Heterojunction Bipolar Transistors

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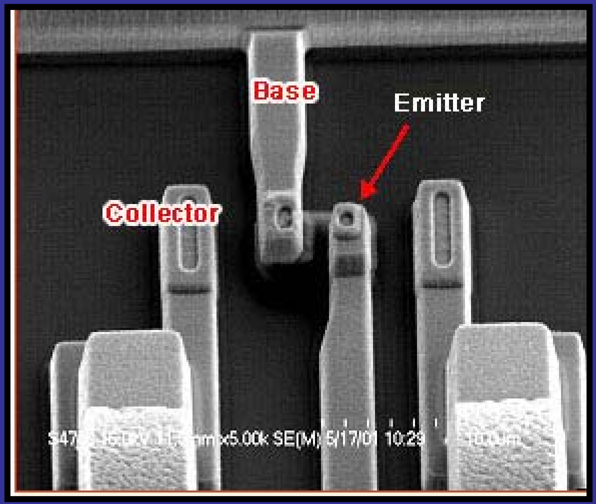
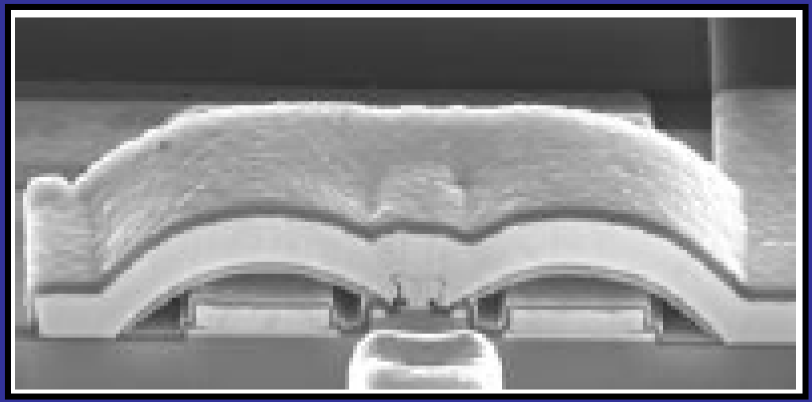
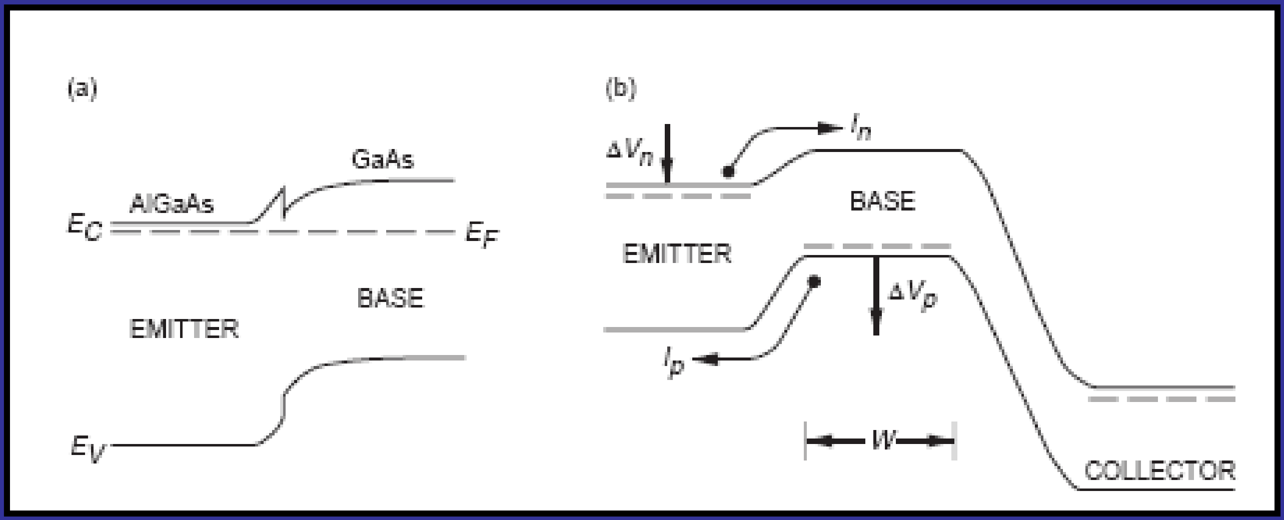




