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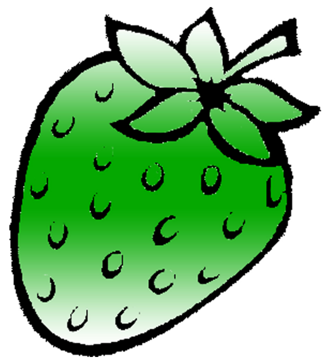

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Unit 1 :

Semiconductor Materials

and

Diodes

Contents

- Review of Semiconductor materials and properties
- The PN junction
- Introduction to Semiconductor Diode Theory
- Diode Circuits: DC Analysis and Models

  AC Equivalent Circuits
- Temperature Effects
- Diode Types: Solar Cell, Photo diode, Light Emitting diode, Schottky barrier diode
- Understanding Manufacturers Specification

Review of
Semiconductor Material

Material Classification

- Conductors
  - Gold , Silver, Copper .
  - Good conductors of Electricity

- Insulators
  - Porcelain, glass, quartz, Rubber, Backellite, etc .
  - Bad conductors of Electricity

- Semiconductors are materials whose electrical properties lie between Conductors and Insulators.

Ex : Silicon and Germanium

Semiconductors

- Neither good conductors nor good insulators.
  - At absolute zero temp.

    Semiconductor behaves as an INSULATORS

- At room temp.
  - Have conductivity considerably lower than CONDUCTORS but higher than INSULATORS
  - Therefore called as SEMICONDUTORS

Semiconductors (Contd.)

- Increase in Temperature.
    - Conductors :
        - conductivity decreases
        - resistivity increases ,
        - it has positive Temperature coefficient of resistance.
  - Semiconductors:
      - conductivity increases
      - resistivity decreases
      - **it has negative temperature of coefficient.**

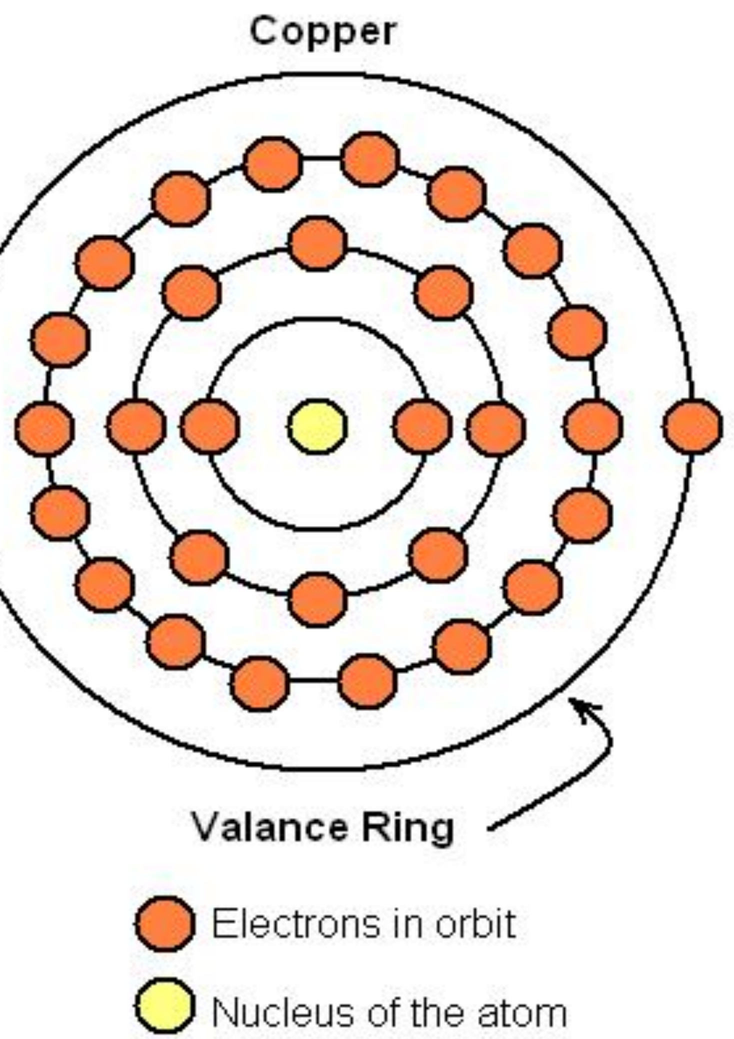
Semiconductors (Contd.)

