Section 27
Heterojunction Bipolar Transistor

27.8 Modern Designs

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School of Electrical and Computer Engineering

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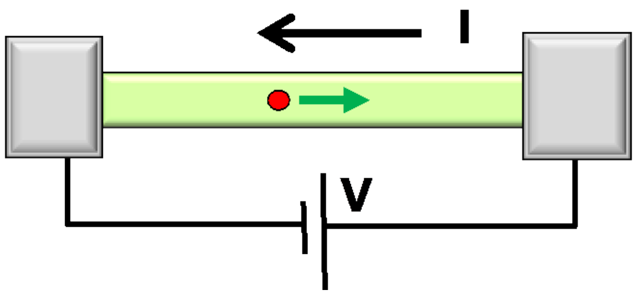
Heterojunction Bipolar Transistor



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

charge density velocity area

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

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

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

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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
- 27.7 Double heterojunction HBTs
- 27.8 Modern Designs

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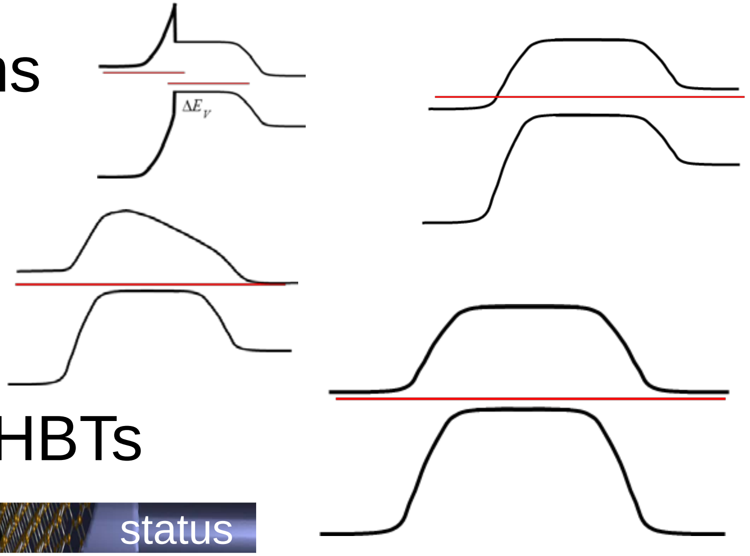
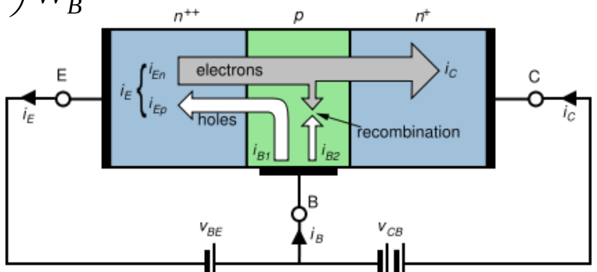
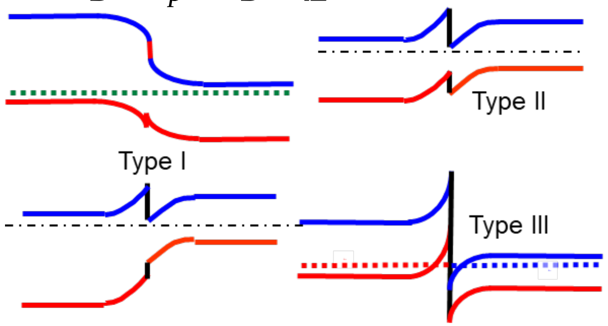