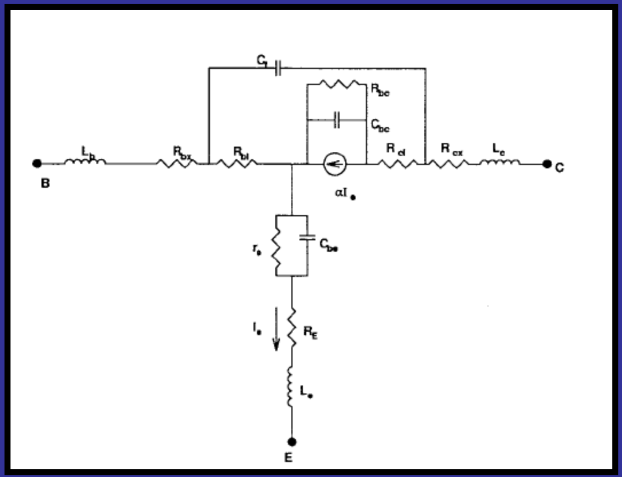
HBT Basics

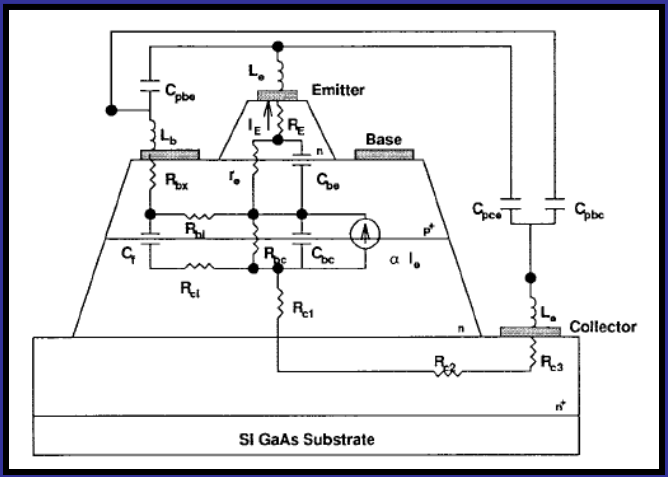


Advantages:

- Base can be thinner (50-1000 Å) and more highly doped (10^{18}–10^{20}/cm^{3}).
- High Early voltage.
- Current density is rarely limited by high injection effects in the base.
- Current gain decreases with increasing T. High current gains possible at low temperatures when diffusion is not effective (with appropriate base grading).

Modeling HBTs



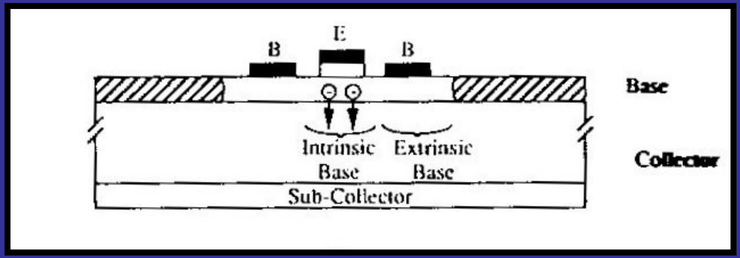


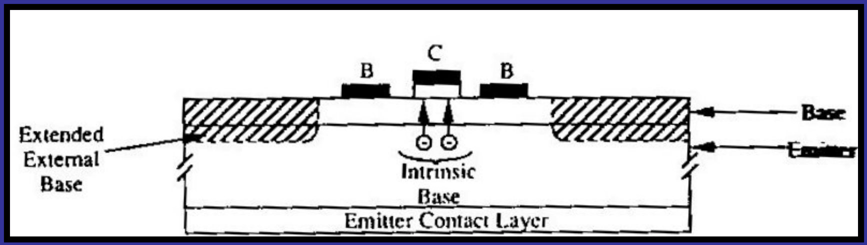
Gummel-Poon Model has 55+ parameters and is mainly used in SPICE simulations.