Conductivity of SC

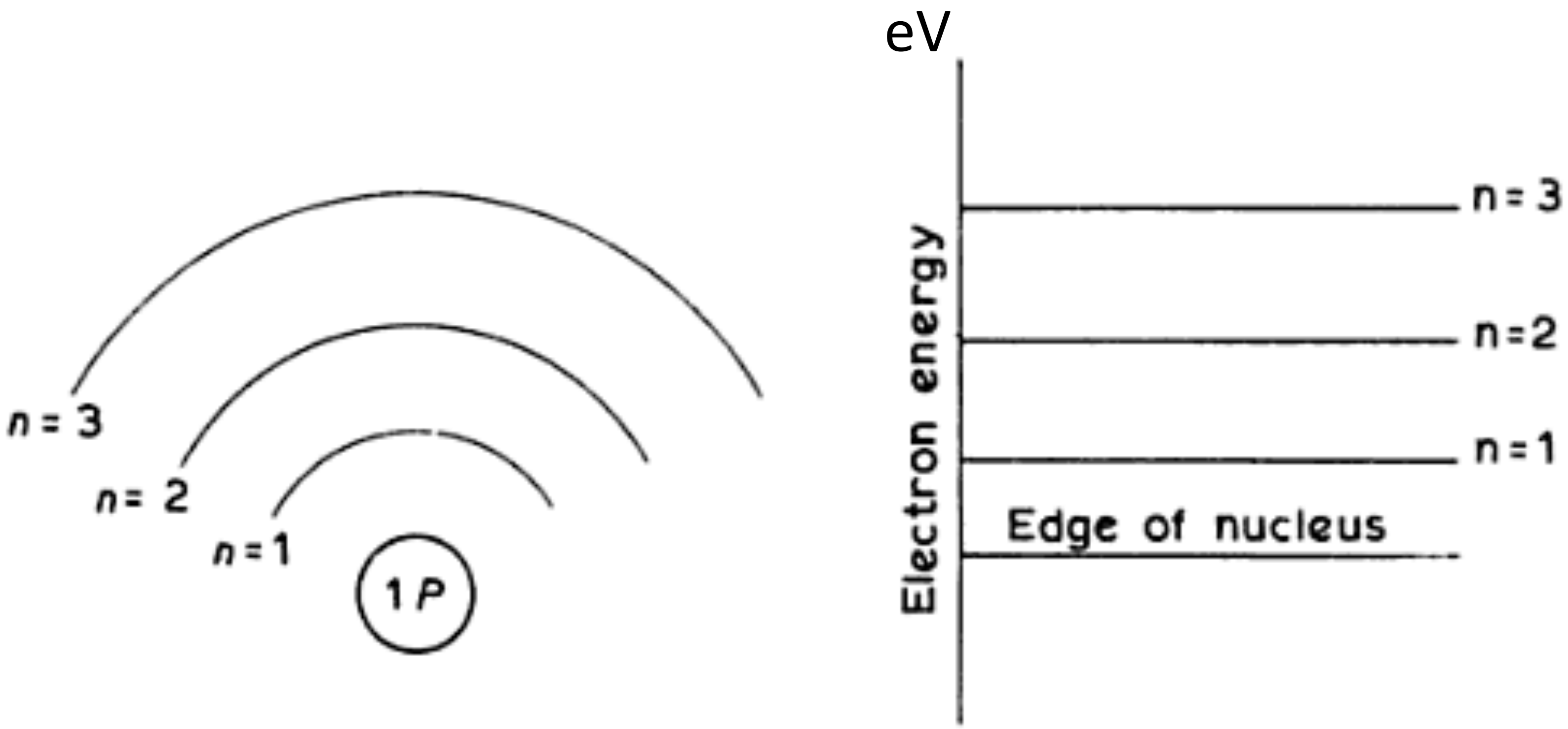
- can be changed to a large extent by adding a small amount of impurity.
- Controlled by controlling the amount of impurity added to it

Energy Band Diagram

Structure of Atom



Energy level diagram



Permissible energy levels in an isolated atom

eV – Unit of Energy

- The energy is measured in Joules.

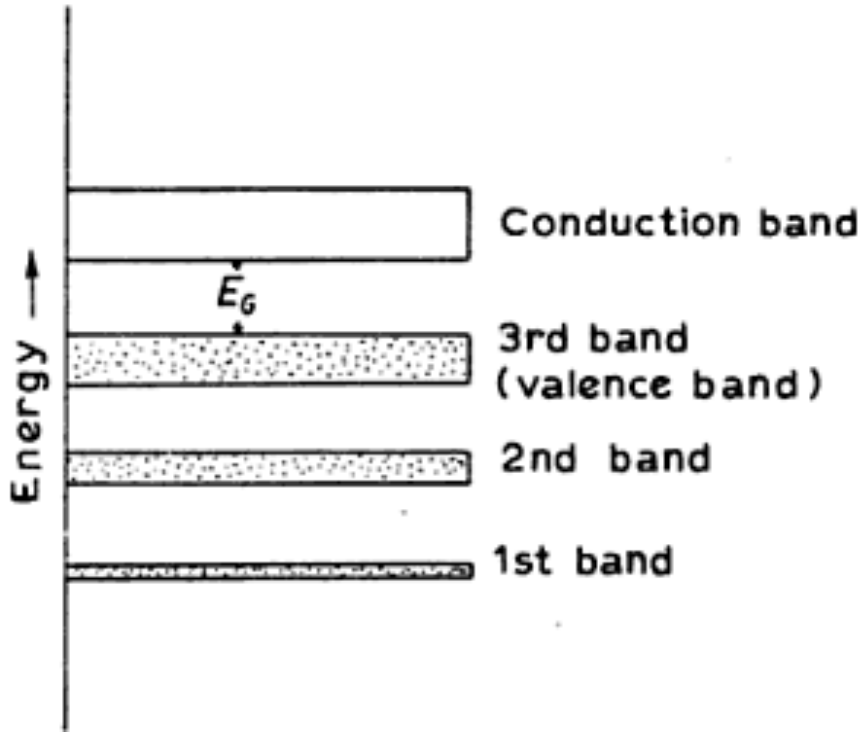
- One eV is defined as the energy which an electron acquires in moving through a potential difference of 1V. .

