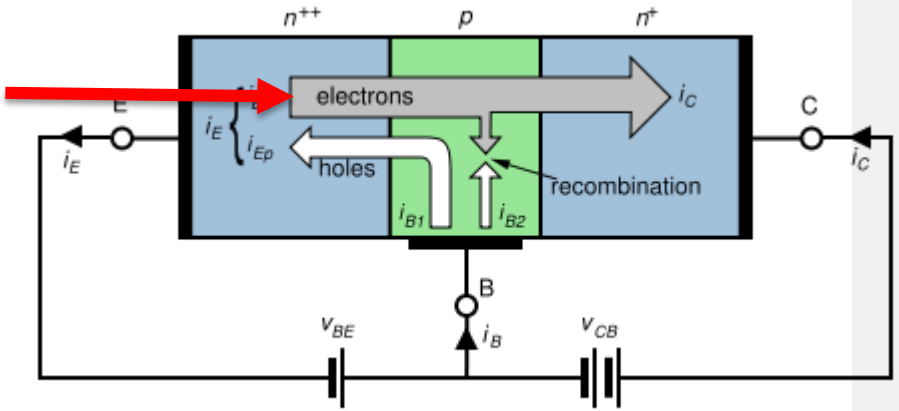

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Graded Bases

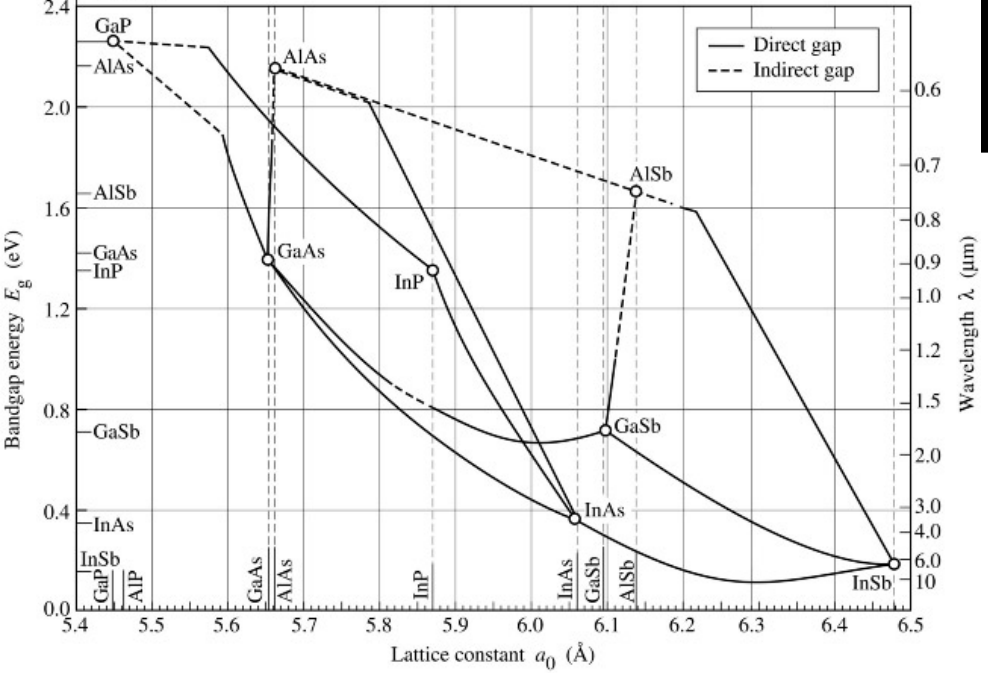
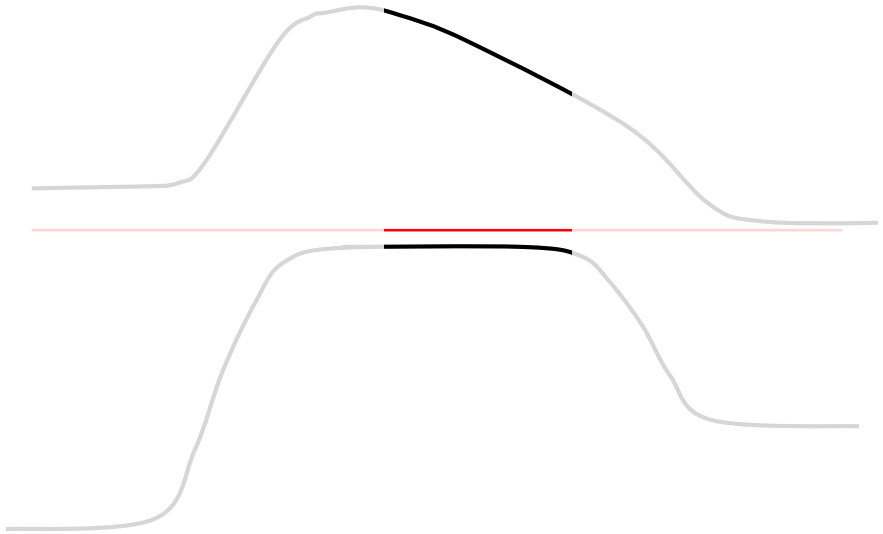