Small signal model is more developed than large-signal model.

BJT models can often be adapted to model HBTs.

Designing an HBT





Emitter-Up Structure:

Easier to make and higher emitter injection efficiency.

Collector-Up Structure:

Reduced base-collector capacitance.

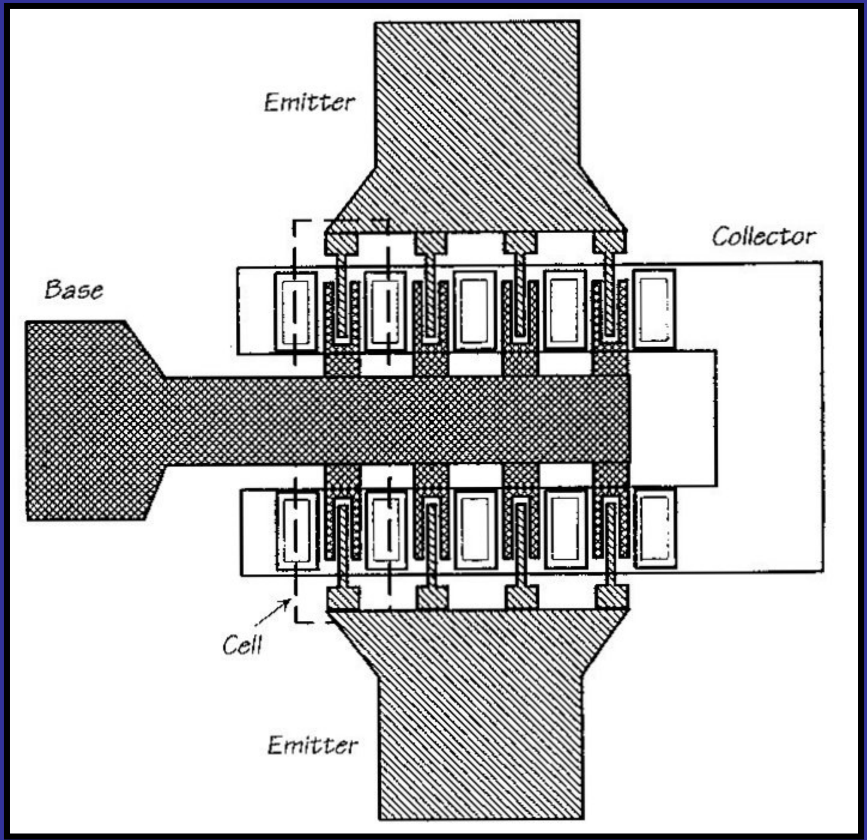
More susceptible to self-heating since the collector holds the largest part of the device voltage.

Designing an HBT

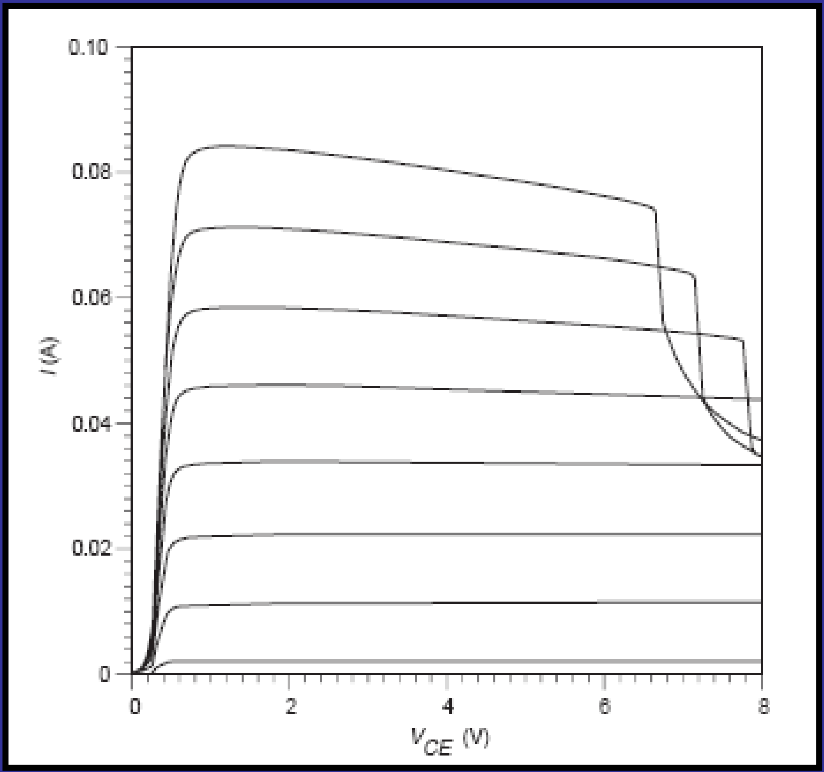
Narrower fingers are better for higher frequencies and low temperatures, but have lower current gain and B-C capacitance is increased.