- The charge of single electron is 1.6×10^{-19} Coulomb.

$$1 \text{ eV} = 1.6\times10^{-19} \text{ (C)} \times 1 \text{ (V)} = 1.6\times10^{-19} \text{ J}$$

$$\mathbf{1 \text{ eV} = 1.6\times10^{-19} \text{ J}}$$

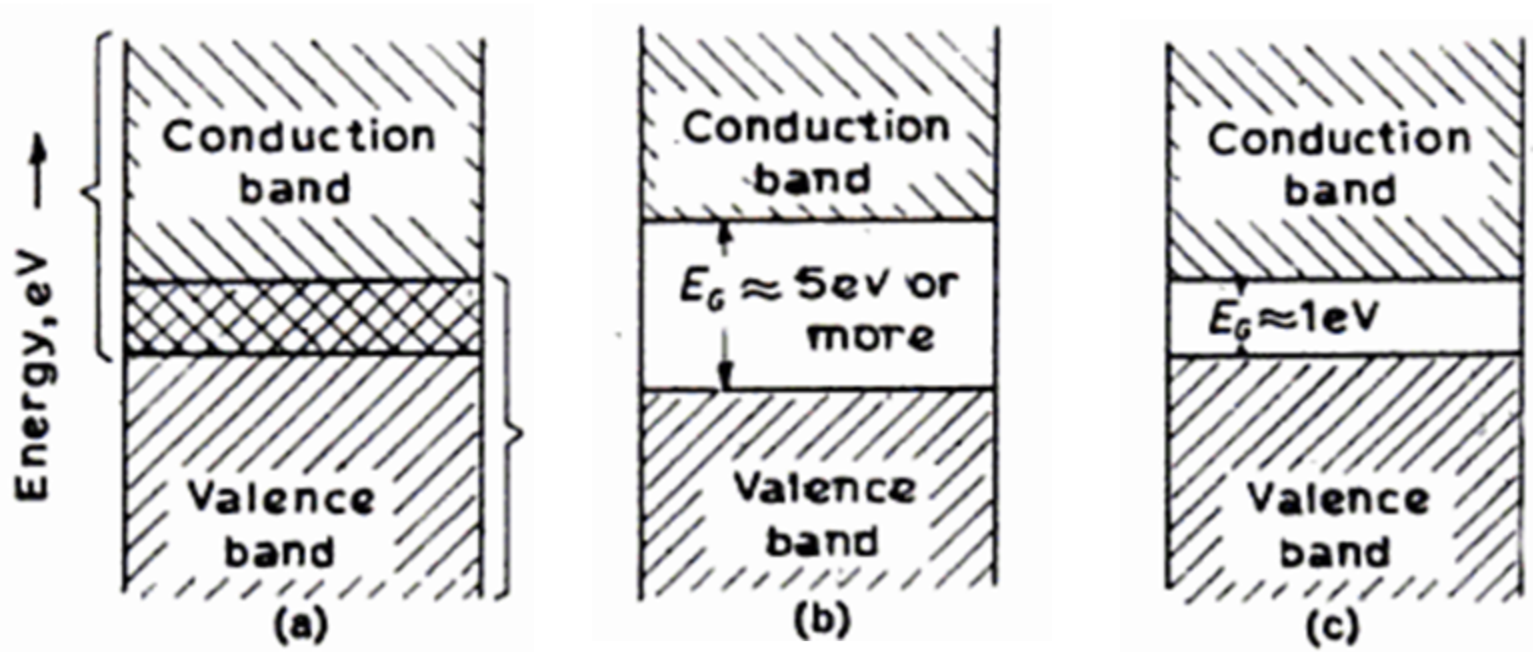
Energy Band Diagram



Energy-band diagram of a solid (silicon)

Energy Band Diagram

Differentiate between the Energy Levels of an Insulator, Semiconductor and Conductor



Energy-band diagram for the three types of materials:
(*a*) Metals (conductors); (*b*) Insulators; (*c*) Semiconductors