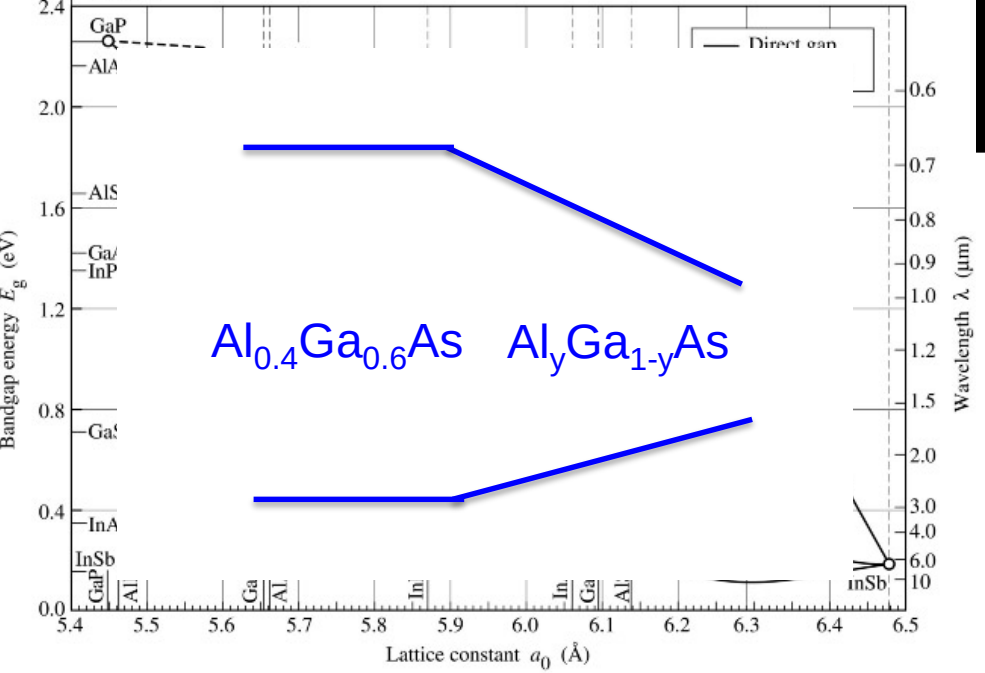


Fig. 7.6. Bandgap energy and lattice constant of various III-V semiconductors at room temperature (adopted from Tien, 1988).