Microwave performance of a single cell represents the best gain, efficiency, and power density of the HBT.

Output power is the sum of the powers generated by each cell.



I-V Characteristics



Self-Heating:

- Collector current > 40mA.
- High current and low thermal conductivity leads to an increase in lattice temperature.
- Higher temperatures make it harder for electrons to pass through the device, reducing the current.

Collector Current Collapse:

- Multifinger layout leads to different temperature and current distributions on each finger.
- One finger begins to rapidly draw current and current gain is decreased.

HBT Parameters

Transit Frequency:

Small-signal current gain is unity.

$$f_T = \frac{1}{2\pi\tau_{total}} \qquad \tau_{total} = \tau_E + \tau_B + \tau_C$$

Maximum Oscillation Frequency:

Small-signal power gain is unity.

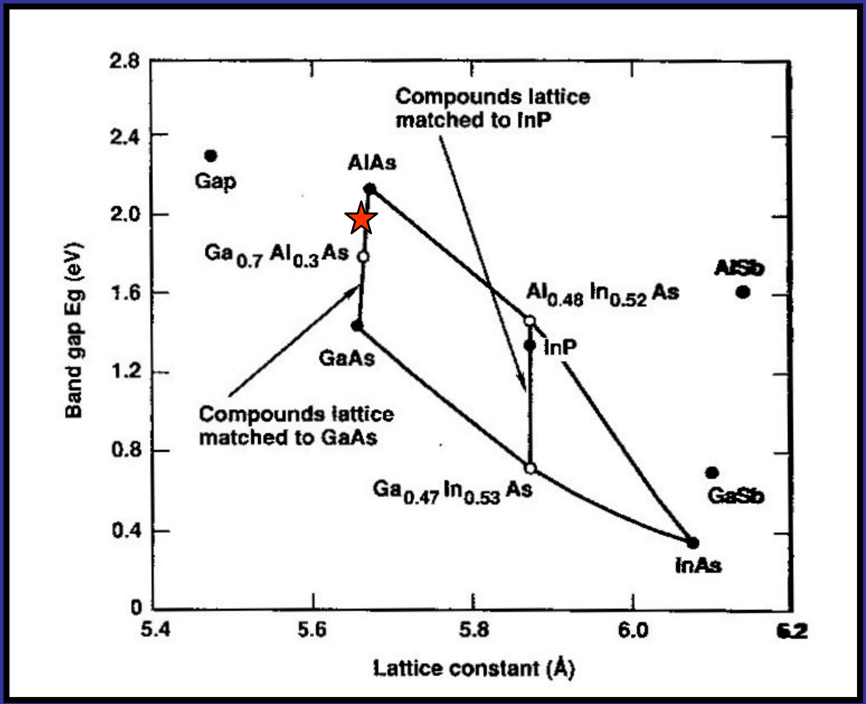
$$f_{\max} = \sqrt{\frac{f_T}{2\pi R_B C_{jc}}}$$

