IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

MICROELECTRONICS: DEVICES TO CIRCUITS

BIPOLAR JUNCTION TRANSISTOR: PHYSICAL STRUCTURE AND MODES OF OPERATION

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Outline

- Physical Structure: Bipolar
- Types of Bipolar Transistor
- Mode of Operation
- Profile of minority carrier concentration
- Collector current
- Base current
- Emitter current
- Large signal equivalent –circuit model of npn BJT
- Recapitulation

Physical Structure

- The bipolar junction transistor (BJT) has three separately doped regions and contains two PN junctions.
- BJT is a three terminal device.
- The Three regions and their terminal connections are called the emitter, base, and collector.

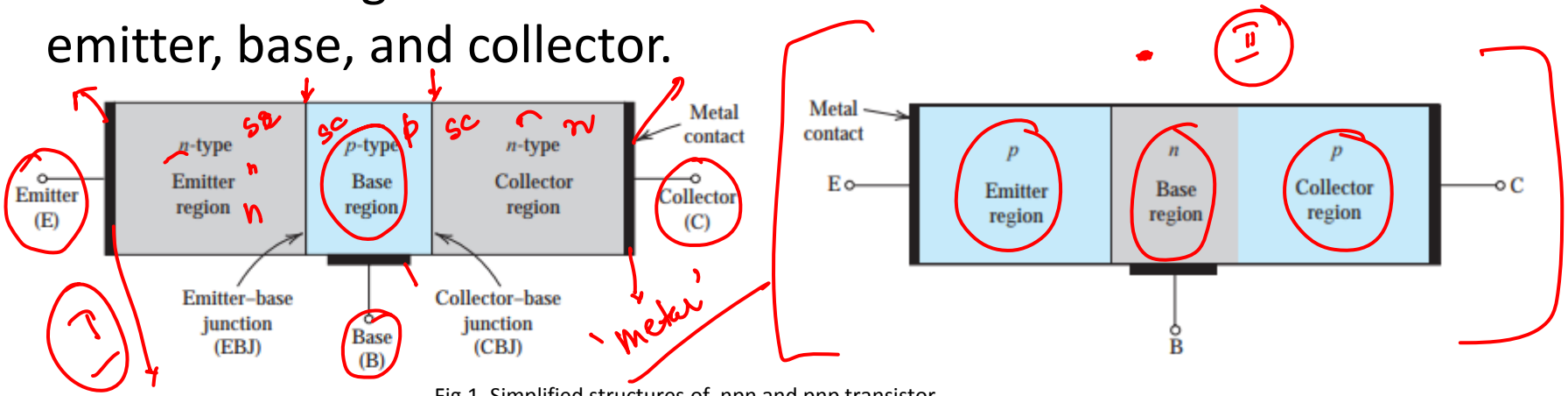


Fig.1. Simplified structures of npn and pnp transistor

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Physical Structure

- BJT consist of two pn junctions
  - Emitter-base junction (EBJ)
  - Collector-base junction (CBJ)
- The width of the base must be very narrow, normally in the range of tenths of a micrometer.

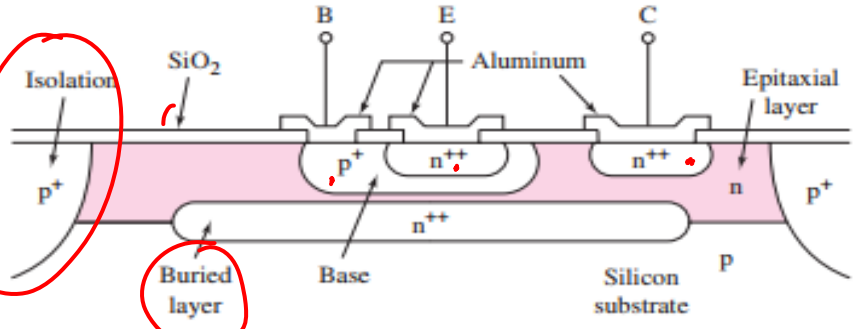


Fig.2.Cross section of a conventional integrated circuit npn bipolar transistor

Source: Microelectronics Circuit Analysis and Design Donald A. Neamen, Fourth edition