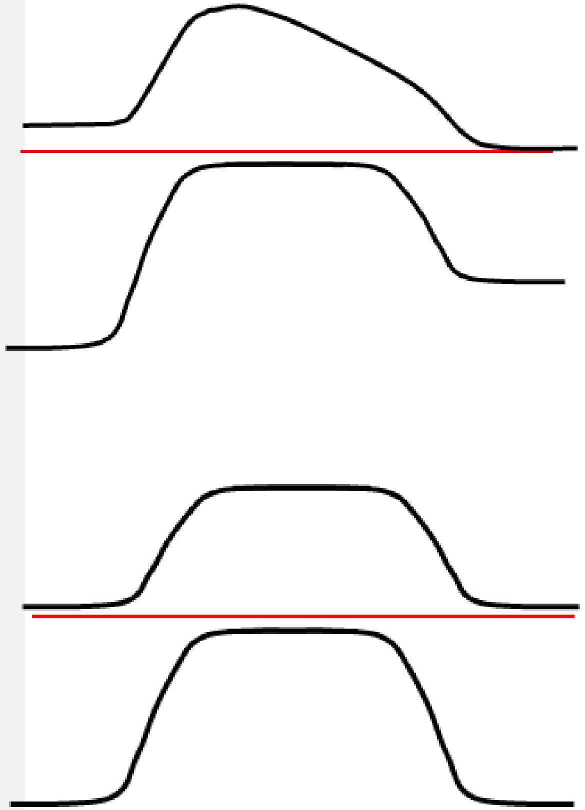


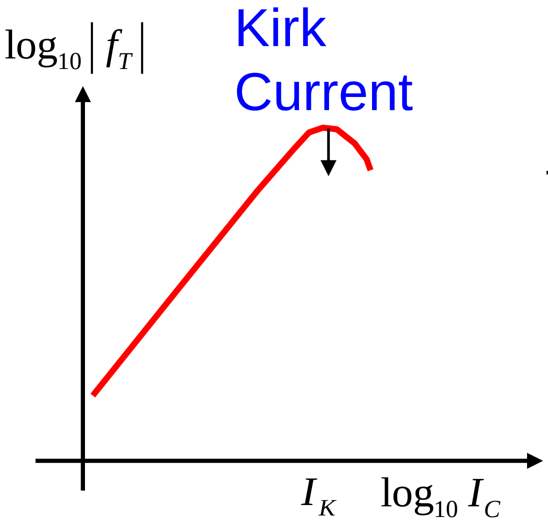
$$\beta_{DC} = \frac{N_E}{N_B}\frac{D_n}{D_p}\frac{W_E}{W_B}\frac{\bar{n}_{iB}^2}{n_{iE}^2}$$



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

Putting the Terms Together
How does the HBT Help?





Base transit time reduced
Graded base with built in field
Can increase base doping N_B

Can decrease W_B

$$\frac{1}{2\pi f_T} = \left[\frac{W_B^2}{2D_n} + \frac{W_{BC}}{2\upsilon_{sat}}\right] + \frac{k_BT}{qI_C}\left[C_{j,BC} + C_{j,BE}\right]$$

