University of Michigan – Shanghai Jiao Tong University Joint Institute
Center of Optics and Optoelectronics

VE 320 – Summer 2012
Introduction to Semiconductor Device

Introduction to Bipolar Transistors

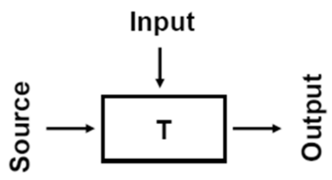
Instructor: Professor Hua Bao

Transistor

tran•sis•tor (trán-zìs′ter)
A solid-state electronic device that is used to control the flow of electricity in electronic equipment and consists of a small block of a semiconductor with at least three electrodes

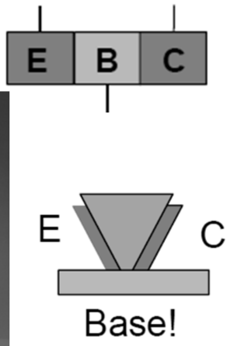
Trans(fer) + (res)istor

Idea: control large output with small input



This device should exhibit *gain*

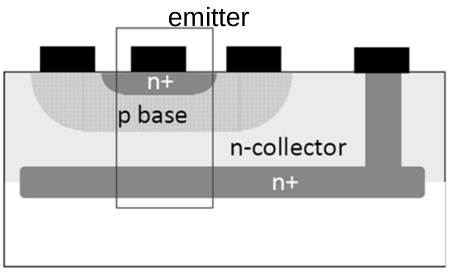
Background



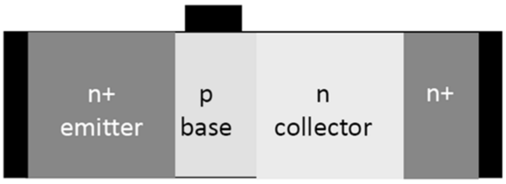
John Bardeen, William Shockley and Walter Brattain at Bell Labs, 1948.

