Lecture #17

ANNOUNCEMENTS

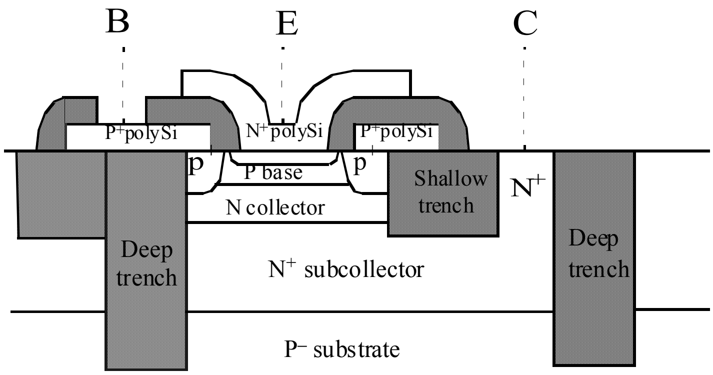
- Special Review Session: Wed. 3/19 @ 5 PM, 293 Cory
- No Coffee Hour this week and next week

OUTLINE

The Bipolar Junction Transistor
  - Bandgap narrowing in emitter, base
  - Poly-Si emitter
  - Gummel plot

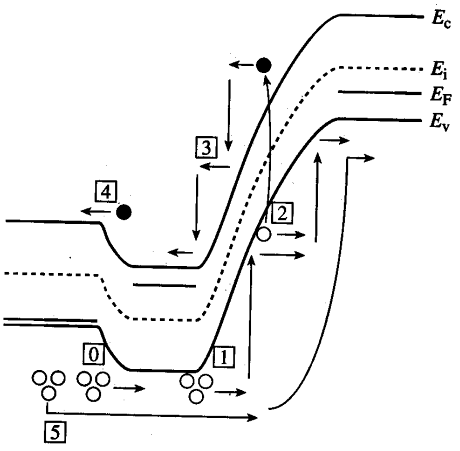
Reading: Finish Chapter 11

NPN BJT Structure (cross-section)



Avalanche Multiplication

- Avalanche may be important:
  1. If it occurs before punchthrough
  2. As an amplification mechanism in a phototransistor
     - Inject a photon into the CB depletion region to cause avalanche multiplication of it



Emitter Bandgap Narrowing

$$\beta \propto \frac{N_E}{N_B}\frac{n_{iB}^2}{n_{iE}^2}$$

To raise β, N_E is typically very large, so $n_{iE}^2 > n_i^2$ (called the heavy doping effect).

$$n_i^2 = N_C N_V e^{-E_g/kT}$$

Since heavy doping can reduce E_G, this effect is also known as band-gap narrowing.

$$n_{iE}^2 = n_i^2 e^{\Delta E_{gE}/kT}$$

ΔE_{GE} is negligible for $N_E < 10^{18}$ cm^{-3}

- 35 meV at 10^{18} cm^{-3}
- 75 meV at 10^{19} cm^{-3}

Narrow-Bandgap (SiGe) Base

$\beta \propto \frac{N_E}{N_B}\frac{n_{iB}^2}{n_{iE}^2}$ To further elevate β, we can raise n_{iB} by using an epitaxial $\mathrm{Si}_{1-\eta}\mathrm{Ge}_{\eta}$ base.

With $\eta = 0.2$, E_{GB} is reduced by 0.1eV.