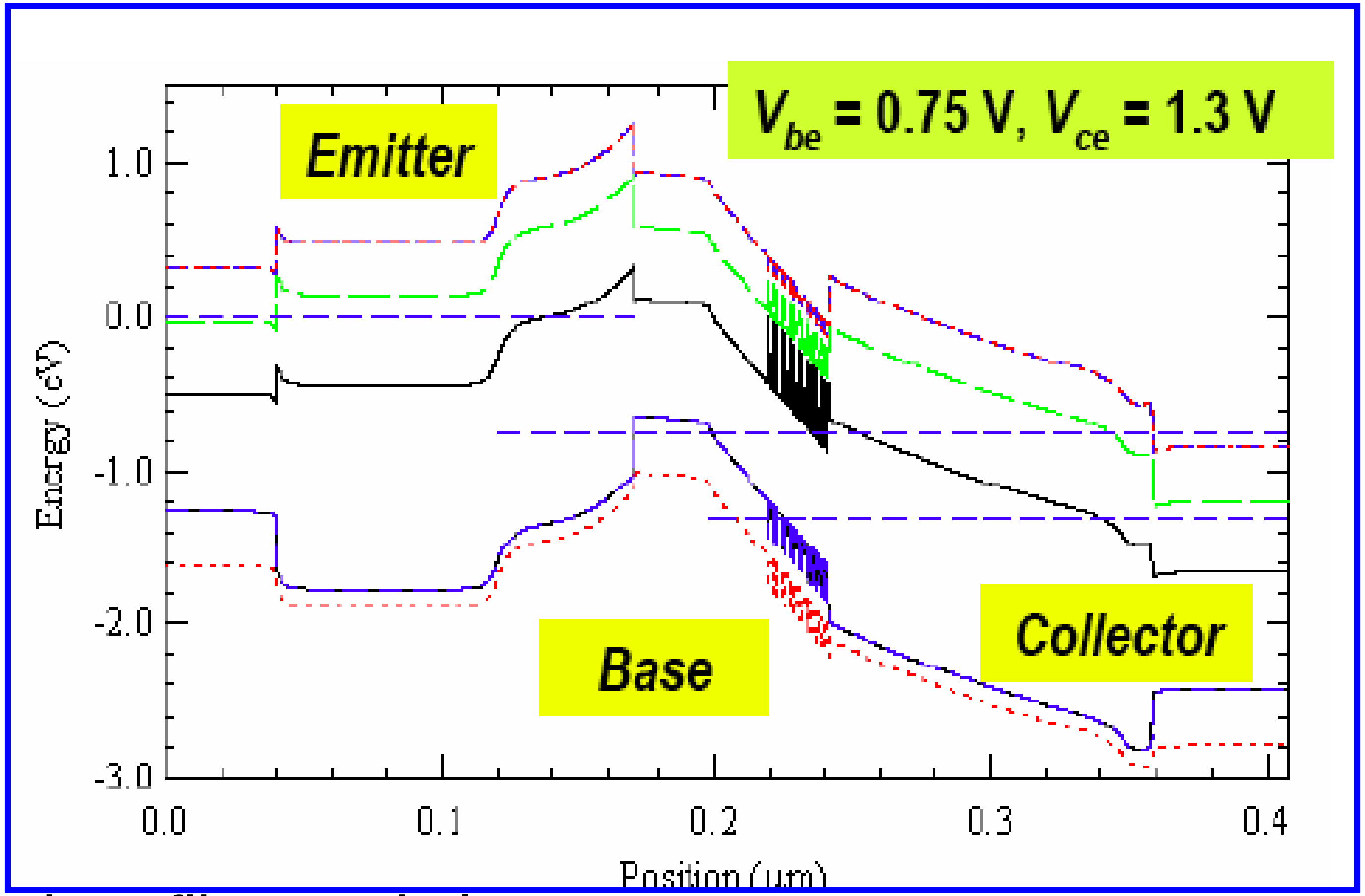
Can increase collector doping
N_C base doping is higher now
no junction loss (Kirk) high I_K

Increased N_C
=> Increased depletion
=> Reduced C_{BC}

Epitaxial Layer Design (II)

DHBT: Abrupt InP emitter, InGaAs base, InAlGaAs C/B grades

InGaAs 3E19 Si 400 Å
InP 3E19 Si 800 Å
InP 8E17 Si 100 Å
InP 3E17 Si 300 Å
InGaAs 8E19 → 5E19 C 300 Å
Setback 3E16 Si 200 Å
Grade 3E16 Si 240 Å
InP 3E18 Si 30 Å
InP 3E16 Si 1030 Å
InP 1.5E19 Si 500 Å
InGaAs 2E19 Si 125 Å
InP 3E19 Si 3000 Å
SI-InP substrate



InP technology typical, to match to fiber optic lasers

InGaAs high doping contact

Si is doping in III-V

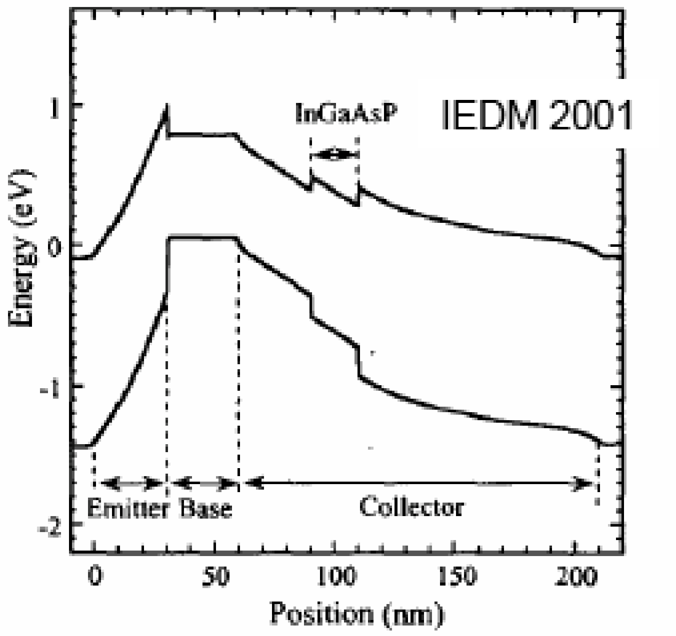
Epitaxial Layer Design (III)

