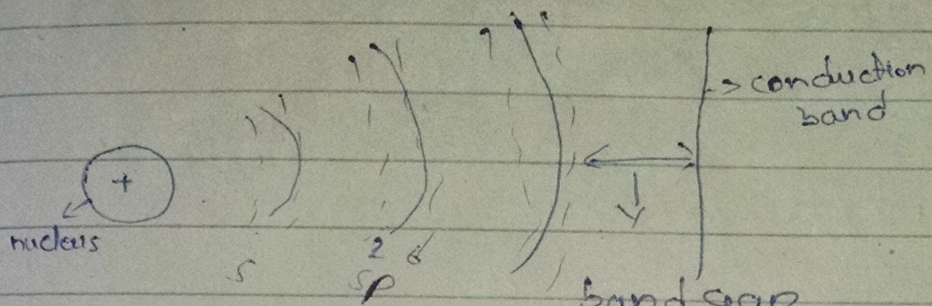
29-01-2016

BSCS-409

"Material, ~~and~~ semi conductors and devices."

A device that can perform arithmetic.



K, L, M, N $\Rightarrow 2n^2$

$1.79\ k\Omega$

1.79×10^3

Conductors $\Rightarrow$ Weak bonding of electron with their

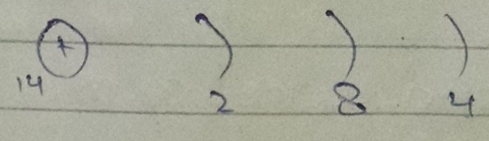
Semi conductors $\Rightarrow$

Insulator $\Rightarrow$ strong bonding of electron

$18 \times 10^2 + 5$

Core charge:

18×10^2



1.79×10^3

~~k~~ 1780

18×10^2] = ~~17.9×10^2~~ ~~18×10^2~~

Core charge = 14 − 2 − 8 = +4

Course Outline

Materials:

- Crystalline and non-crystalline solids
- Energy band in solids
- Types of Material
- Metals
- Semi conductors
- Imperfections in solids

Semi Conductors:

- Extrinsic and Intrinsic Semi conductors
- Conductivities of semiconductors.
- Important Semi conductors
- Effect of temperature on Semi conductors
- Semiconductor growth
- Cutting, diffusion and liquid crystals

Devices:

- PN Junction
- Semi conductor diode and Zener diode
- Bipolar transistors
- Junction field Effect transistors (JFET)
- Metal oxide semi conductor FET (MOSFET)
- Solar cells
- Display Devices

- Integrated Circuits (IC's)

Book:

i) INtroduction to material science
James F. Shakelfort

ii) Electronic Material Science
James W. Mayer

iii) Electronic Device 9th Edition
Floyd

Insulator:

An insulator is a material that doesnot conduct electrical current under normal conditions. Most good insulators are compounds rather than single element materials. Valence electrons are tightly bond to the atoms, therefore there are very few free electrons in an insulator. Example rubber, Plastic, glass.

Conductors:

A conductor is a material that easily conducts electrical current. Most metals are good conductors. The best conductors are single-element materials, such as copper (Cu), Silver (Ag), gold (Au) and Aluminium (Al) which are characterized by atoms with only one valence electron. Very loosely bond to the atom. These very loosely bound valence electrons. In conductive material free electrons are valence electrons.

Types of Materials:

(i) Crystalline
(ii) Emorphous
(iii) Poly Crystalline

Semi-Conductors:

A semi conductor in its pure (intrinsic) state is neither a good conductor nor a good insulator. Single element semi conductors are Antimony (Sb), Arsenic (As) Astatine (At), Boron (B), Polonium (Po), Tellurium (Te), Silicon (Si) and Germanium (Ge). Compound semi conductor such as gallium arsenide, silicon carbide and silicon germanium are also commonly used.
The single element semi-conductors are characterized by atom with four valence electrons. Silicon is most commonly used semi conductor.

• Crystalline Solids:

A crystalline solid has its molecules (or atoms) arranged in a lattice i.e. they are arranged in a regular fashion with equal spacing and angular relationship in all three dimensions.

Non-Crystalline Solids:

Also called amorphous, has no such arrangement of molecules.

- ionic compound are usually crystalline.
- Not all crystalline compounds are ionic.

Solid Materials are ~~tt~~ usually distinguished as:

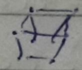
- Amorphous
- Poly crystalline
- Single crystalline solids.

12-02-2016

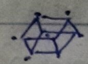
- Each type is characterized by the size of an ordered region within the material
- An ordered region is a spatial volume in which atoms (or molecules) have a geometric arrangement
- Amorphous materials have order only within a few atomic or molecular dimensions.
- Poly crystalline material relatively have high degree of order.
- The ordered region vary is size of orientation
- Each ordered region is called a grain and are separated from one another by grain boundaries.
- Single crystal material have regular geometric periodicity throughout the material.
- Electrical properties of single-crystal material are superior to others.

- A primitive cell is the smallest unit cell that can be repeated to form the Lattice.
- For simple type of crystal structure we choose unit cells (fundamental unit) having orthogonal (90°) and equal distance structure.

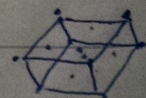
Some simple type of single-crystal Lattice structures are:

i) Simple cubic (SC): (8-atoms) 

Structure having an atom located at each corners of a cube.

ii) Body centered Cubic (bcc): (9-atoms) 

BCC structure has an atom at each corner and an additional atom at the center.

iii) Face centered Cubic (fcc): (14-atoms). 

fcc structure has an atom at each corner and additional atom at the center of each face plane.

Band Gap:

The difference in energy between the valence band and the conduction band is called an energy gap or band gap.
This is the amount of energy that a valence electron must have in order to jump from valence to conduction band.
Once in conduction band electron is free to move throughout the material and is not tied to any given atom.

Core:

Core of an atom consist of every thing except its valence shell (valence electrons).

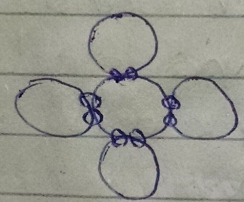
Silicon Vs Germanium:

The valence electrons in germanium are in the fourth shell while those in silicon are in the third shell (closer to the nucleus) i.e. Germanium valence electrons are at high energy level, than those in silicon, this require smaller amount of additional energy to escape from atom. This property make germanium more unstable at high temperature. This is why silicon is more commonly used in semiconductor devices.

Intrinsic Silicon Bonding:

In its purest form silicon atoms form covalent bond with four of its neighbouring atoms.

- Each silicon atom has eight shared valence electrons.



(pure silicon).

pentavalent impurity:

Conduction in Semiconductor:

At room temperature pure silicon has sufficient energy for some valence electrons to jump the gap from the valence to conduction producing a free electron (conduction electron) and a hole (vacancy left in valence band within the semi-conductor crystal), called electron-hole pair.
In a piece of semiconductor there are equal number of free electrons and holes.

Recombination:

When a conduction band electron loses energy and falls back into a hole in the valence band the process is called recombination.

Electron current:

When voltage is applied across a piece of material. The free electrons in conduction band are attracted toward positive end. This movement of electron is called electron current.