Point contact Germanium transistor

Shockley's Bipolar Transistors



Double diffused BJT

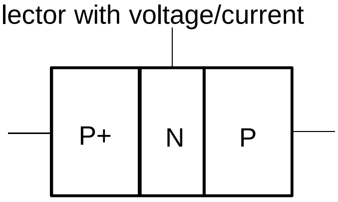


Terminals of BJT

pnp

Base
Controls carrier flow from emitter to collector with voltage/current

Emitter
Inject carriers

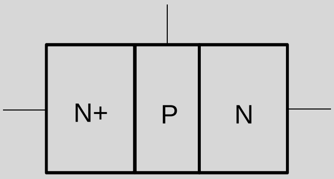


Collector
Collect carriers

npn

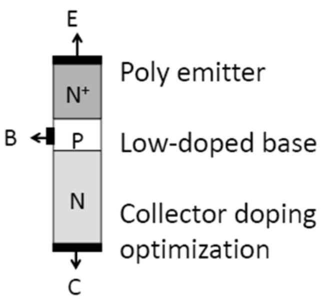
Base

Emitter

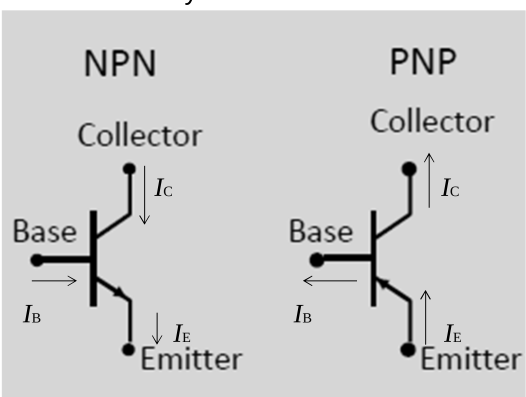


Collector

Symbols and Convention



Symbols

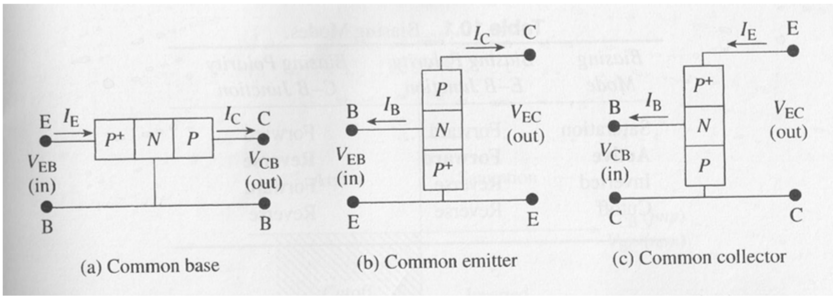


Depends on how you define…

$$I_E = I_B + I_C$$

$$V_{EB} + V_{BC} + V_{CE} = 0$$

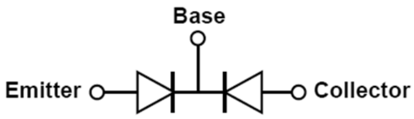
Circuit Configuration (pnp)



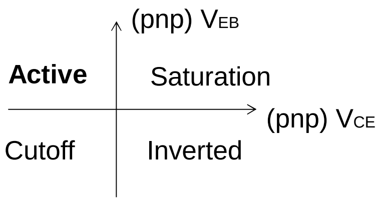
- Common emitter: most widely used
- Common collector: almost never used

Biasing Mode (pnp)

- Two face to face p-n junctions
- Base voltage/current control hole current



Four regions of operation corresponding to forward/reverse bias of base-emitter and base-collector p-n junctions



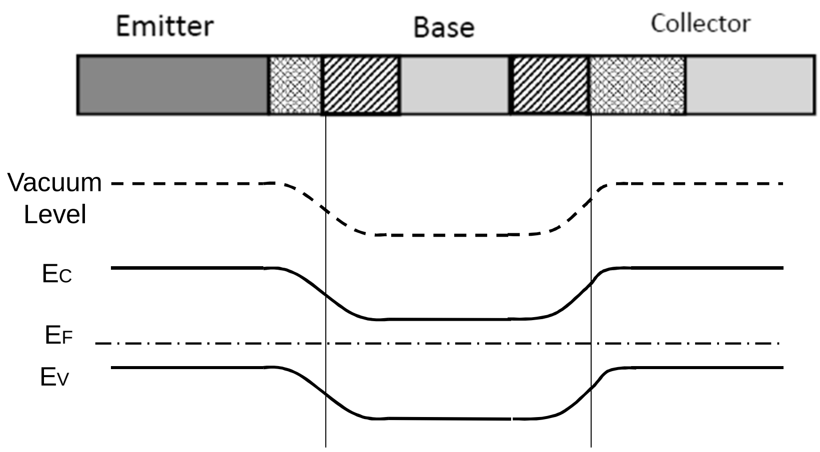
Active: most widely encountered. Large signal gain and small signal distortion

Electrostatics

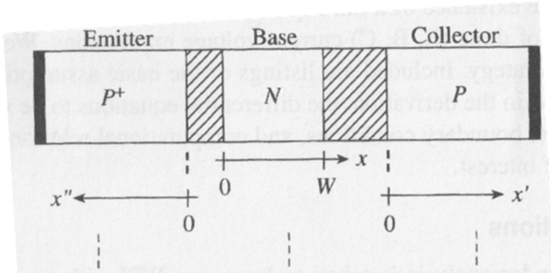
$$\nabla \bullet D = q\left(p - n + N_D^+ - N_A^-\right) \longrightarrow \text{Electrostatic}$$

$$\left.\begin{aligned}
&\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_N - r_N + g_N \\
&\mathbf{J}_N = qn\mu_N \mathcal{E} + qD_N \nabla n \\
&\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla \bullet \mathbf{J}_P - r_P + g_P \\
&\mathbf{J}_P = qp\mu_P \mathcal{E} - qD_P \nabla p
\end{aligned}\right\} \text{DC/AC/Transient}$$

Band Diagram at Equilibrium (pnp)