Graded Bases



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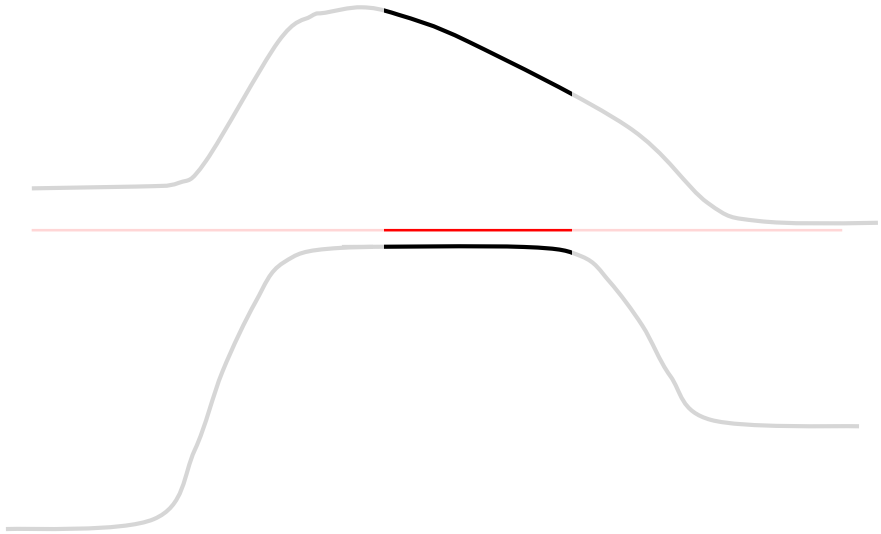
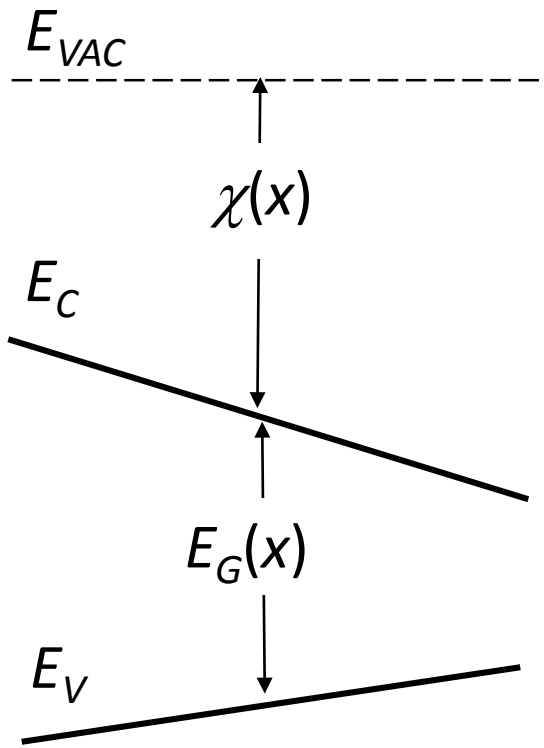
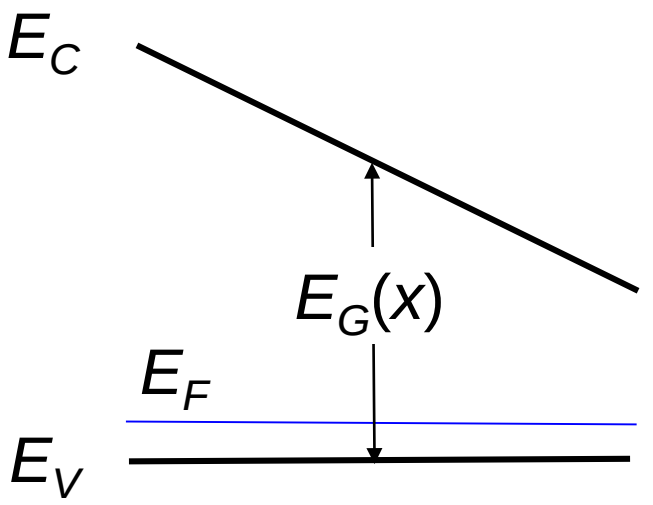