Hole current:

Valence electrons attached to their atoms in crystal structure can move into a nearby hole, leaving another hole. This movement of hole from one place to another create another current in semi-conductor material called hole current.

Doping:

The controlled addition of impurities to the intrinsic (pure) semi conductor material is called doping.

Doping increase the number of current carries (electrons or holes).

1- trivalent impurity → increase no. of wholes

11- Pentavalent impurity → increase no. of electrons.

19-02-2016

N-Type Semiconductor:

Piece of semiconductor having more free electrons (conduction band electrons) than wholes is called N-type semi conductor material.

Pentavalent (Arsenic (As), Phosphorus (P), Bismath (Bi) or Antimony (Sb) atoms with five valence electrons) impurities are added to increase number of free electrons.

P-type Semiconductor:

Piece of semi conductor having more number of holes in the crystal structure than free electrons is called P-type semiconductor.

P-type semiconductors are produced by doping intrinsic material with tri-valent impurities (atoms with 3 valence electrons Boron (B), Indium (In), Gallium (Ga).

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Valence electrons attached to their atoms in crystal structure can move into a nearby hole, leaving another hole. This movement of hole from one place to another create another current in semi-conductor material called hole current.

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19-02-2016

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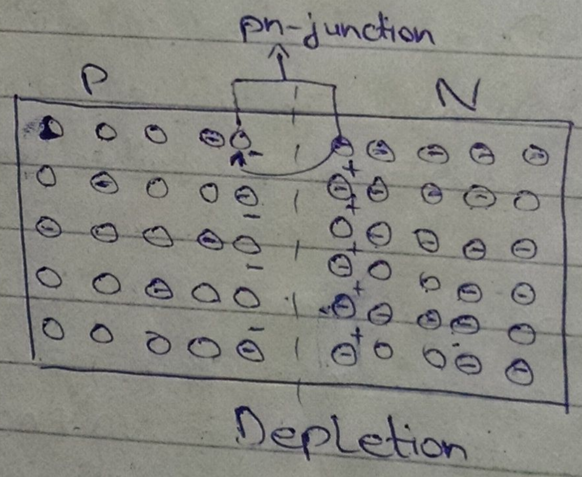
Majority and Minority Carrier:

- In N-type semi conductor free electrons are majority carrier of current, while holes are minority carriers (holes produced by thermally generated free electrons

- In P-type semiconductor holes are the majority carrier of current while conduction band (free) electrons are the minority carriers.



Si = 0.7 V

Ge = 0.3 V

The PN-Junction:

- Even after doping number of free electrons or holes can be increased, number of electrons and protons in material remain same resulting in material to be neutral.

- A pn-junction is formed when a part of material is doped n-type and part of it is doped p-type.

- A depletion region forms starting at the pn-junction when majority electrons of n region start diffusing across the junction and combines with holes in p-region, thus creating positive ions in n-region near junction and negative ions in p-region.

- These two layers of -ve and +ve charges from the depletion ~~layer~~ region (depleted of charge carriers).

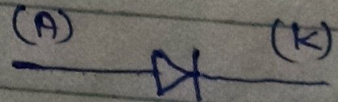
- A point is reached when total -ve charge in depletion region repels any further diffusion of electrons and creating an electric field.

- External energy must be applied to get the electrons to move across the barriers of the electric field into depletion layer.

Diode:

A diode is a piece of semi conductor material, half doped as a p-region (by addition of trivalent impurities) and half doped as a n-region (by addition of pentavalent impurities) with a pn-junction and depletion region in between.

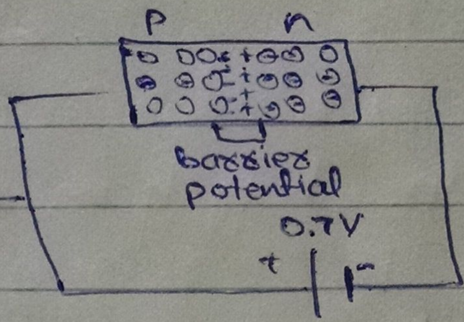
The P-region is called Anode (A)
The N-region is called Cathode (K)

Schematic symbol 

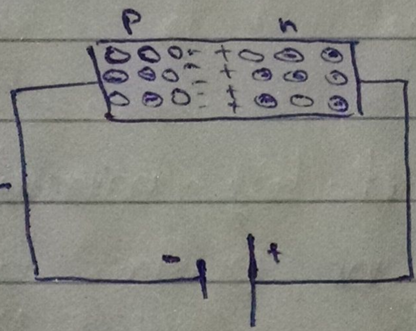
~~Ad~~

We can provide external energy to diode in two ways.

forward biase ⟵



Reverse biase ⟵



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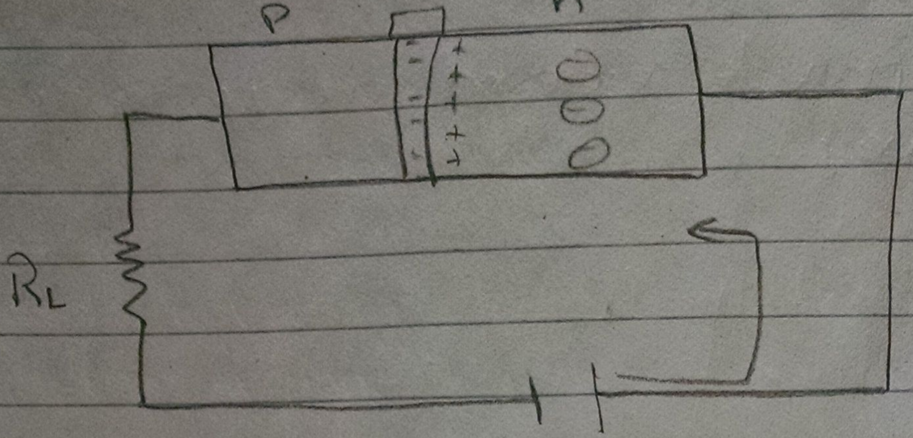
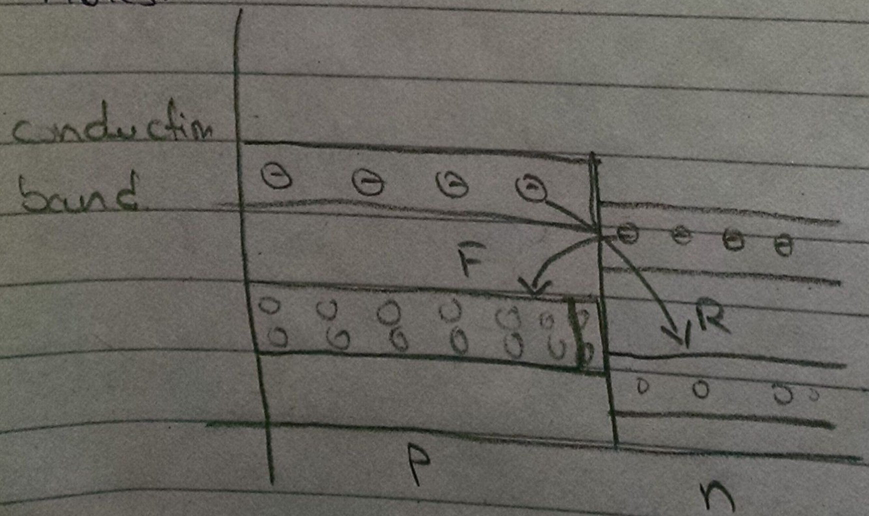


Reverse Current:

Current caused by minority carriers of P region electrons pushes by -ve terminal cross the junction, and fall down the energy hill to combine with the minority holes.