Coordinates and Convention

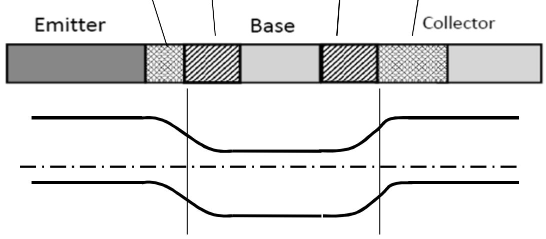


Emitter	Base	Collector
$N_E = N_{AE}$	$N_B = N_{DB}$	$N_C = N_{AC}$
$D_E = D_N$	$D_B = D_P$	$D_C = D_N$
$\tau_E = \tau_n$	$\tau_B = \tau_p$	$\tau_C = \tau_n$
$L_E = L_N$	$L_B = L_P$	$L_C = L_N$
$n_{E0} = n_{p0}$	$p_{B0} = p_{n0}$	$n_{C0} = n_{p0}$

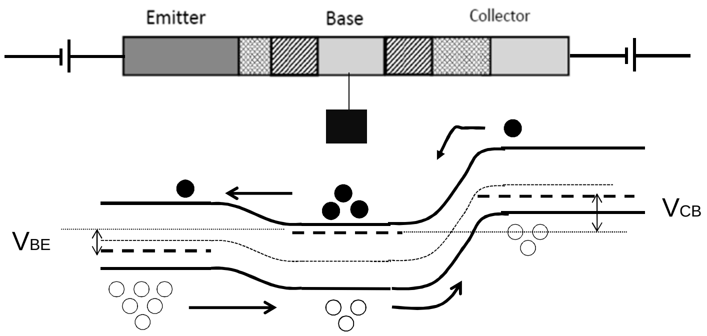
Electrostatics in Equilibrium

$$x_{n,BE} = \sqrt{\frac{2K_S\varepsilon_0}{q}\frac{N_E}{N_B(N_E+N_B)}V_{bi}} \qquad x_{n,BC} = \sqrt{\frac{2K_S\varepsilon_0}{q}\frac{N_C}{N_B(N_C+N_B)}V_{bi}}$$

$$x_{p,E} = \sqrt{\frac{2K_S\varepsilon_0}{q}\frac{N_B}{N_E(N_B+N_E)}V_{bi}} \qquad x_{p,C} = \sqrt{\frac{2K_S\varepsilon_0}{q}\frac{N_B}{N_C(N_C+N_B)}V_{bi}}$$



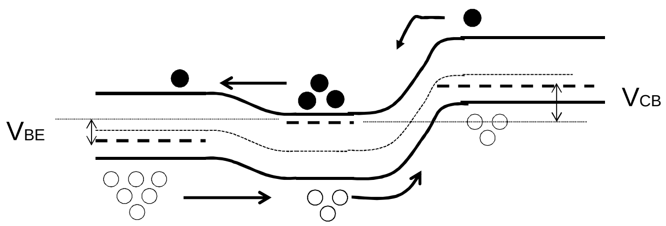
Band Diagram with Bias (Active)



Depletion width of EB diode is reduced, CB diode is widen.
Equations are similar to the previous slides except that

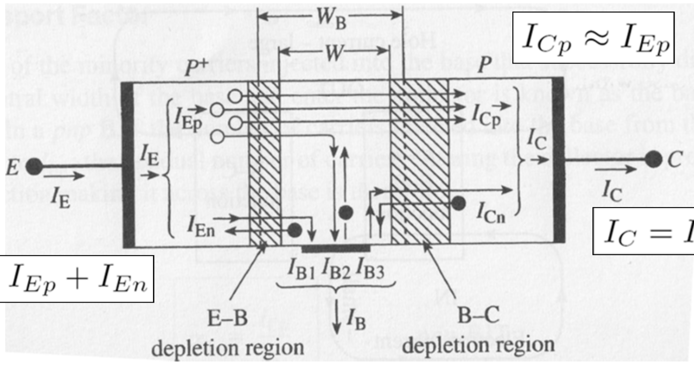
V_{bi} -> V_{bi} –V_{BE} at the E-B side V_{bi} -> V_{bi} –V_{BC} at C-B side

Narrow Base



- Base is narrow comparing to minority carrier diffusion length
- Holes injected to the base almost completely diffused to the collector
- This is a BJT, not two back-to-back pn junctions