InGaAs/InGaAsP/InP grade

InP/InGaAs DHBTs with 341-GHz f_T at high current density of over 800 kA/cm^2

Minoru Ida, Kenji Kurishima, Noriyuki Watanabe, and Takatomo Enoki

IEDM 2001



-suitable for MOCVD growth
- excellent results

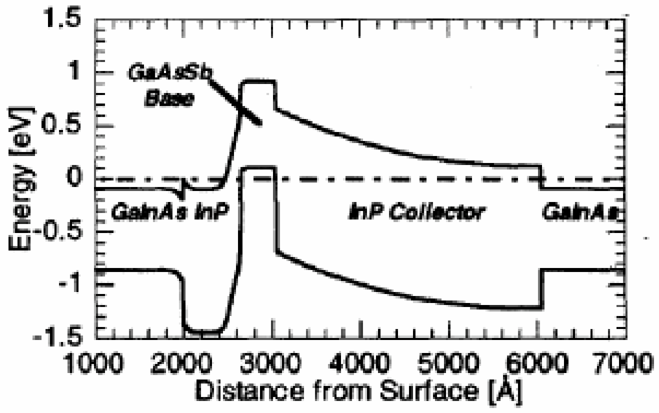
InP/GaAsSb/InP DHBT

11th International Conference on Indium Phosphide and Related Materials
16-20 May 1999 Davos, Switzerland

TuA1-3

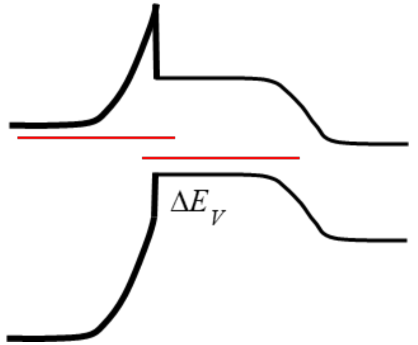
InP/GaAsSb/InP DOUBLE HETEROJUNCTION BIPOLAR TRANSISTORS WITH HIGH CUT-OFF FREQUENCIES AND BREAKDOWN VOLTAGES

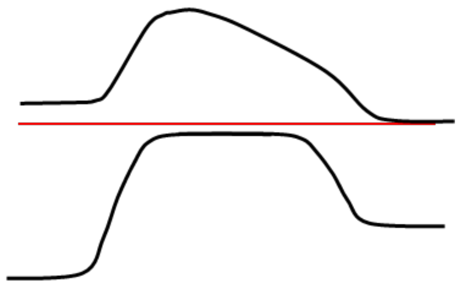
N. Matine, M. W. Dvorak, X. G. Xu, S. P. Watkins, and C. R. Bolognesi

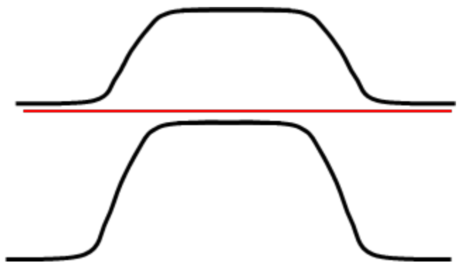


- does not need B/C grading
- E/B band alignment through GaAsSb alloy ratio (strain) or InAlAs emitter
- somewhat poorer transport parameters to date for GaAsSb base

HBT Summary



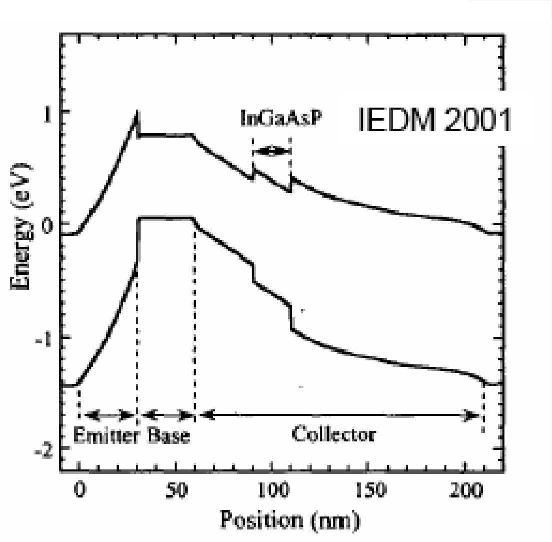




1) The use of a wide bandgap emitter has two benefits:
   - -allows heavy base doping
   - -allows moderate emitter doping