Valence and conduction band in N-type material are valence bond at slightly lower energy level than p-type material due to difference in atomic characteristics of impurities.

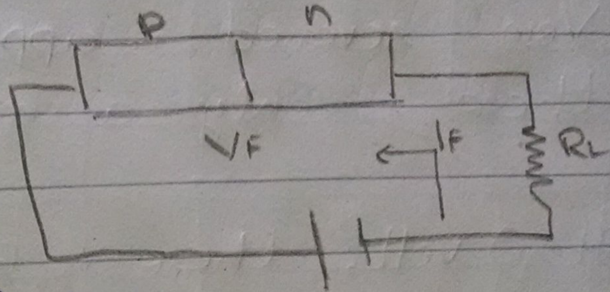
Reverse Break down:

- Reverse break down is due to avalanche multiplication.
- If the external reverse-bias voltage is increased to a value called breakdown voltage, then reverse current will drastically increase.
- The high reverse bias voltage imparts energy to the free minority electrons so that as they speed through P region, they collide with atoms with enough energy to to knock valence electrons out of orbit and into conduction band.

- The newly created free electrons are also high in energy and repeat the process and the number of free electrons multiply.
- The high energy electrons go through the depletion region, they have enough energy to go through the n-region as conduction electrons, rather than combining with few minority holes.
- Avalanche multiplication can damage the diode.

VI Characteristics:

Forward Bias:

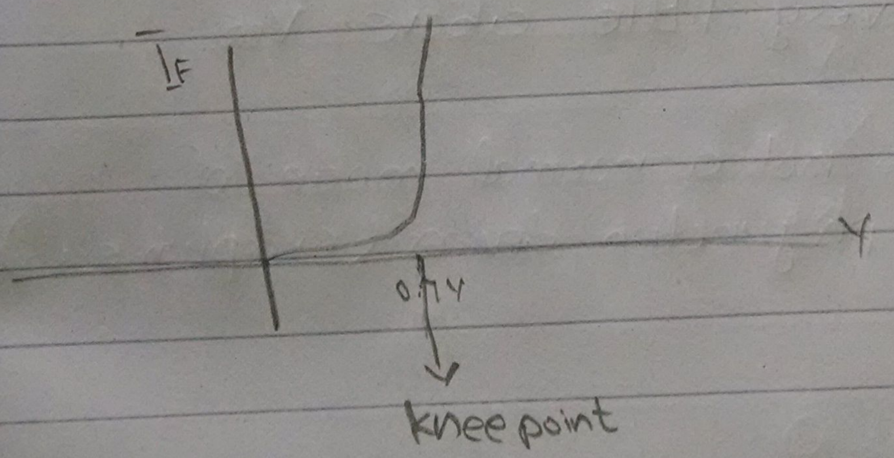


when $V_{BIAS} = 0V$ across diode $\bar{I}_F = 0$.

As V_{BIAS} increased I_F & V_{DIODE} increases.

When V_{BIAS} is such that V_{DIODE} reaches 0.7V I_F increases rapidly.

With V_{BIAS} increasing I_F increased rapidly but V_{DIODE} increase gradually because of voltage drop across internal dynamic resistance of the semi conductor (r'_d) decreases as we move up the curve.



Reverse Bias:

- V_{BIAS} reversed is applied across a diode. there is only a small reverse current (I_R)

- At 0 volt, there is no reverse current.

- As V_{BIAS} reverse increases very small I_R flow and V_R increases.

- when V_{BIAS} reaches the V_{BR} (break down value), I_R begins to increase drastically.

- As we continues to increase V_{BIAS}, I_R continues to increase but the voltage across diode V_R increases very little above V_{BR}.

- Breakdown is not a normal mode of operation for pn-junction devices (exception exists).

Temperature Effect:

The barrier potential decreases by 2mV for each degree increase in temperature.

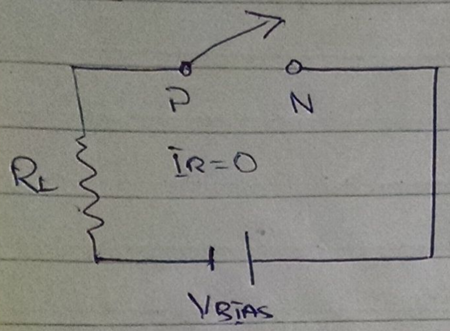
$$2mV = 0.002\,V$$

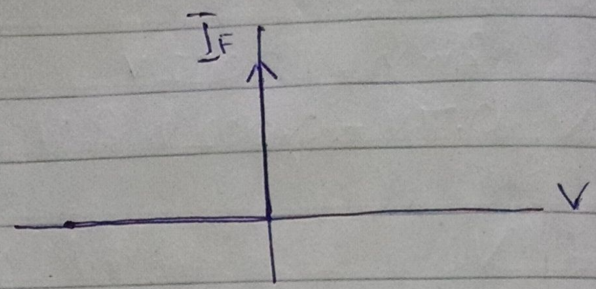
$$0.7V - 0.002\,V.$$

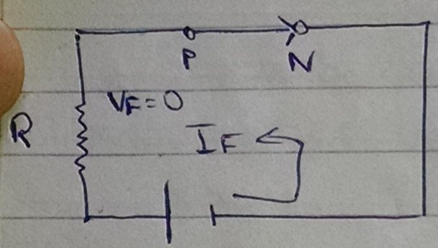
04-03-2016

Diode Models:

1- IDEAL MODELS:







Least accurate approximation

Forward Bias:

$$V_F = 0V$$

$$I_V = \frac{V_{BIAS}}{R_L}$$

Reverse Bias:

$$I_R = 0$$

$$V_{DIODE} = V_{BIAS}$$

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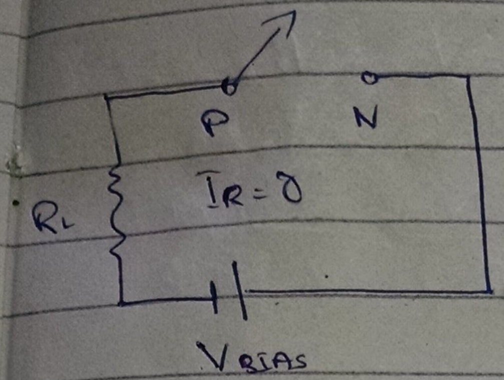
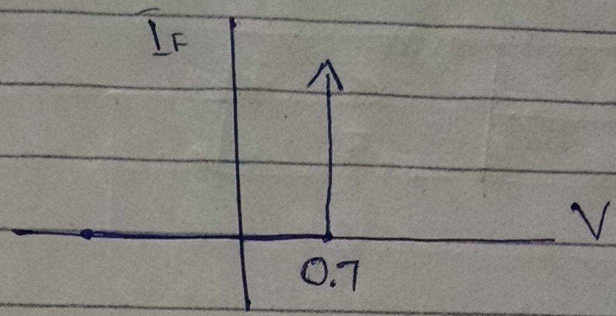
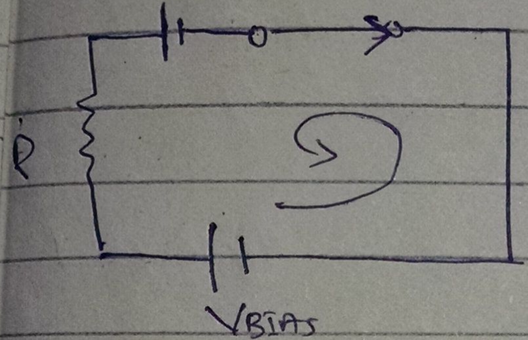
2. PRACTICAL MODEL:







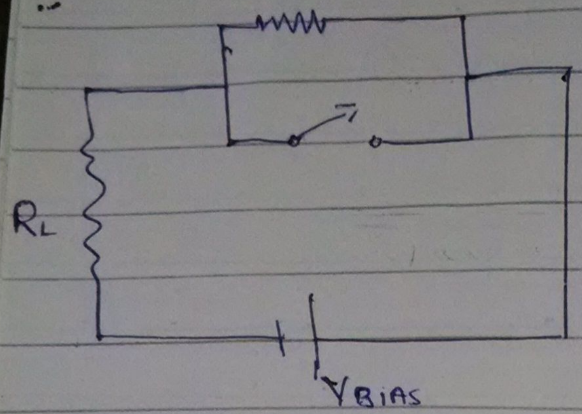
Forward Bias:

$$V_{BIAS} = V_{R_L} + V_F$$

$$V_{R_L} = I_F R_L$$

$$I_F = \frac{V_{BIAS} - V_F}{R_L}$$

3- COMPLETE MODEL:

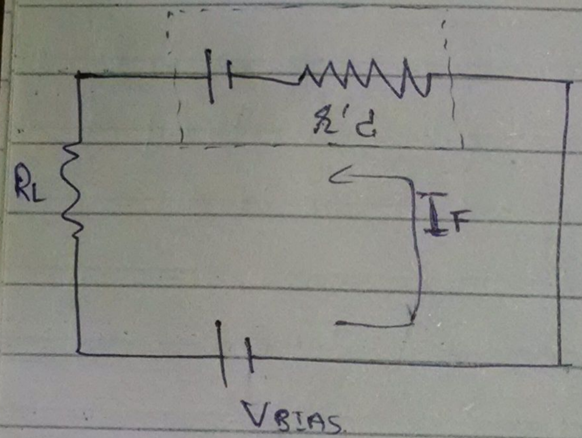


$$V_{BIAS} = V_{RL} + V_{r'R}$$

$$V_{BIAS} = I_R R_L + I_R r'_R$$

$$I_R = \frac{V_{BIAS}}{R_L + r'_R}$$

r'_R = large internal reverse resistance



$r'd$ = small internal dynamic resistance

$$V_F = 0.7V + I_F r'd$$

$$I_F = \frac{V_{BIAS} - 0.7}{R_L + r'd}$$

Normal diodes are called Rectifies.

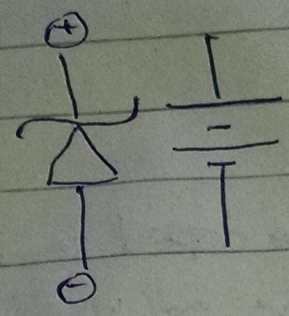
ZENER DIODE:

- Zener diodes maintains a nearly constant dc voltage under proper operating conditions.
- Zener diode is a silicon pn junction device that differs from rectifier diode as it is designed for operation in the reverse break down region.
- The break down voltage of a zener diode is set by carefully controlling the doping level during manufacturing.
- In reverse break down region, diode voltage remain almost constant and the current changes drastically.
- If a zener diode is forward biased, it operates the same as rectifier diode.
- Two types of reverse break down are ~~avaib~~ available in zener diode: Avalanche break down and Zener Break down.
- Avalanche break down occurs at a very high reverse voltage.

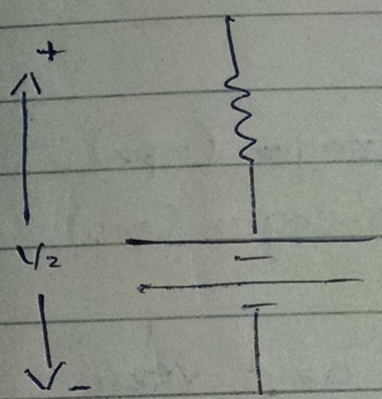
- Zener break down occurs in a zener diode at low reverse voltage.
- A zener diode is heavily doped to reduce the break down voltage.
- High doping causes a very thin depletion region with intense electric field with in depletion region.
- Zener diodes with break down voltages of less than 5V operates predominately in zener break down.
- Avalanche break down occurs in lightly doped p-n junction where depletion region is comparatively long.
- In Zener Break down the electrostatic force of attraction between the negative electrons and a large positive voltage is so great that it pulls electrons out of their covalent bonds and away from their parent atoms i.e. electrons are transferred from valence to conduction band.

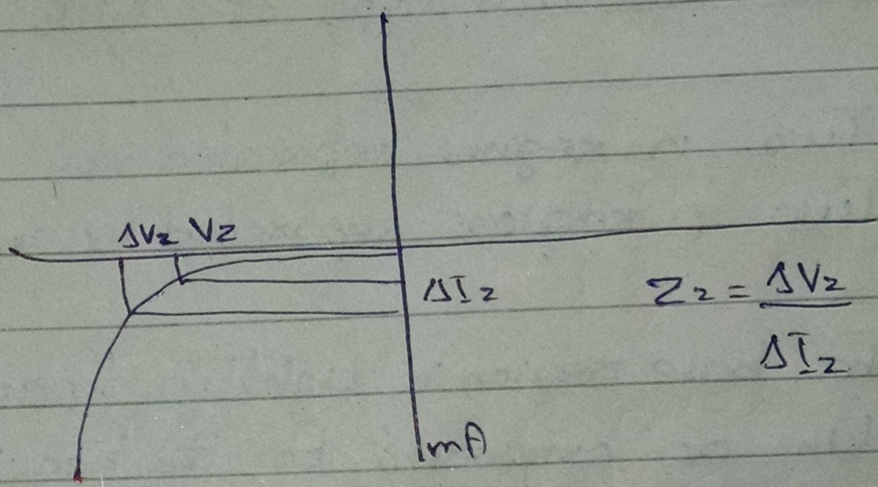
Scanned by CamScanner

Ideal Model:



Practical Model:





$$Z_z = \frac{\Delta V_z}{\Delta I_z}$$

TRANSISTORS:

Bipolar Junction transistors:

- The BJT is constructed with three doped semi-conductor regions separated by two pn junction.
- The three regions are called Emitter, Base and collector.
- There are two types of BJTs.