Power Added Efficiency:

$$PAE = \frac{(P_{out} - P_{in})_{RF}}{P_{DC,total}}$$

And now for some real HBTs…

InGaP HBTs



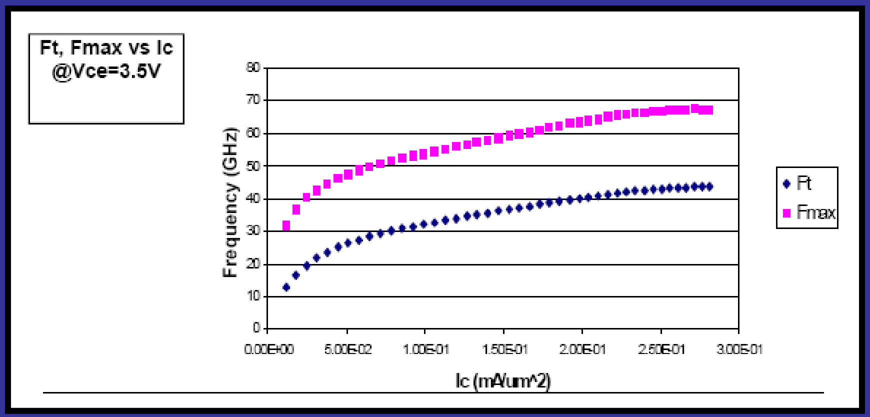
Indium has low reactivity compared to aluminum and is much more stable.

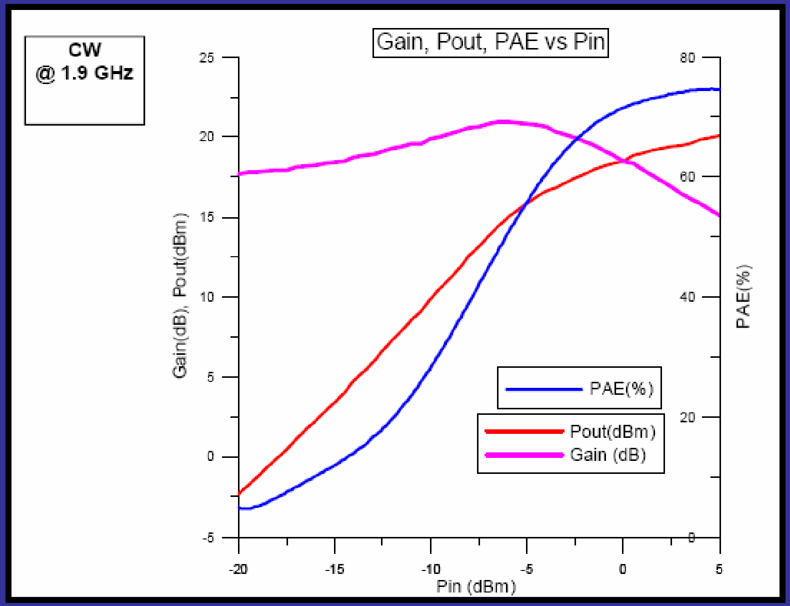
E_g = 1.89eV when lattice matched to GaAs.

Bandgap difference appears mainly in the valence band.

Significantly less deep-level traps than in AlGaAs/GaAs.

InGaP HBTs





HBTs made by Triquint:

ß = 130

V_{be} = 1.15V

Emitter can be as small as 2µm.

PAE as high as 90% recorded in 1-2GHz range.

Applications:

Handsets, cellphones, A/D converters, and anything else involving high frequencies.

SiGe HBTs

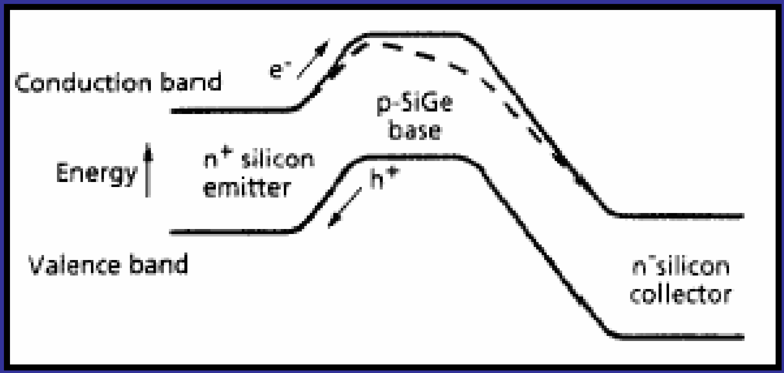
Implementing in Si is harder than meets the eye….