Classification of Semiconductor

Intrinsic Semiconductor

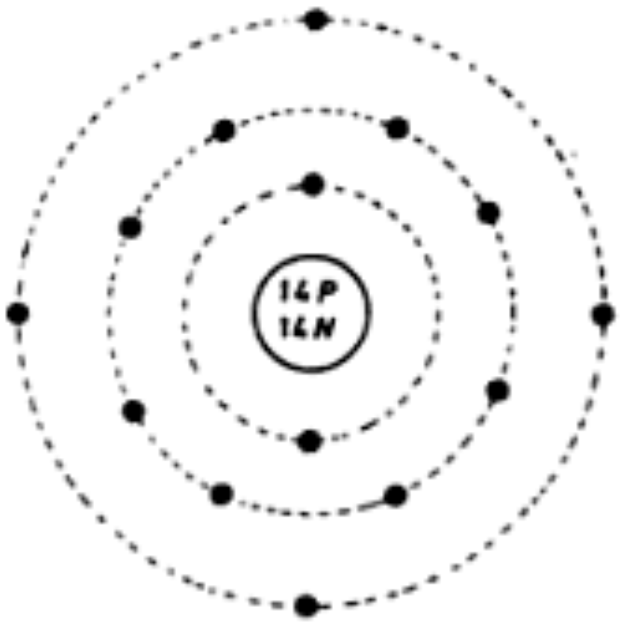
Extrinsic Semiconductor

Q: Compare the extrinsic and the intrinsic semiconductor material

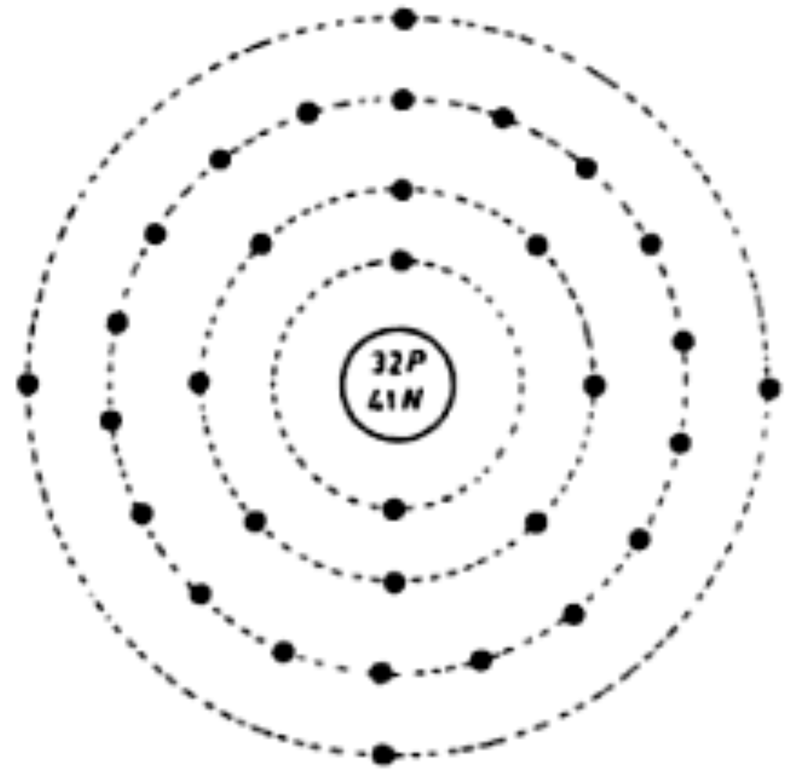
Intrinsic, Extrinsic

- Semiconductors are either intrinsic or extrinsic.
- In an intrinsic semiconductor, n and p are determined by the thermally generated electrons and holes.
- In an extrinsic (doped) semiconductor, the carrier concentration (n, p) are controlled by doping.