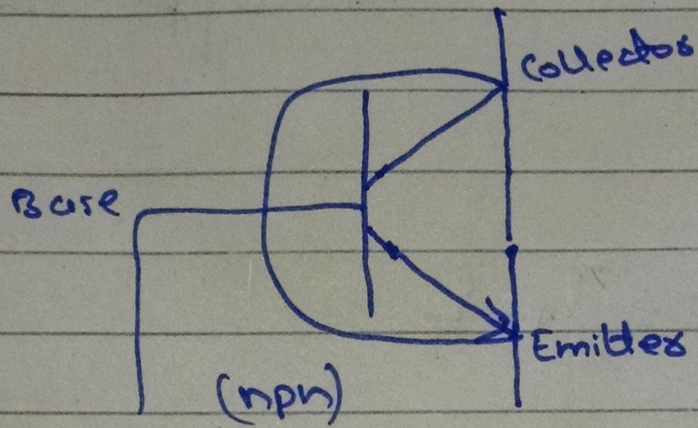
i- Two n regions separated by p region (npn)
ii- Two p regions separated by an n-region (pnp)

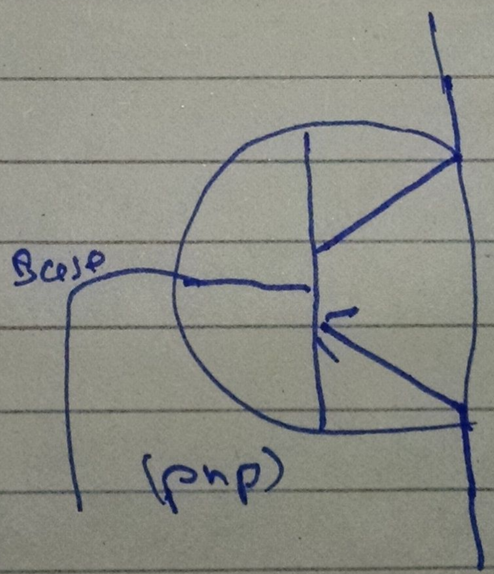
- The base region is lightly doped and very thin as compared to the heavily doped Emitter and the moderately doped collector region.

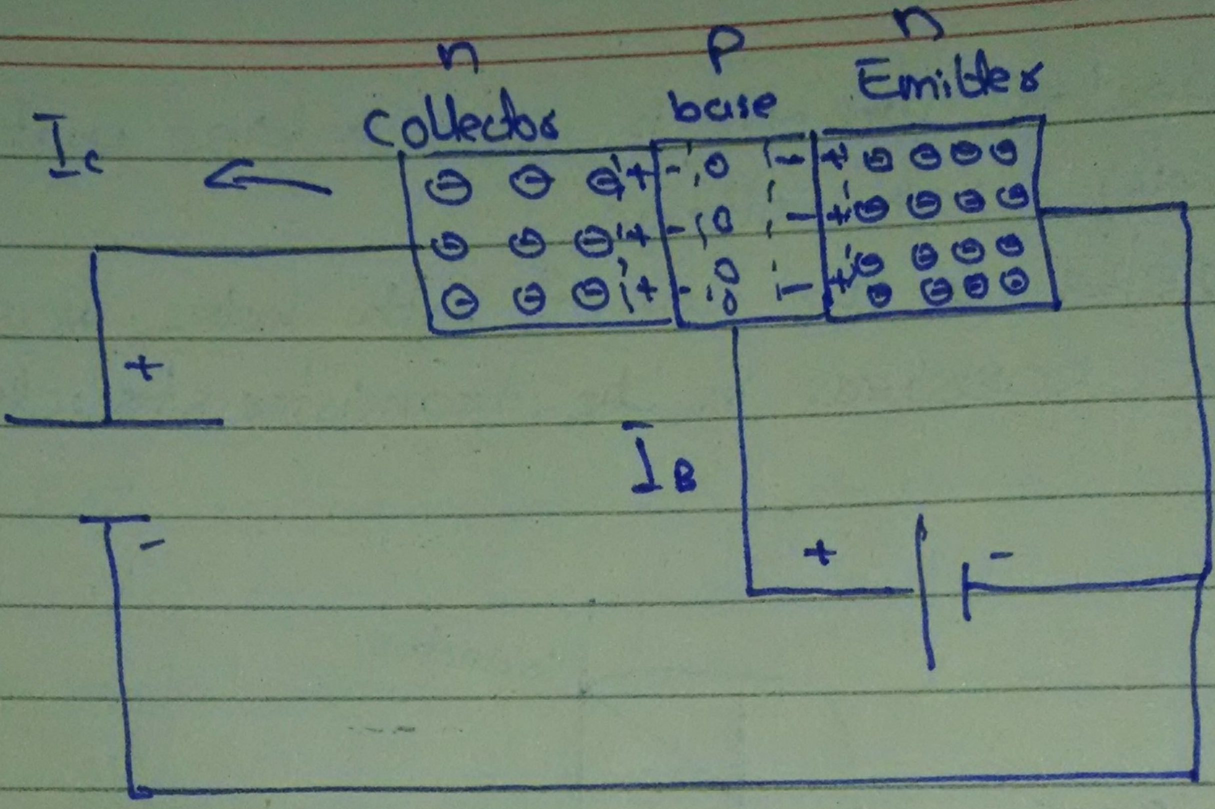
- In order for the transistor to operated properly, the pn junction must be correctly bias.
- Base Emitter junction is forward bias with small voltage.

- Base Collector junction is reverse bias with a relatively high voltage.
- Bipolar refer to the use of both holes and electron carriers in the transistor structure.

Symbol:







$$I_E = I_B + I_C$$

What happens inside (npn) transistor?

- The forward bias from base to emitter ~~m~~ narrows the BE depletion region.
- The reverse bias from base to collector widen the BC depletion region.
- The heavily doped Emitter (n-type) region is full of free (conduction band) electrons, that easily diffuse through the forward bias (BE) junction into the p-type base region, where they become minority carriers.
- The base region is lightly ~~and~~ doped and very thin having limited numbers of holes.
- Only a small percentage of all electrons flowing through BE junction combines with the available holes in the base.
- These few recombined electrons flow out of the base lead as valence electrons forming small base electron current.
- Most of electrons flowing from emitter into (thin, lightly, doped) base region don't recombine but diffuse into the BC depletion region.

- Once in BC depletion region they are pulled through the (reverse-bias) BC junction by the electric field setup by the force of attraction b/w positive and negative ions.