Physical Structure

- BJT is not symmetrical electrically, because of geometries of the emitter and collector regions are not the same.
- The impurities doping concentrations in three regions are different.
- Emitter- $10^{19}/cm^3$
- Base- $10^{17}/cm^3$
- Collector- $10^{15}/cm^3$

Source: Microelectronics Circuit Analysis and Design Donald A. Neamen, Fourth edition

Types of Transistor

- PNP Transistor
- NPN Transistor

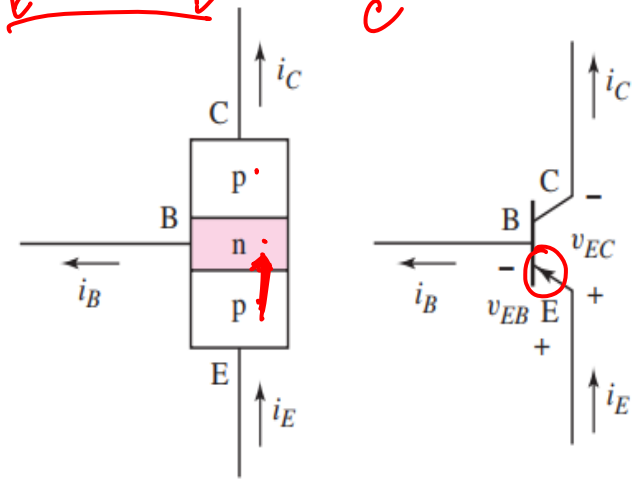
i_B Base current

i_E Emitter current

i_C Collector current

v_{BE} Base to emitter voltage

v_{CE} Collector to emitter voltage



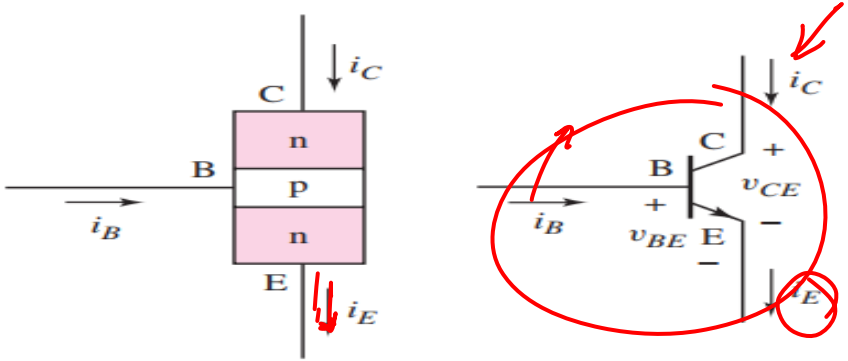


Fig.3. pnp and npn transistor block diagram and symbol

Source: Microelectronics Circuit Analysis and Design Donald A. Neamen, Fourth edition

PNP Transistor

- Current in pnp transistor is mainly conducted by holes.