Representation of Silicon and Germanium atom



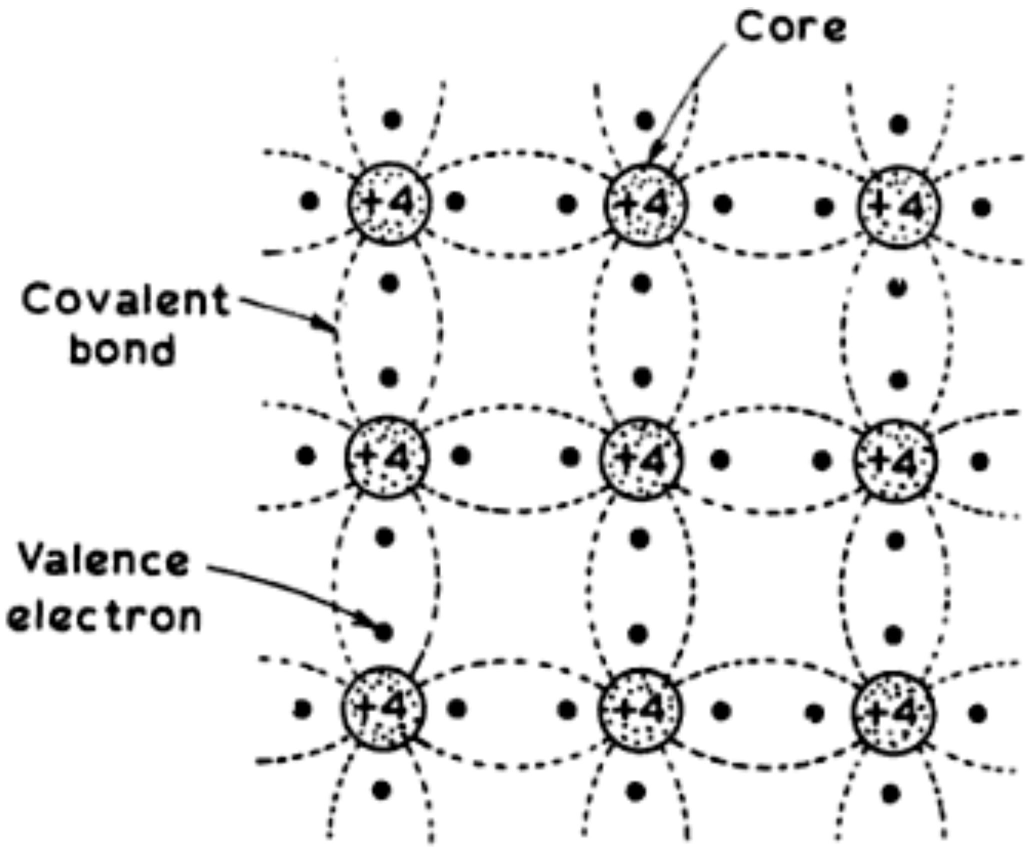
Silicon atom



Germanium atom

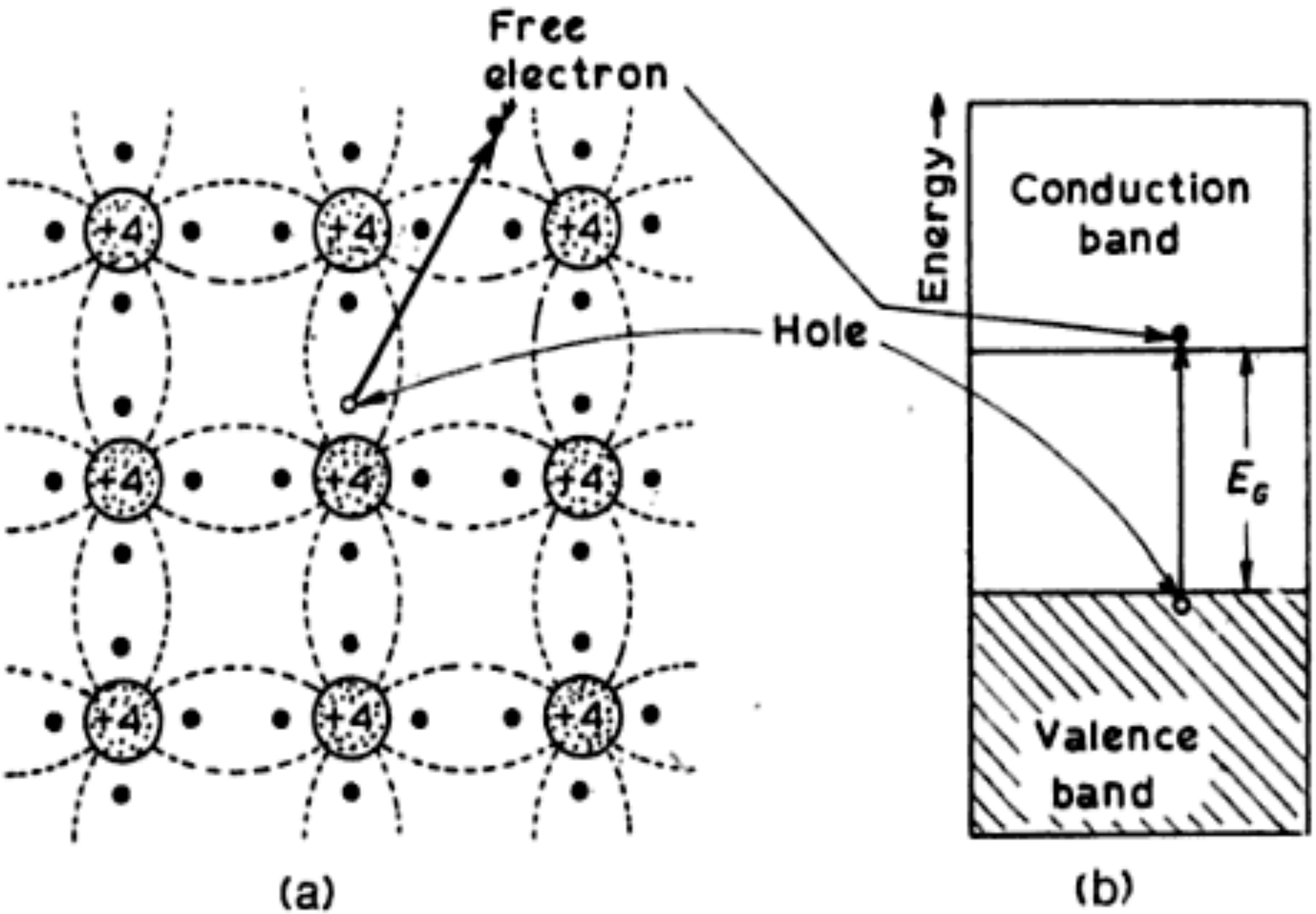
Intrinsic Semiconductor

- Semiconductor in its purest form.



Simplified representation of the crystalline structure of a semiconductoı at absolute zero

Thermal generation of Electron Hole Pair in Intrinsic Semiconductor



Intrinsic Semiconductor

- Intrinsic SC acts as a PERFECT INSULATOR at absolute zero (-273^0 C).

- At room temperature (300 K) Intrinsic SC has SMALL CONDUCTIVITY due to thermal generated Electron Hole pairs .