EXAMPLE: Emitter Bandgap Narrowing

Assume $D_B = 3D_E$, $W_E = 3W_B$, $N_B = 10^{18}\ cm^{-3}$, *and* $n_{iB}^2 = n_i^2$. *What is* β_{dc} *for* ***(a)*** $N_E = 10^{19}\ cm^{-3}$, ***(b)*** $N_E = 10^{20}\ cm^{-3}$, *and* ***(c)*** $N_E = 10^{19}\ cm^{-3}$ *and a SiGe base with* $\Delta E_{gB} = 60\ meV$ *?*

(a) At $N_E = 10^{19}\ cm^{-3}$, $\Delta E_{gE} \approx 35\ meV$,

$$n_{iE}^2 = n_i^2 e^{\Delta E_{gE}/kT} = n_i^2 e^{35meV/26meV} = 3.8n_i^2$$

$$\beta_{dc} = \frac{D_B W_E}{D_E W_B}\cdot\frac{N_E n_i^2}{N_B n_{iE}^2} = \frac{9\cdot 10^{19}\cdot n_i^2}{10^{18}\cdot 3.8n_i^2} = 23.6$$

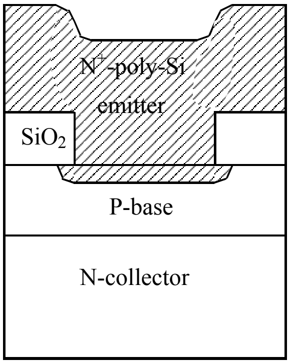
(b) At $N_E = 10^{20} cm^{-3}$, $\Delta E_{gE} \approx 150\,meV$

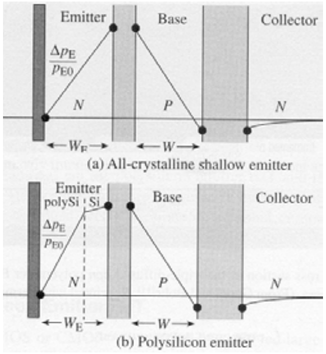
$$n_{iE}^2 = 320n_i^2 \qquad \beta_{\mathrm{dc}} = 3$$

(c) $n_{iB}^2 = n_i^2 e^{\Delta E_{gB}/kT} = n_i^2 e^{60meV/26meV} = 10n_i^2 \qquad \beta_F = 236$

Polycrystalline-Silicon (Poly-Si) Emitter

- β_F is larger due to the large W_E, mostly made of the N$^+$ poly-Si.
- Decreased mobility in poly-Si reduces p_E slope at B-E edge, improving γ

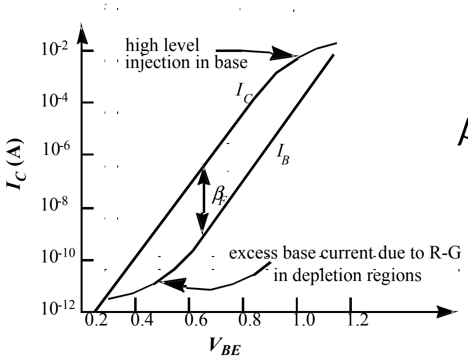


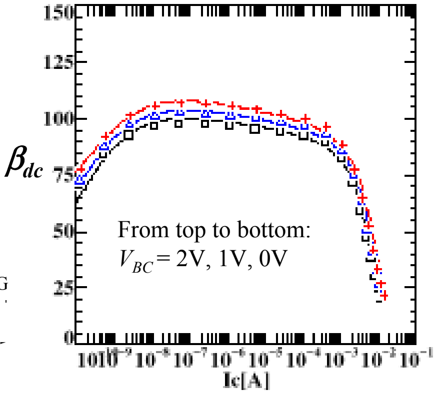


(a) All-crystalline shallow emitter

(b) Polysilicon emitter

Gummel Plot and β_{dc} vs. I_C





From top to bottom: V_{BC} = 2V, 1V, 0V

Gummel Numbers

Non-Ideal Effects at Low V_{EB}

- In the ideal transistor analysis, thermal R-G currents in the emitter and collector junctions were neglected.

- Under active-mode operation with small V_{EB}, the thermal recombination current is likely to be a dominant component of the base current
  $\Rightarrow$ **low emitter efficiency, hence lower gain**

Non-Ideal Effects at High V_{EB}

- Decrease in β_F at high I_C is caused by:
  - high-level injection
  - series resistance
  - current crowding