EECS130
Integrated Circuit Devices

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11/27/2007

BJTs- Lecture 5

Reading Assignment: Finish Chapter 11

Announcements

- HW10 is due Thursday, 11/29.

Pop Quiz

- Draw the minority and majority carrier concentration profiles for a n^+pn BJT at equilibrium and in the saturation mode. Assume $W \ll L_B$. Clearly label the emitter, base, and collector regions. Label p_E, n_E, p_B, n_B, p_C, n_C

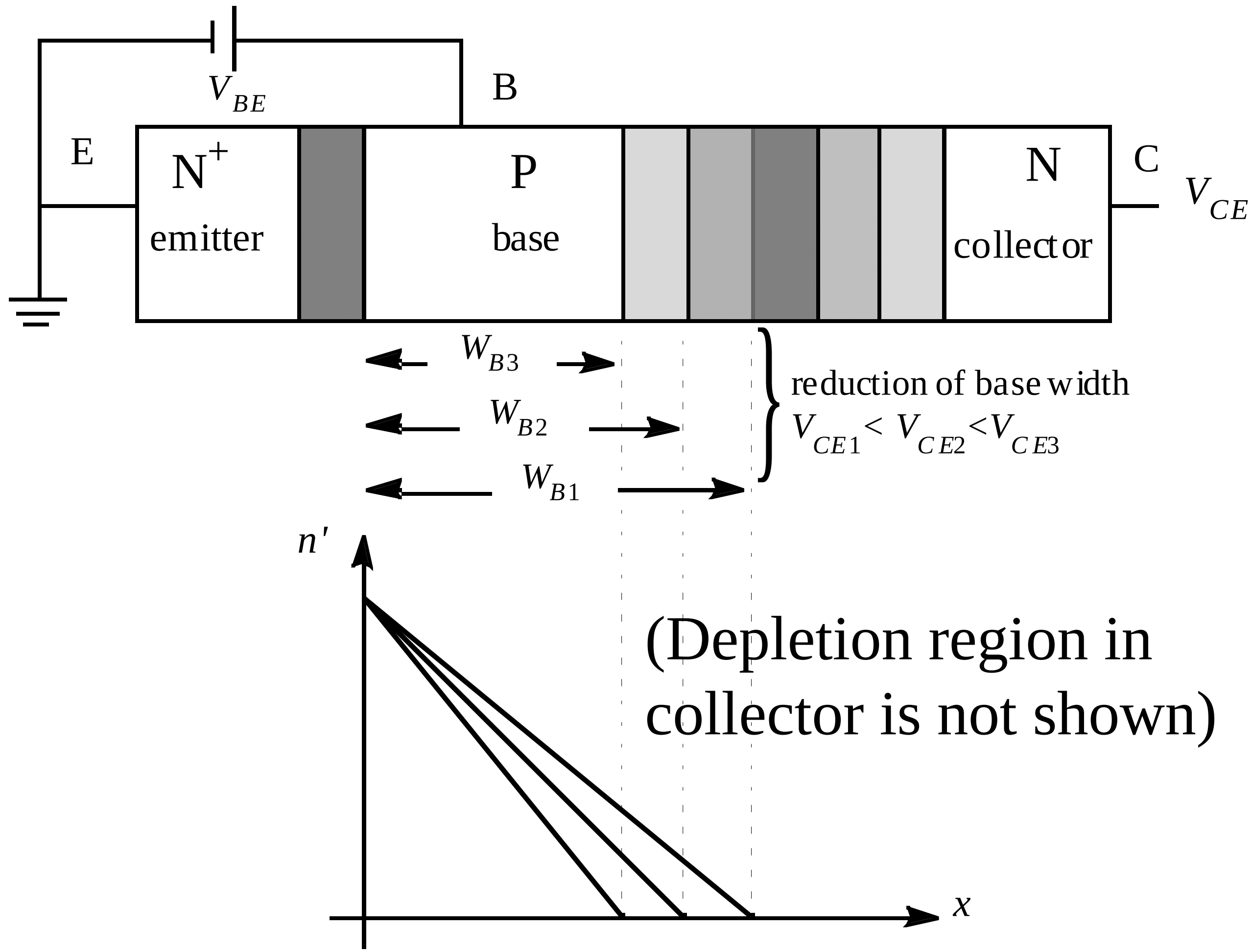
Punchthrough

Punch-through can be viewed as base width modulation carried to the extreme, i.e., punch-through occurs when $W \rightarrow 0$. For C-B voltage beyond punch-through, the E-B barrier lowers and results in large increase in carrier injection from emitter to collector.