Intrinsic compositionally graded

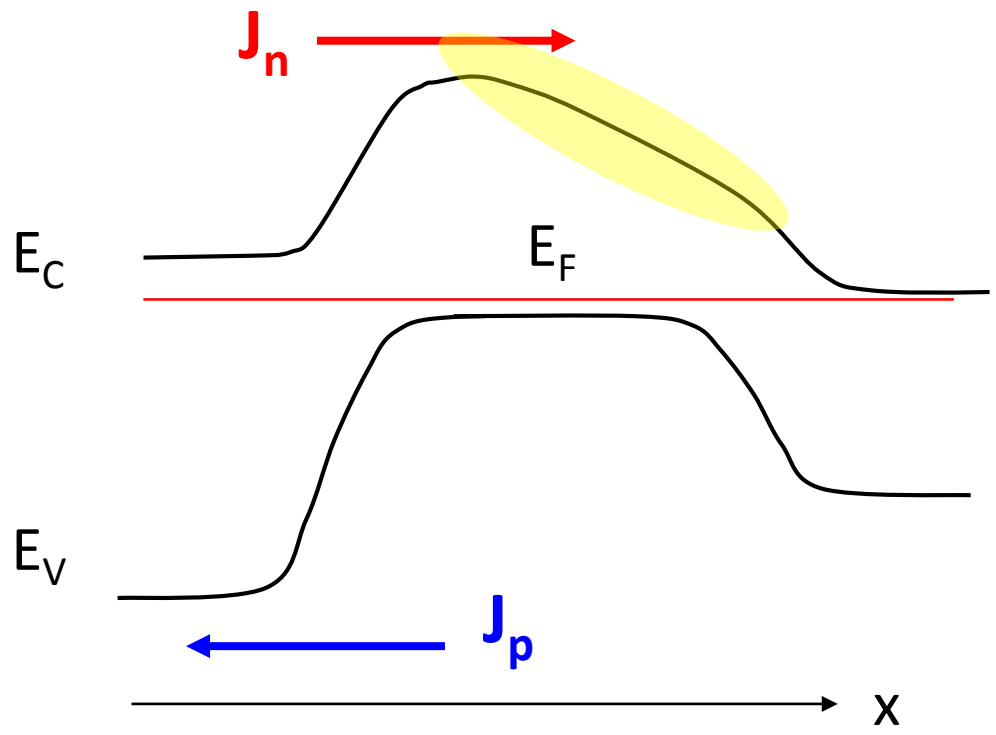
Uniformly p-doped compositionally graded

In real devices this grading is NOT continuous!

Step-like grading => steps in E_C and E_V

Why do they not matter?

Graded Base HBTs



$$\mathcal{E}_{eff} = \frac{\Delta E_G / q}{W_B}$$

$$\tau_b = \frac{W_B}{\mu_n \mathcal{E}_{eff}} << \frac{W_B^2}{2D_n}$$

$$J_n = q\left(\frac{\overline{n}_{iB}^2}{N_B}\right)\frac{D_n}{W_B}e^{qV_{BE}/k_BT}$$

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

$$\beta_{DC} = \frac{N_E}{N_B}\frac{D_n}{D_p}\frac{W_E}{W_B}\frac{\overline{n}_{iB}^2}{n_{iE}^2}$$

Base transit time

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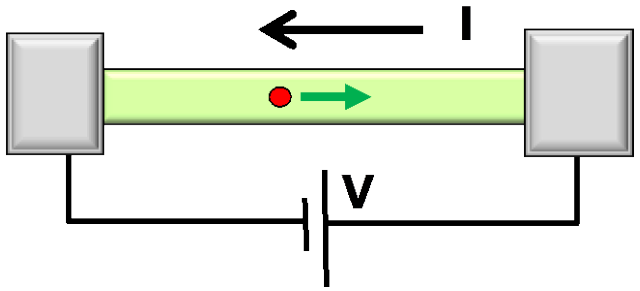

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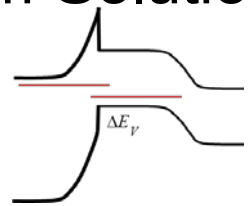
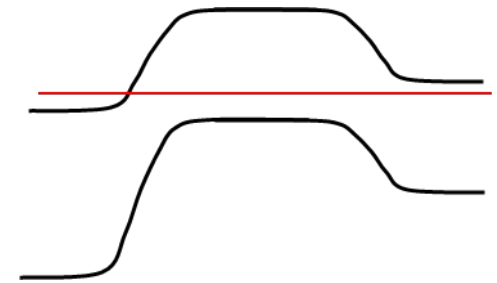
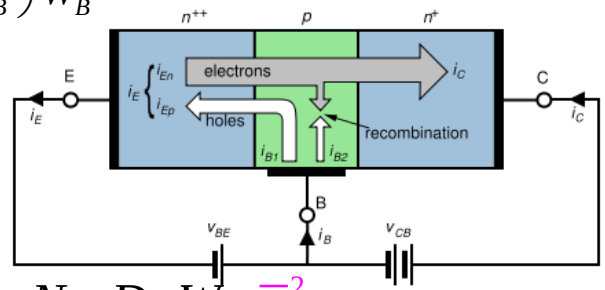
status