2) The use of a wide bandgap collector has benefits:
   - -symmetrical device
   - -reduced charge storage in saturation
   - -reduced collector offset voltage
   - -higher collector breakdown voltage

3) Bandgap engineering has potential benefits:
   - -heterojunction launching ramps
   - -compositionally graded bases
   - -elimination of band spikes



4) HBTs have the potential for THz cutoff frequencies.
However, it has yield issues and heating and contact R problems.

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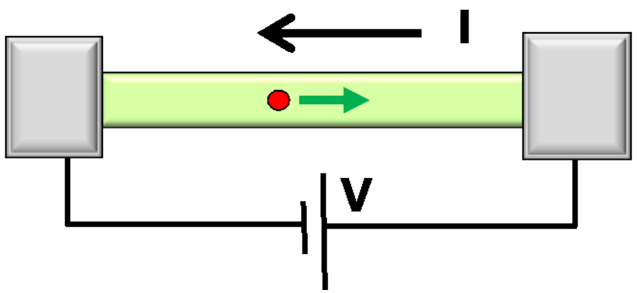

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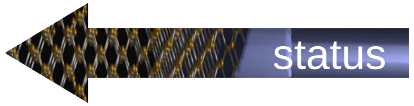

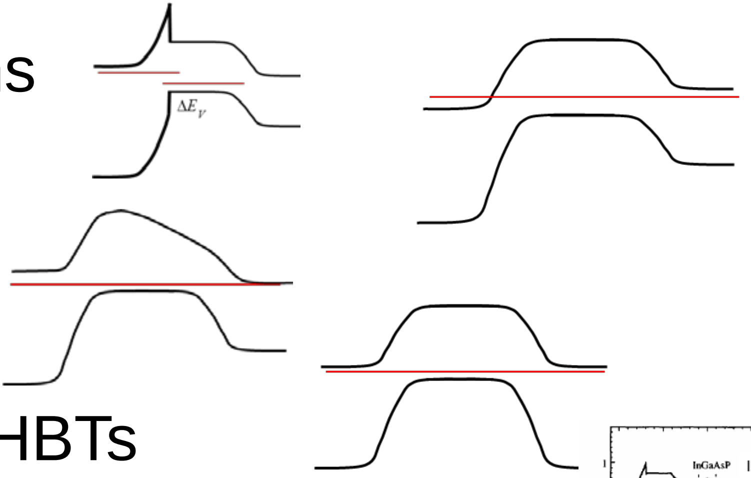

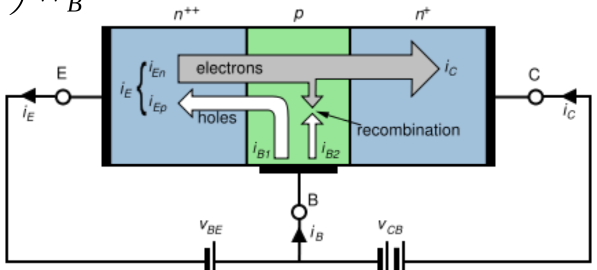

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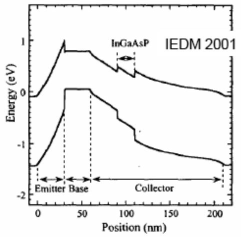

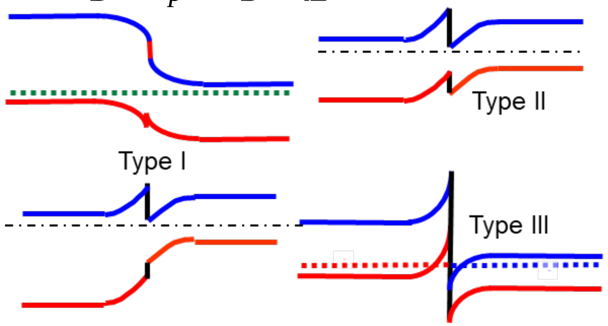

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