- Conductivity of Si is less than that of Ge

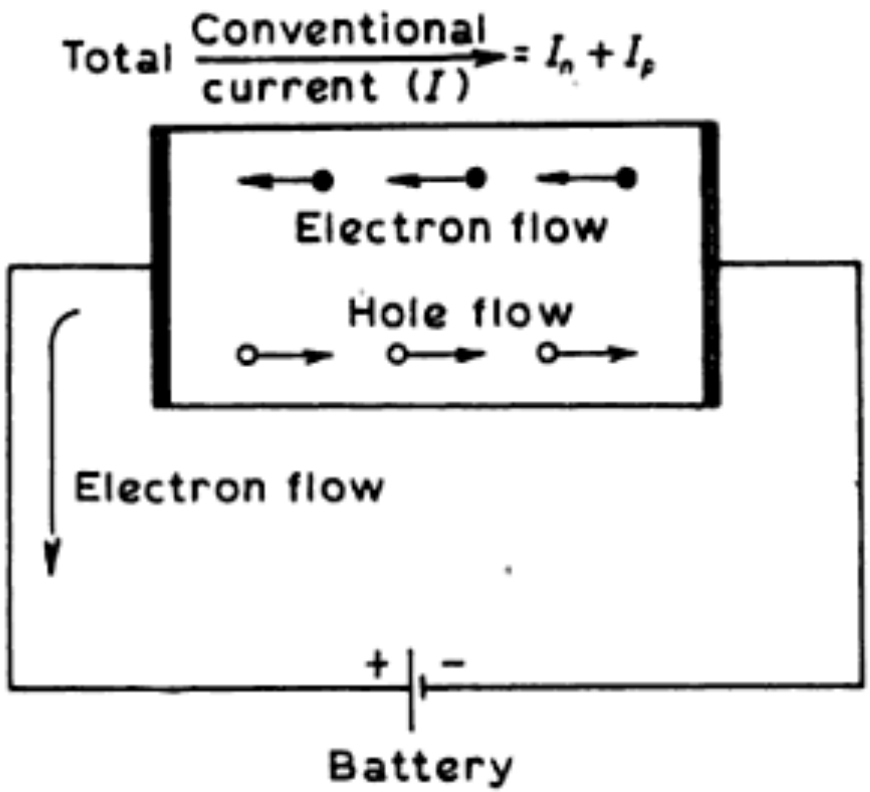
  Eg (Si) = 1.12eV (more for Si)

  Eg (Ge) = 0.72 eV (less for Ge)

Intrinsic Semiconductor

- Effect of temperature on Intrinsic SC
  - Higher is the concentration of charge carriers.
  - Higher is the conductivity.
  - Resistivity decreases.
  - Semiconductor has **NEGATIVE TEMPERATURE COEFFICIENT OF RESISTANCE.**

Current Conduction in Intrinsic Semiconductor



Conduction of current in an intrinsic semiconductor

Extrinsic Semiconductor

- Doped Semiconductor

Conductivity of Intrinsic SC is very small

Semiconductors are doped to
improve its conductivity

Doping : Deliberately adding impurity

Extrinsic Semiconductor

Types of Extrinsic Semiconductor

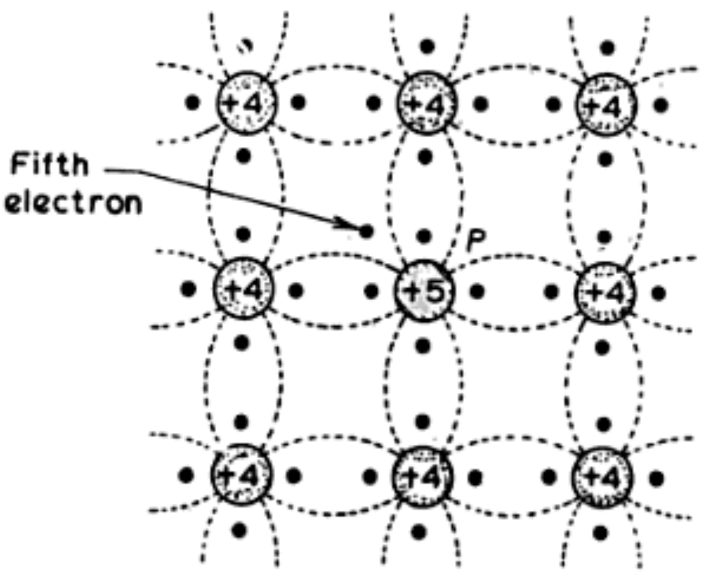
- N type Semiconductor
- P type Semiconductor

Extrinsic Semiconductor

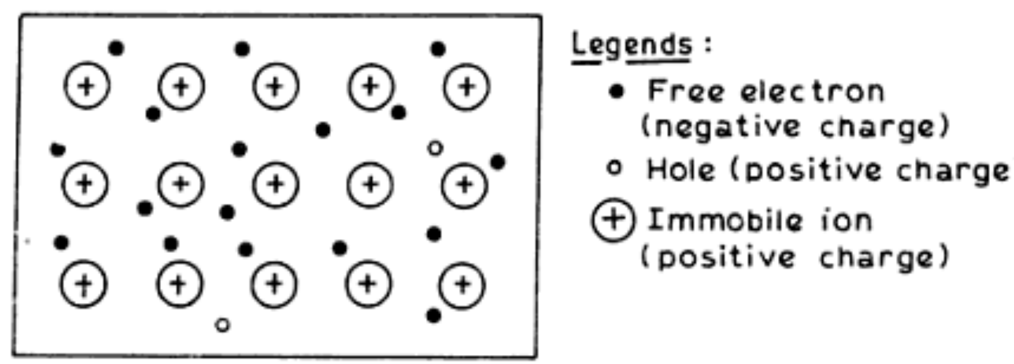
- The semiconductor is contaminated or *"doped".*
- "Doping" is the intentional introduction of chemical elements into the semiconductor.
- Depending on the type of dopant
  one can obtain a surplus of either
  positive charge carriers (called) *p- conducting semiconductor* or
  negative charge carriers(called) *n-conducting semiconductor*
- By doping *trivalent* element, we get p-type semiconductor. (with excess amount of hole).
- By doping *pentavalent* element, we get n-type semiconductor (with excess amount of electron)