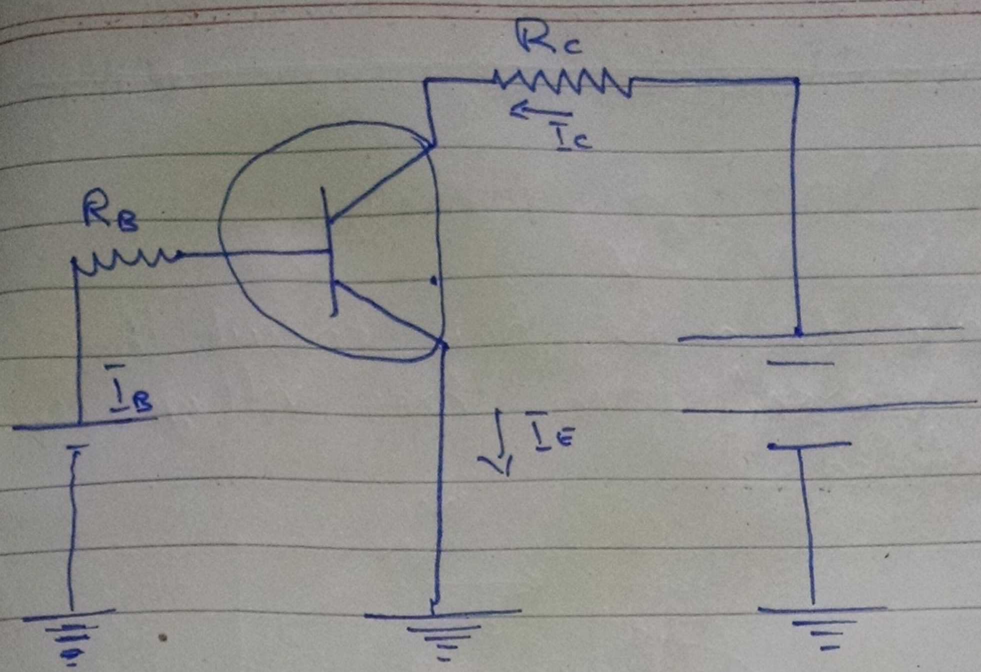
- Alternatively, we can think of the electrons as being pulled across the reverse bias BC junction by the attraction of collector supply voltage

- These electrons now move through the collector region into the positive terminal of the collector voltage source forming collector electron current.
- The collector current is much larger than the base current

Transistor Currents:

Emitter current (I_E) is the sum of the collector current (I_C) and the base current (I_B)

$$I_E = I_B + I_C \quad \text{——} \quad (a)$$



Transistor Characteristics & Parameters:

- Ratio of the collector current (I_C) to the base current (I_B) is the β, which is called as the current gain of a transistor.

$$\beta = \frac{I_C}{I_B} \quad \text{---} \quad (5)$$

(β ranges from less than 20 to 200 or higher)

- Ratio of collector current (I_C) to the emitter current is alpha (α)

$$\alpha = \frac{I_C}{I_E}$$

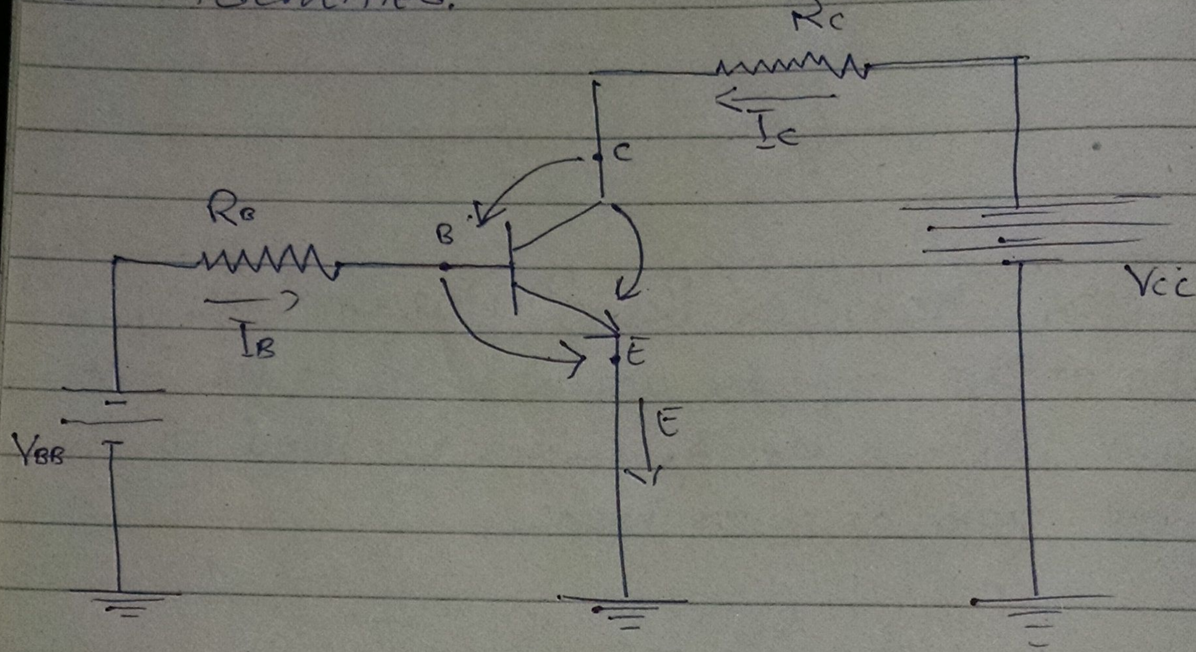
ranges from 0.95 to 0.99 or greater but less 1.

18-03-2016

~~Transistor Characteristics and Parameters:~~

Current Voltage Analysis:

In a basic transistor bias circuit, three transistor currents and three voltages can be identified.



I_B = Base current
I_E = Emitter current
I_C = Collector current
V_{BE} = Voltage at base w.r.t emitter
V_{CB} = Voltage at collector w.r.t base
V_{CE} = Voltage at collector w.r.t. emitter

V_{BB} forward bias the Base emitter junction

V_{CC} Reverse bias the base collector junction

When Base Emitter Junction is forward bias it act like a forward bias diode with a nominal forward voltage drop of

$V_{BE} \cong 0.7V$. — (i)

Since Emitter is at ground (0V); by Kirchoff's voltage law voltage across R_B is

$$V_{RB} = V_{BB} - V_{BE}$$

By Ohm's law, $V_{RB} = I_B R_B$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \quad \text{—— (ii)}$$

Voltage at Collector w.r.t grounded emitter is;

$$V_{CE} = V_{CC} - V_{RC}$$

$$V_{CC} = V_{RC} + V_{CE}$$

From Ohm's law,

$$V_{RC} = I_C R_C$$

$$V_{CE} = V_{CC} - I_C R_C \quad \text{— (iii)}$$

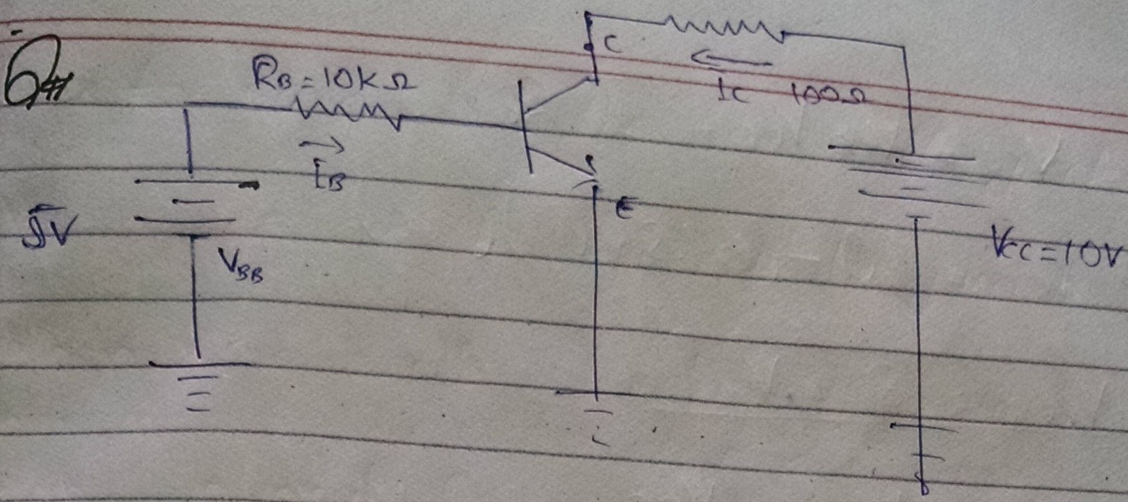
Voltage across the reverse bias collector base junction.