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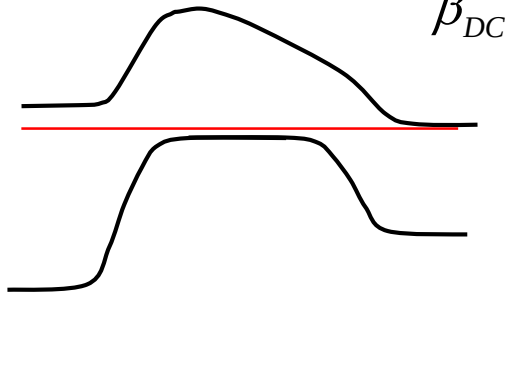

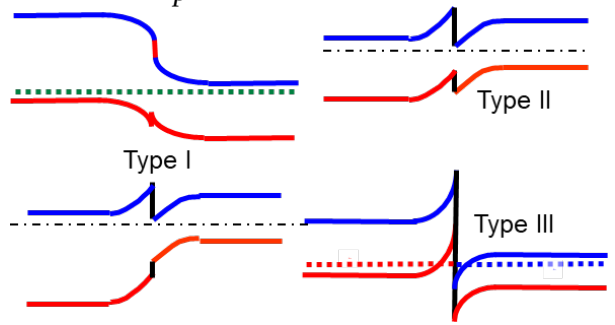

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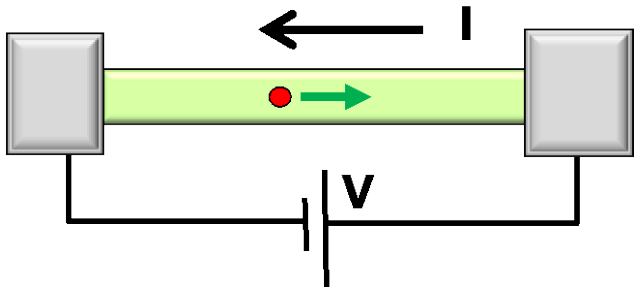

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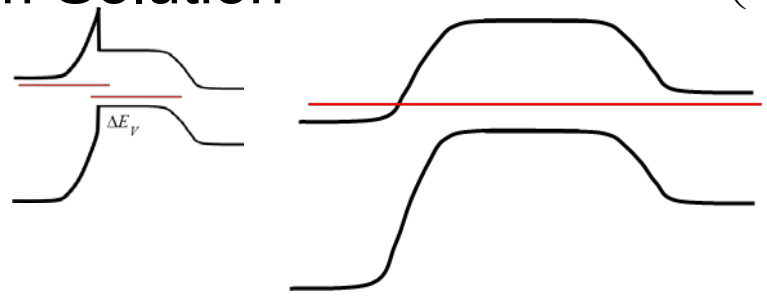

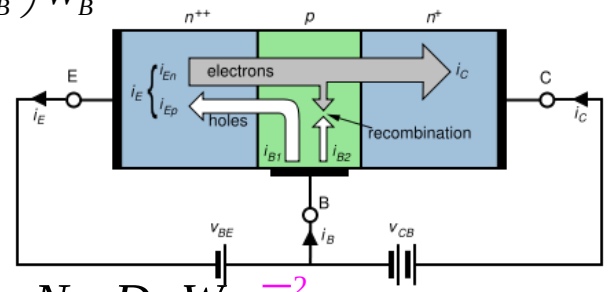

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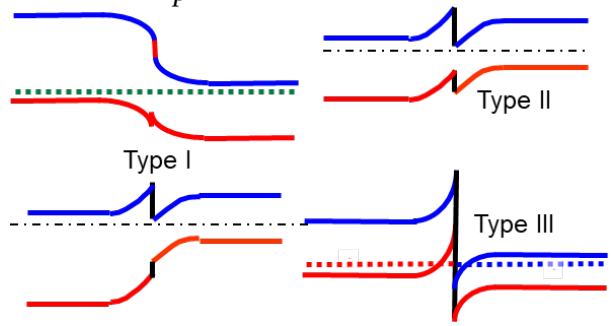

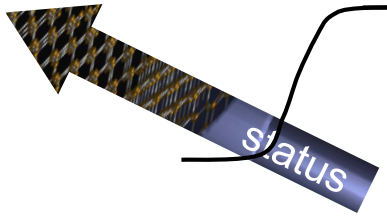

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