Large increase in collector currents at high V_{CE0} occurs due to two reasons:

Punchthrough or
Avalanche multiplication

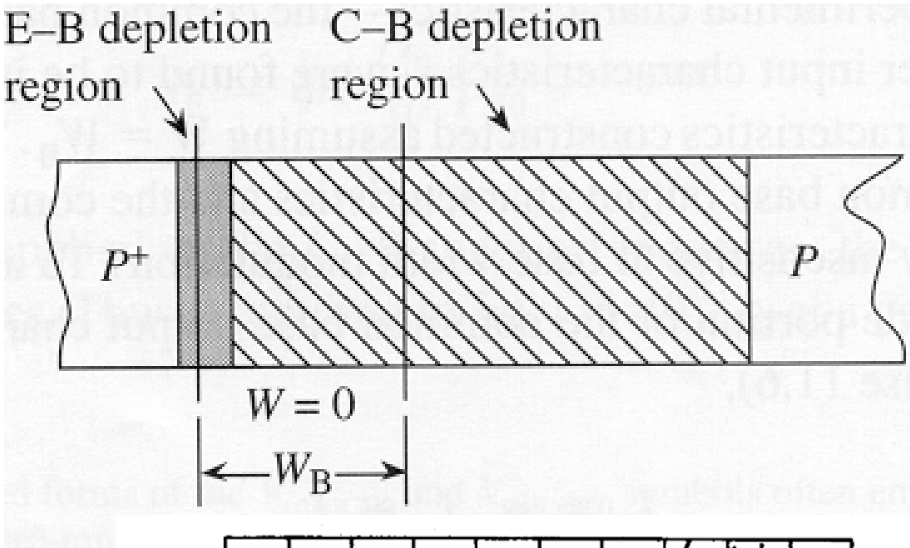
Base-Width Modulation by Collector Voltage