More Details



$$I_{Cp} \approx I_{Ep}$$

$$I_C = I_{Cp} + I_{Cn}$$

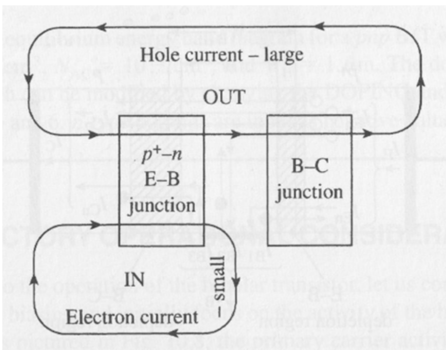
$$I_E = I_{Ep} + I_{En}$$

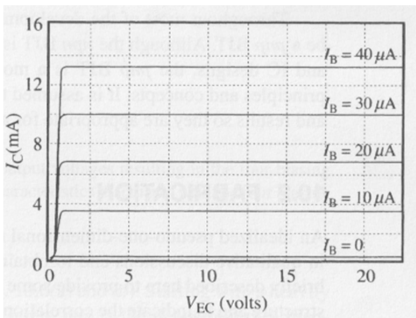
$$I_{En} \ll I_{Ep}$$
$$I_{Cn} \ll I_{Cp}$$

$$I_B = I_E - I_C$$

I_B is very small.

Amplify a Signal



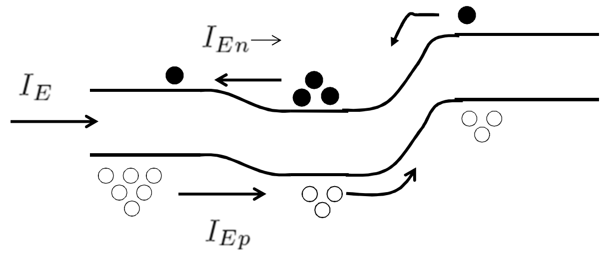


DC current gain is ***I_B/I_C***

Emitter Injection Efficiency

What fraction of the emitter current is due to the intended carrier injection?

$$\gamma = \frac{I_{Ep}}{I_E} = \frac{I_{Ep}}{I_{Ep} + I_{En}}$$

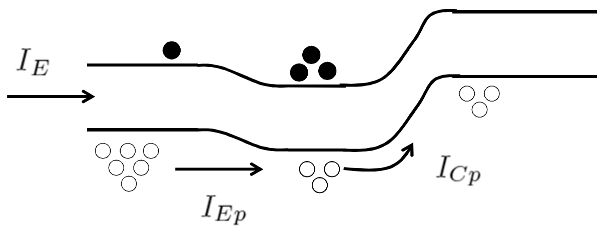


Determined by doping levels and diffusion process.

Base Transport Factor

What fraction of the injected electron shows up as collector current?

$$\alpha_T = \frac{I_{Cp}}{I_{Ep}}$$

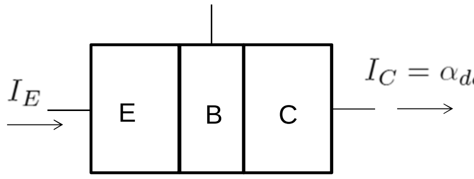


Determined by base width and carrier diffusion length in base

Common Base d.c. Current Gain

How much of the emitter current shows up at the collector?

$$\alpha_{dc} = \gamma \alpha_T = \frac{I_{Cp}}{I_E} \approx \frac{I_C}{I_E}$$



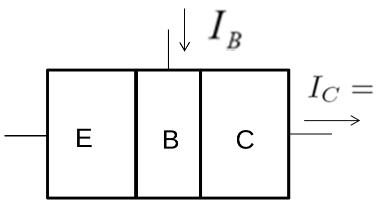
$$I_C = \alpha_{dc} I_E + I_{CB0}$$

Depends on emitter injection efficiency and base transport factor

Common Emitter d.c. Current Gain

What is the output current (collector) relative to the input (base) current?

$$\beta = \frac{I_C}{I_B} = \frac{\alpha_{dc}}{1 - \alpha_{dc}}$$



$$I_C = \beta_{dc} I_B$$

Depends on emitter injection efficiency and base transport factor.