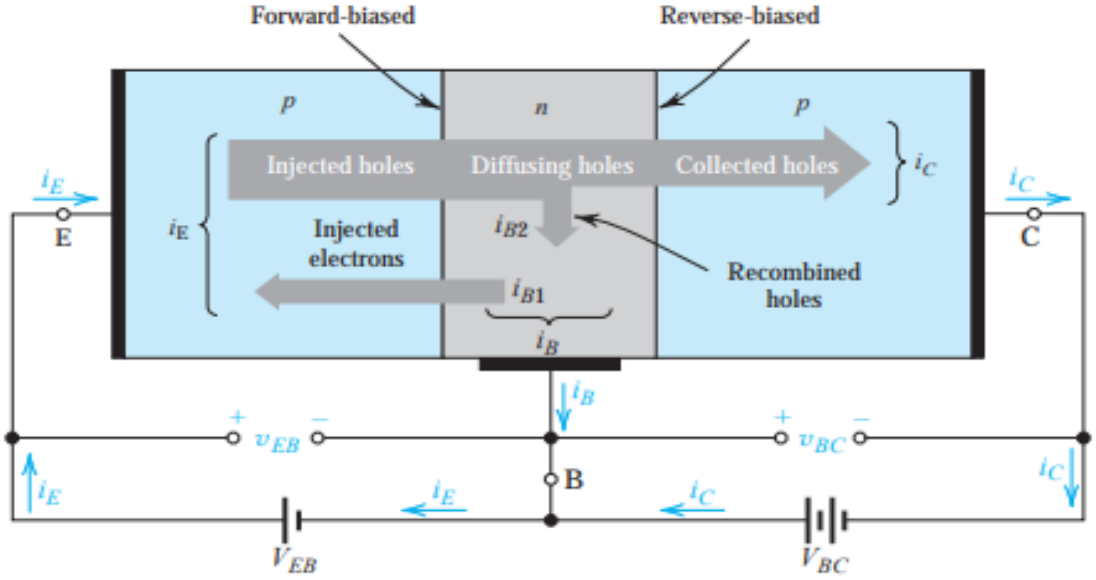


Fig.4.Current flow in pnp transistor biased to operate in active mode

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

NPN Transistor

- Current in npn transistor is mainly conducted by electrons.

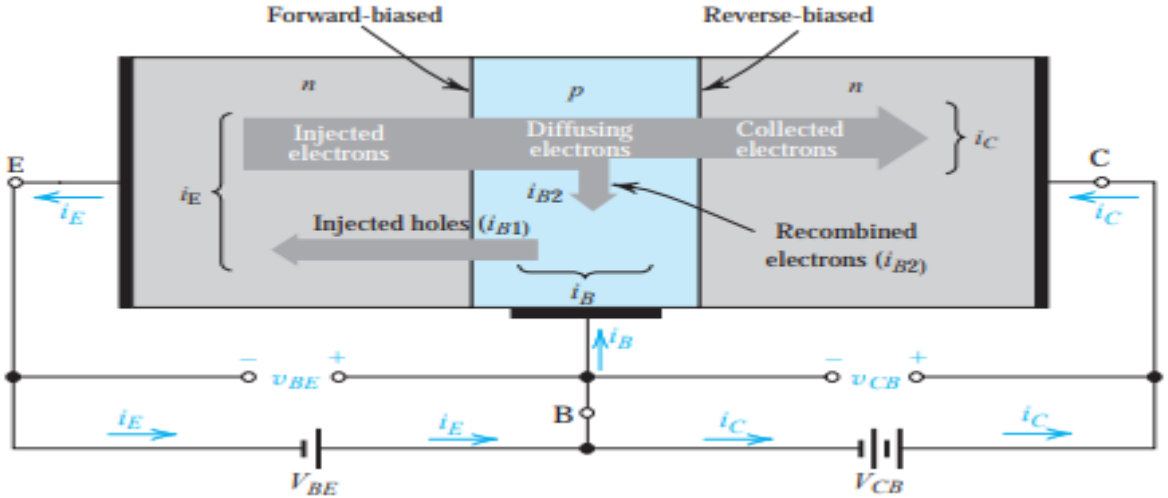


Fig.4.Current flow in npn transistor biased to operate in active mode

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Modes of Operation

- Depending on bias condition (forward or reverse) of pn junctions, different modes of operation of BJT.
- Active mode(forward active mode)
- Saturation mode
- Cutoff mode
- Reverse active mode
- Transistor operate as an amplifier in active mode.
- Transistor operate as a switch in both cutoff and saturation mode.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Modes of Operation