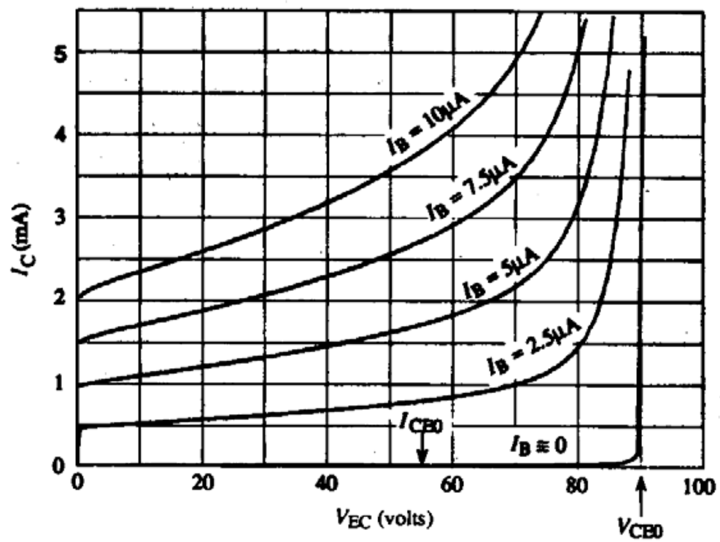


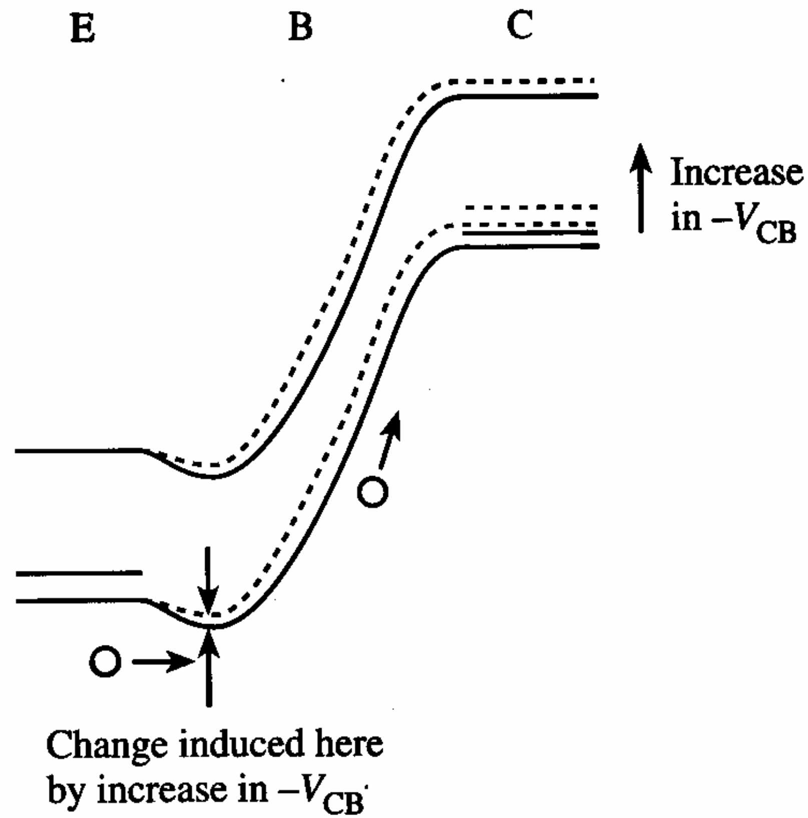
(Depletion region in collector is not shown)

How can we reduce the base-width modulation effect?

Punchthrough

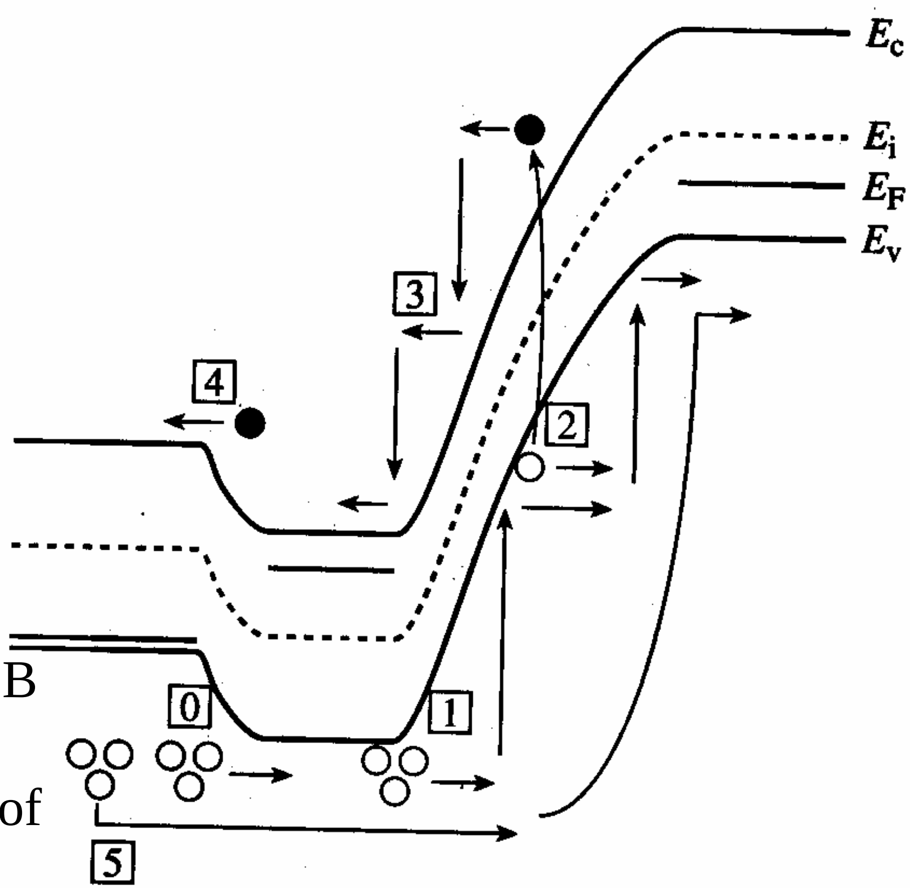






Avalanche Multiplication

- 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.