Extrinsic Semiconductor

N Type Semiconductor



N-type semiconductor



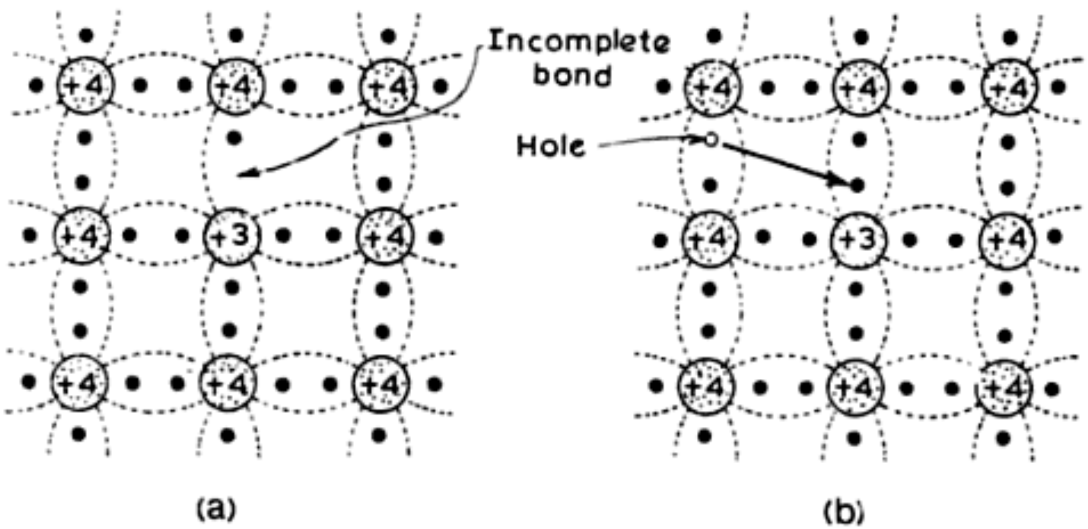
Representation of an *N*-type semiconductor

N Type Semiconductor

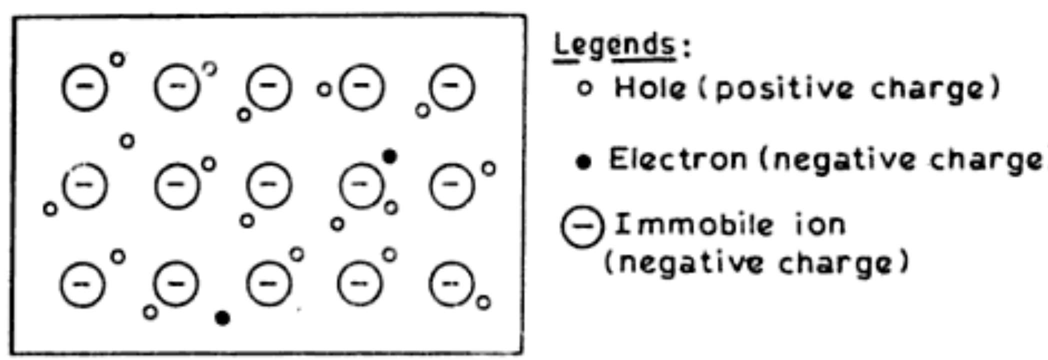
- A small amount of pentavalent impurity (Phosphorous) is added.
- Donor impurity has one extra electron in its valence shell.
- At room temperature , each impurity donates one electron to the conduction band .
- All the donated electrons take part in the conduction of electric current .
- Besides there are thermally generated electron hole pairs.
- Total number of holes and immobile ions are exactly same as the number of free electrons created.
- **Majority charge carriers : Electrons**
- **Minority charge carriers : Holes**

Extrinsic Semiconductor

P type Semiconductor



(a) **Boron added to silicon** *(b)* **Creation of a hole**



Representation of a *P*-type semiconductor

P Type Semiconductor

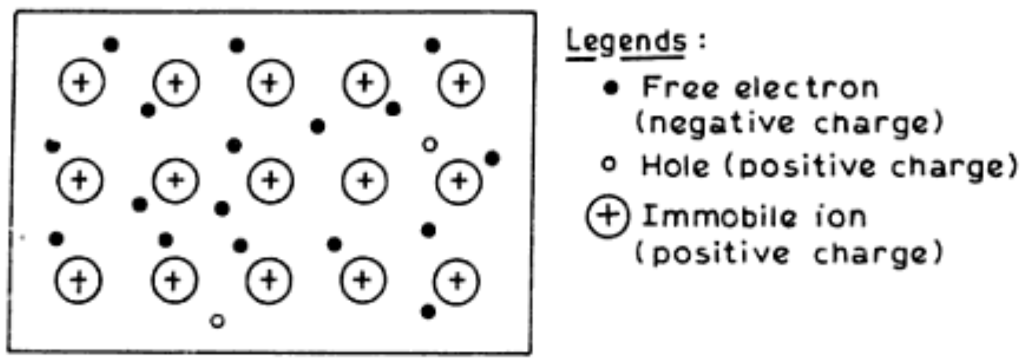
- A small amount of Trivalent impurity (Boron) is added.
- Acceptor impurity has a deficiency of electron (hole) in its valence orbit.
- At room temperature , the thermal energy is sufficient to provide energy to neighboring electron ,so as to fill up the incomplete bonds around the Boron atom
- Besides there are thermally generated electron hole pairs.
- Total number of electrons and immobile ions are exactly same as the

  number of holes created.
- **Majority charge carriers : Holes**
- **Minority charge carriers : Electrons**