$$V_{CB} = V_{CE} - V_{BE} \leftarrow \text{(iv)}$$

$$\cancel{V_{CE} = V_{CB} + V_{BE}}$$

$\beta_{DC} = 150$

Q#



1) Determine I_B, I_C, I_E

V_{BE}, V_{CE}, V_{CB}

Start with $\boxed{V_{BE} = 0.7V}$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{10 \times 10^3} = 0.43\ mA$$

$\beta = 150$

$\frac{I_C}{I_B} = 150$

$I_C = 150 \times 0.43 \times 10^{-3}$

$\boxed{I_C = 64.5\ mA}$

$I_E = I_B + I_C$

$I_E = 0.43mA + 64.5mA$

$\boxed{I_E = 64.93\ mA}$

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$$V_{CE} = \cancel{V_{CB}}\ V_{CC} - I_C R_C$$

$$V_{CE} = 10 - (64.5 \times 10^{-3})(100)$$

$$\boxed{V_{CE} = 3.55\,V}$$

$$V_{CB} = V_{CE} - V_{BE}$$
$$V_{CB} = 3.55 - 0.7$$

$$\boxed{V_{CB} = 2.75\,V}$$

Q7

$V_{CC} = 9V$
$R_C = 220\,\Omega$
$R_B = 22K\,\Omega$
$V_{BB} = 6V$
$\beta_{DC} = 90$

Solution:

Start with $\boxed{V_{BE} = 0.7V}$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{6 - 0.7}{22 \times 10^{3}}$$

$$\boxed{I_B = \cancel{240}\ 0.24\,mA}$$

$$\beta_{dc} = 90$$

$$\frac{I_C}{I_B} = 90$$

$$I_C = 90 \times 0.24m$$

$$\boxed{I_C = 21.6\,mA}$$

$$I_E = I_B + I_C$$

$$= 0.24\,mA + 21.6\,mA$$

$$\boxed{I_E = 21.84\,mA}$$

$$V_{CE} = V_{CC} - I_C R_C$$

$$V_{CE} = 9 - (21.6 \times 10^{-3})(220)$$

$$\boxed{V_{CE} = \cancel{4.28}\ 4.248\,V}$$

$$V_{CB} = V_{CE} - V_{BE}$$

$$V_{CB} = 4.24 - 0.7$$

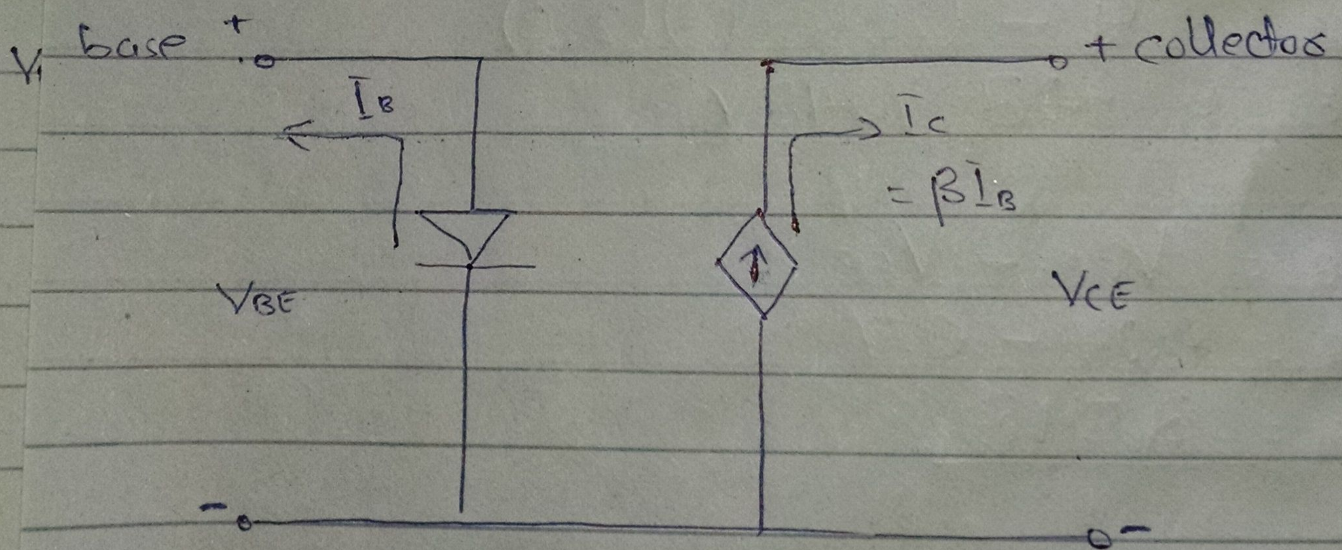
$$\boxed{V_{CB} = 3.548}$$

25-03-2016

Transistor DC Model:

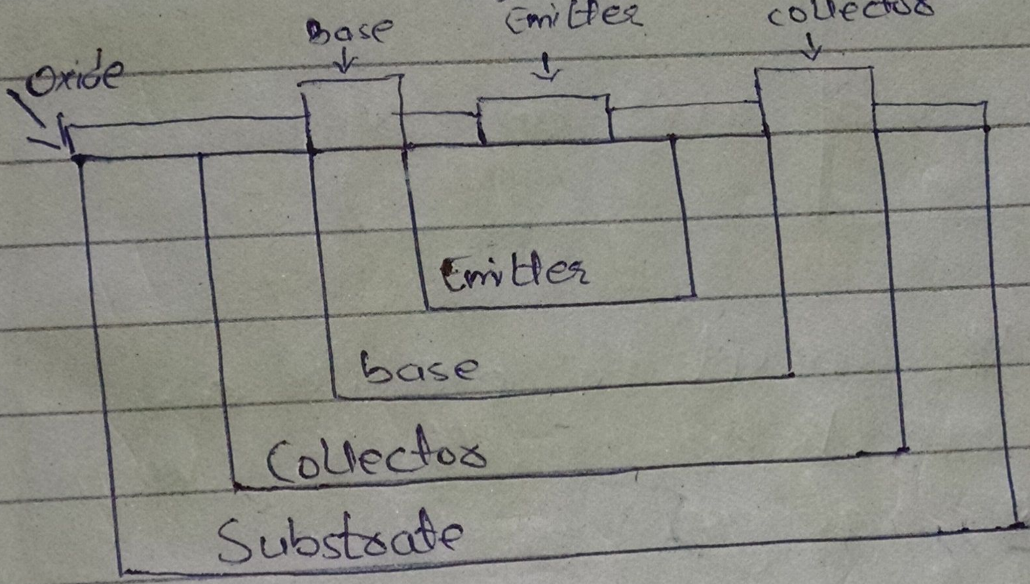
- You can view the BJT as a device with a current input and a dependent current source in the output circuit.