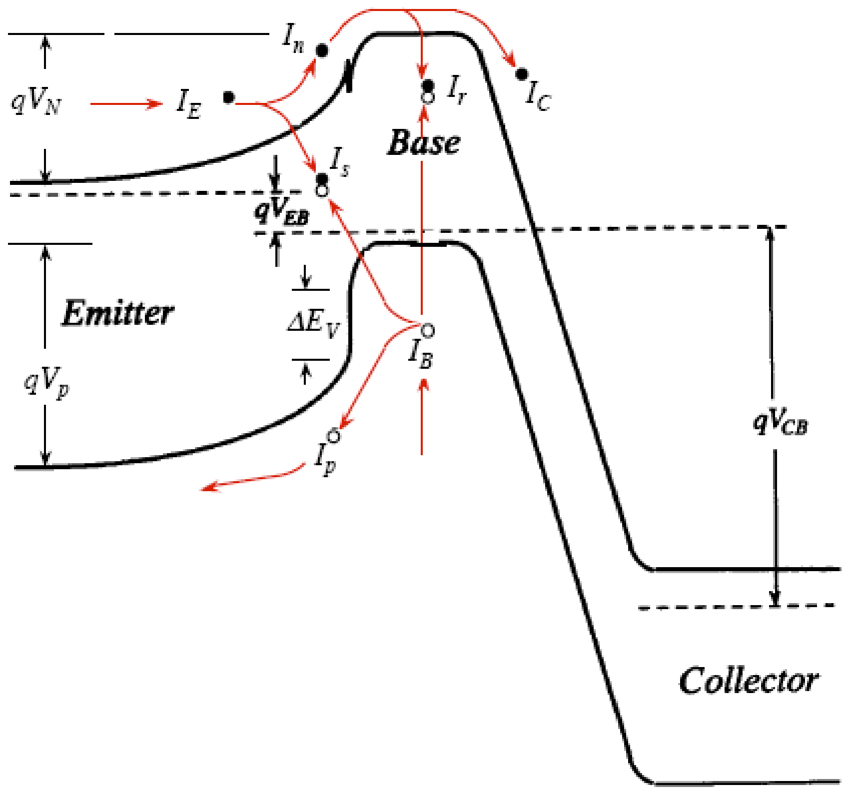
$$n_{iE}^2 = n_i^2 e^{\Delta E_{gE}/kT}$$

ΔE_{gE} is negligible for $N_E < 10^{18}$ cm^{-3}, is 50 meV at 10^{19}cm^{-3}, 95 meV at 10^{20}cm^{-3}, and 140 meV at 10^{21} cm^{-3}.

Heterojunction BJTs

The idea of using heterostructure at the emitter-base junction in a bipolar junction transistor is not new. It was pointed out and patented by Bill Shockley at the time of the invention of the bipolar transistor at Bell Labs that a large bandgap emitter can be used to increase the efficiency of the device.[1] Herb Kroemer proposed the first heterojunction bipolar transistor (HBT) structure in 1957.[2] As any other heterostructure devices, the HBT technology has been progressing rapidly only after the material growth technologies were matured. Recently, the InGaAs/InP HBT demonstrated the highest operation frequency of $f_T > 800\text{GHz}$ among all semiconductor devices. New functions, such as high-speed spontaneous and stimulated light emissions, were also been demonstrated in HBTs (Light-emitting transistors and HBT lasers).

Heterojunction BTJs



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

npn heterojunction BJT with wide band gap emitter

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 $Si_{1-\eta}Ge_{\eta}$ base.

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

EXAMPLE: Emitter Bandgap Narrowing

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

(a) At $N_E = 10^{19}$ cm^{-3}, $\Delta E_{gE} \approx 50$ *meV,*

(b) At $N_E = 10^{20} cm^{-3}$, $\Delta E_{gE} \approx 95$ *meV*

(c)