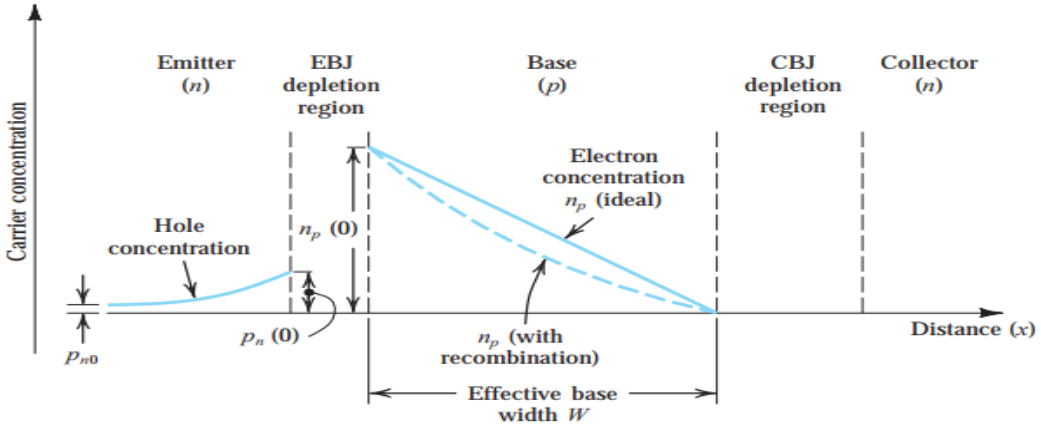
Table: 1

Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Reverse Active	Reverse	Forward
Saturation	Forward	Forward

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Profile of minority carrier concentration

- Electron will be minority carriers in the p-type base region.
- The base is usually very thin, in steady state the excess minority carrier(electron) concentration in the base will have an almost straight line profile.



$n_p(0)$ Electron concentration at emitter side

$n_p 0$ Electron concentration in base region at thermal equilibrium

$V_{BE} > 0$ Active mode operation

$V_{CB} \geq 0$

Fig.5.Profile of minority- carrier concentration in the base and in the emitter of an npn transistor

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

- The concentration $n_p(0)$ will be proportional to $e^{\frac{v_{BE}}{v_T}}$.

$$n_p(0) = n_{p0} e^{\frac{v_{BE}}{v_T}}$$

- The electron diffusion current I_n is directly proportional to the slope of the straight line concentration profile.

$$I_n = A_E q D_n \frac{d_{n_p(X)}}{dx}$$

$$I_n = A_E q D_n \left(-\frac{n_p(0)}{W} \right)$$

A_E Cross-sectional area of the base-emitter junction

q Electron charge

D_n Electron diffusivity in the base

W Effective width of the base

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Collector current

$$I_C = I_n$$

$$I_C = I_S e^{\frac{v_{BE}}{V_T}}$$

$$I_S = A_E D_n q \frac{n_{p0}}{W}$$

$$n_{p0} = \frac{n_i^2}{N_A}$$

$$I_s = \frac{A_E q D_n n_i^2}{N_A W}$$

I_s Saturation current

I_C Collector Current

n_i Intrinsic carrier density

N_A Doping Concentration

I_s is doubling for every 5°C rise in temperature

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Base current

$$I_B = \frac{I_C}{\beta}$$

β Common-emitter current gain

$$I_B = \frac{I_S}{\beta} e^{\frac{v_{BE}}{v_T}}$$

- For modern npn transistor β is in the range 50 to200.
- β is highly influenced by, width of base region W and relative doping of base region and emitter region $\frac{N_A}{N_D}$.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Emitter current

$$I_E = I_c + I_B$$

$$I_E = \frac{\beta + 1}{\beta} I_C$$

$$I_E = \frac{\beta + 1}{\beta} I_S e^{\frac{v_{BE}}{v_T}}$$

$$I_C = \alpha I_E$$

$$\alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1 - \alpha}$$

$$I_E = \frac{I_S}{\alpha} e^{\frac{v_{BE}}{v_T}}$$

α Common base current gain

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Large signal equivalent –circuit model of npn BJT