- The input circuit is a forward-bias diode through which there is a base current.
- The output is a dependent current source with a value that is dependent on the base current I_B and is equal to βI_B



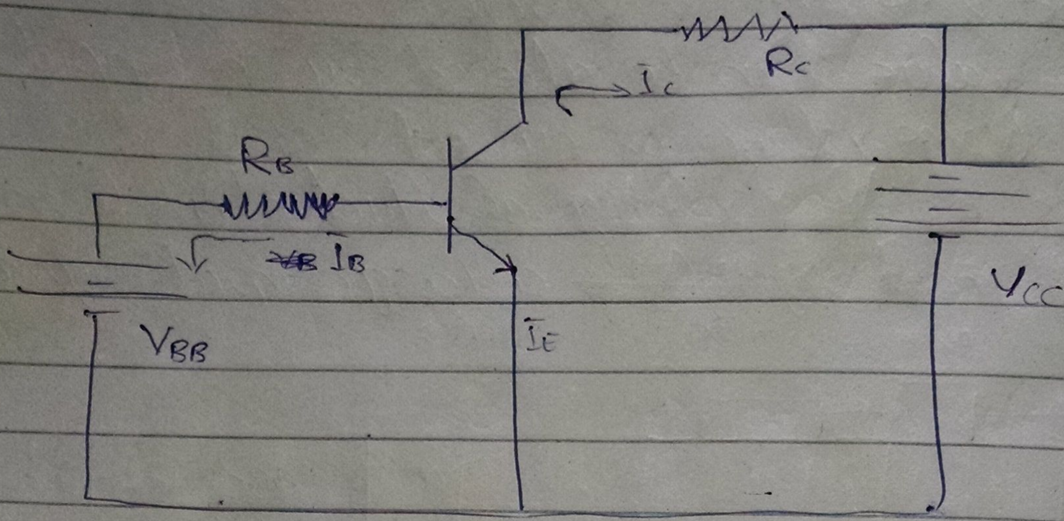
• Transistor is shortened form of original term "transfer resistor."

• Transistor effect is to make a resistance whose value can be altered by the input signal (some voltage or current) and to transfer pattern of signal fluctuation from a small input signal to a large input signal.



Basic epitaxial planner structure

Collector Characteristic Curve:



- Assume that V_{BB} is set to produce a certain value of I_B.

- For $V_{CC} = 0V$, both base emitter and base collector Junction are forward bias.

- Base will be at 0.7V and emitter and collector would be at 0V.

- In above condition $I_C = 0A$, as base current will flow through the base emitter junction because of low impedance path to ground. $\boxed{I_B = I_E}$

- When both junctions are forward biased, the transistor is said to be in saturation region of its operation.

- As V_{CC} is increased, V_{CE} increase gradually as the collector current increase

- I_C start to increase as V_{CC} increase until V_{CE} remains less than 0.7V due to the forward bias base collector junction.

- When V_{CE} exceeds 0.7V base collector junction become reverse bias and the transistor goes into the active or linear region of its operation

- Ideally, once the base collector junction is reverse bias, I_C levels off and essentially remains constant for a given value of I_B as V_{CE} continues to increase.

- Actually I_C increase only slightly as V_{CE} increase (due to widening of base collector depletion layer).

- In linear region the value of I_C is determined by the relationship $I_C = \beta I_B$

- When V_{CE} reaches a sufficiently high voltage, the reverse bias base collector junction goes into breakdown and the collector current increase rapidly.

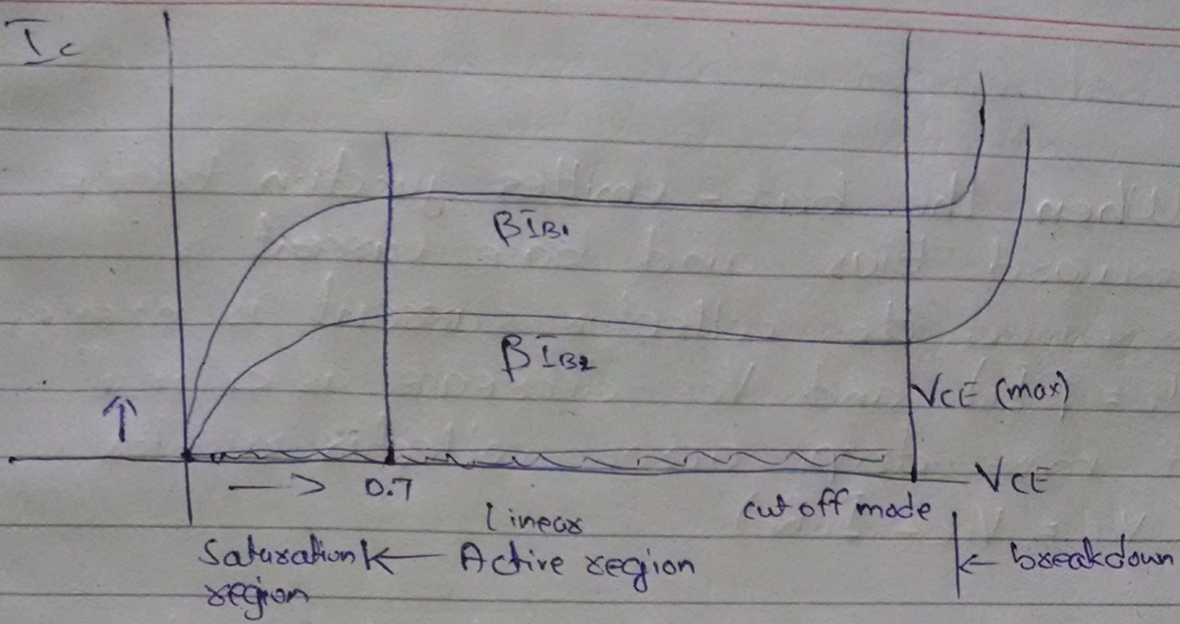
- A transistor should never be operated in break down region.

- If $I_B = 0$ the transistor is in the cut off region and there will be a very small collector leakage current.

- Cut off is a non-conducting state of a transistor.

- Saturation is the state of BJT in which the collector current has reached a maximum and is independent of I_B.

killing me softly



Cut off:

- When $I_B = 0$, transistor is in the cut off region of operation.
- In cutoff region, there is a very small amount of collector leakage current, I_{CEO} (collector to emitter with base open) mainly due to thermally procedure carriers.
- As I_{CEO} is too small it can be neglected giving $V_{CE} = V_{CC}$
- In cut off neither the base emitter nor the base collector junction are forward bias.

Saturation:

When the base-emitter junction become forward bias and base current is increased the collector current is increased ($I_c = \beta I_B$) and V_{CE} decrease as a result of more drop across collector resistor ($V_{CE} = V_{CC} - I_c R_c$)

- When V_{CE} reaches its saturation value $V_{CE(sat)}$, the base collector junction become forward bias and I_c can increase no further even with a continued increase in I_B.

- At the point of saturation, the relation $I_c = \beta I_B$ is no longer valid.

- $V_{CE(sat)}$ for a transistor occurs some where below the knee of the collector curve, and is usually only a few tenth of a volt.