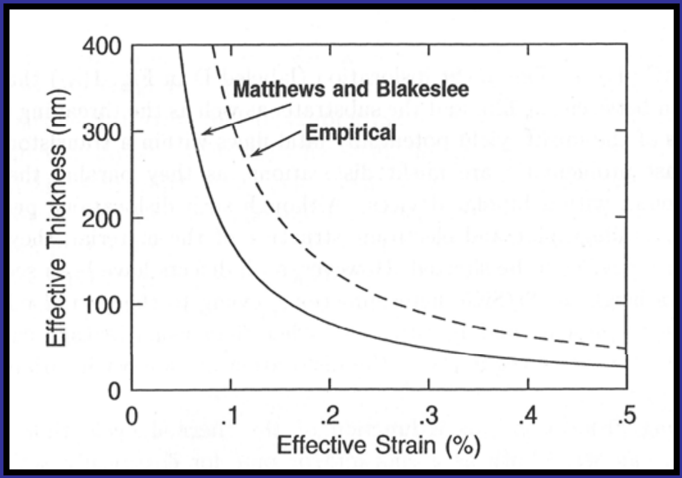
Lattice constant of Si is 4% smaller than Ge.

SiGe is in the base rather than the emitter.

Critical or Effective Thickness:

Thickness to which a SiGe layer can be grown psuedomorphically grown on Si before relaxing back to its natural lattice constant.





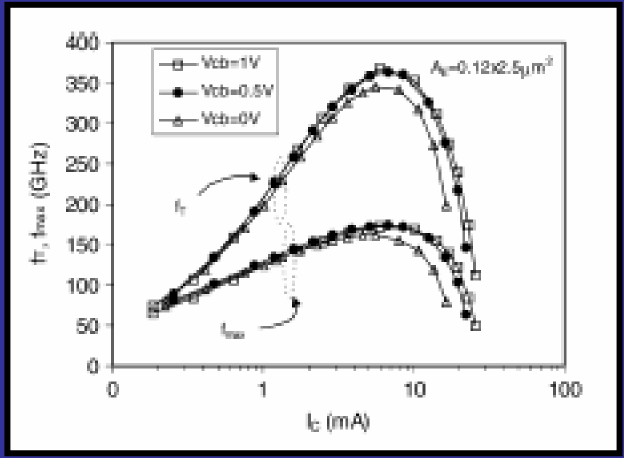
SiGe HBTs

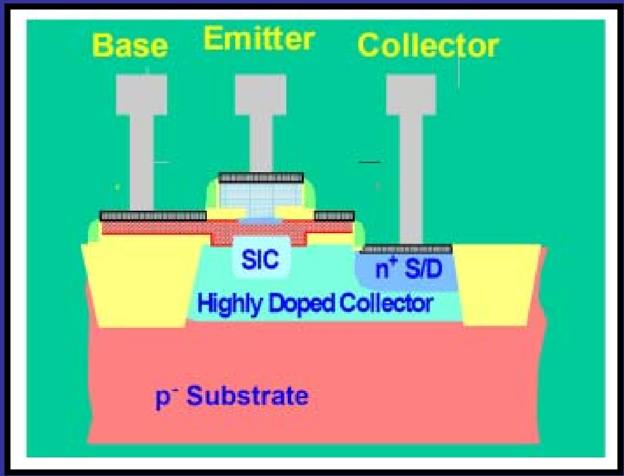
Advantages:

Conduction and valence band edges of SiGe are within the band edges for Si, making the device faster.

Band offsets are not very large, but grading can be used to induce large electric fields.

Strained layers increase carrier mobility.





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