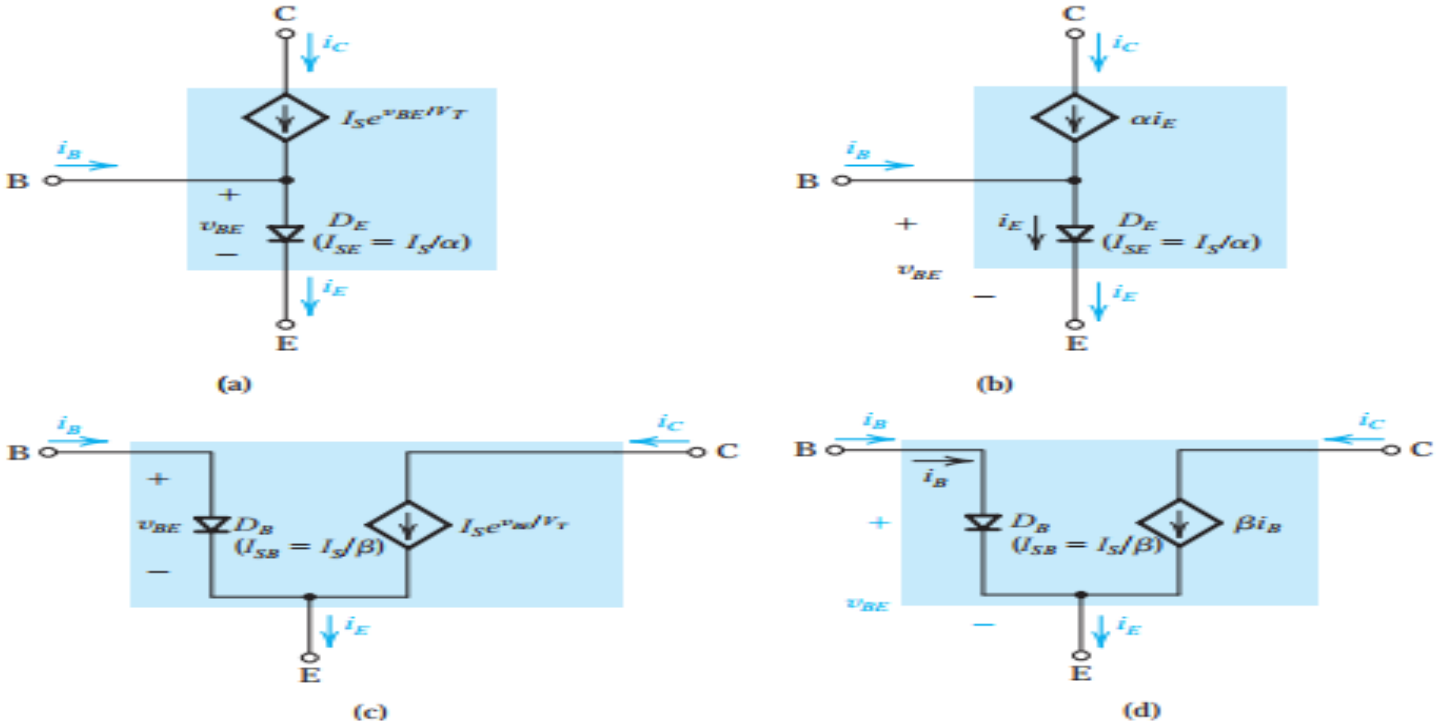


Fig.6. Large signal equivalent –circuit model for npn transistor in active mode

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Recapitulation

- Presented first order model of npn transistor operated in active mode.
- The forward bias voltage v_{BE} causes an exponential related current I_C to flow in the collector terminal.
- The collector current I_C is independent of the value of the collector voltage as long as collector- base region junction remains reverse biased.
- In the active mode the collector terminal behaves as an ideal constant-current source.
- The base current I_B is a factor 1/β of the collector current.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Thank You