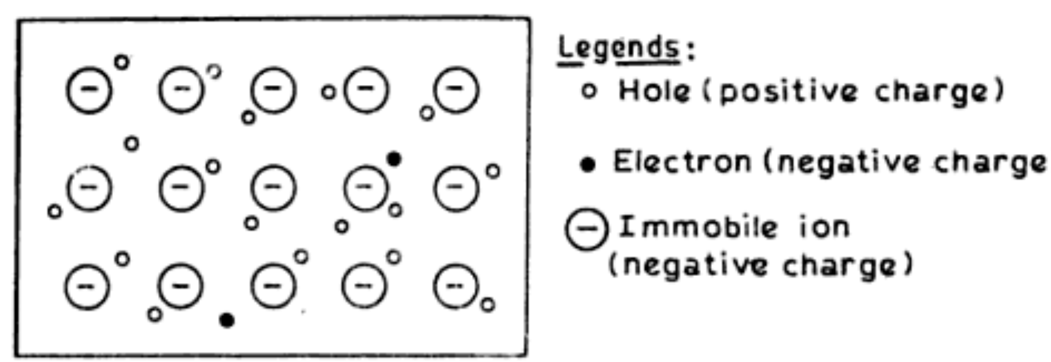
Effect of Temperature on Extrinsic Semiconductor

- Small amount of impurity (donor / acceptor) creates large amount of charge carriers in Extrinsic SC.
- At room temp. Conductivity of Extrinsic SC is many times that of Intrinsic SC.
- Additional thermal energy increases the thermally generated charge carriers.
- As a result the no. of majority and minority charge carriers increases.
- Hence Conduction increases (RESISTANCE DECREASES).
- SEMICONDUCTORS have **negative temperature coefficient of resistance.** (Decreasing resistance with increasing Temperature)

Summary



Representation of an *N*-type semiconductor

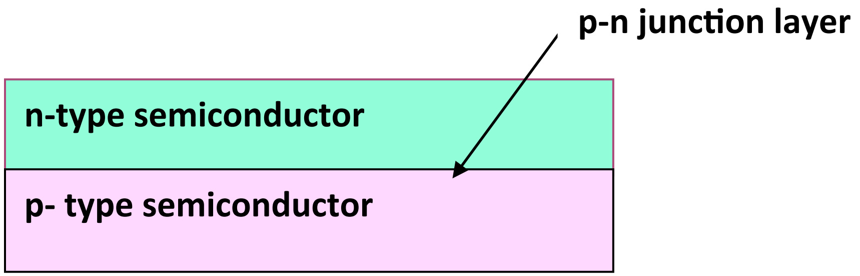


Representation of a *P*-type semiconductor

SEMICONDUCTOR DIODE

SEMICONDUCTOR DIODE

- If *two differently* contaminated semiconductor *layers* are combined, then a so-called *p-n-junction results* on the boundary of the layers.



- By doping *trivalent* element, we get p-type semiconductor. (with excess amount of hole)

- By doping *pentavalent* element, we get n-type semiconductor (with excess amount of electron)

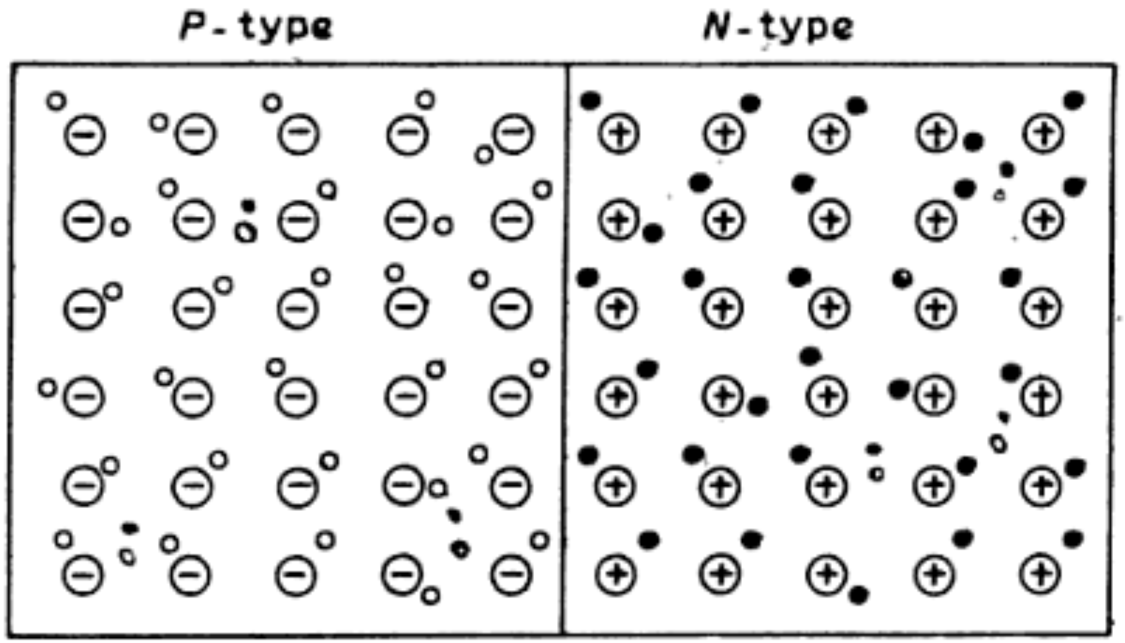
UNBIASED PN JUNCTION

BIASING

Applying external voltage to the PN junction.

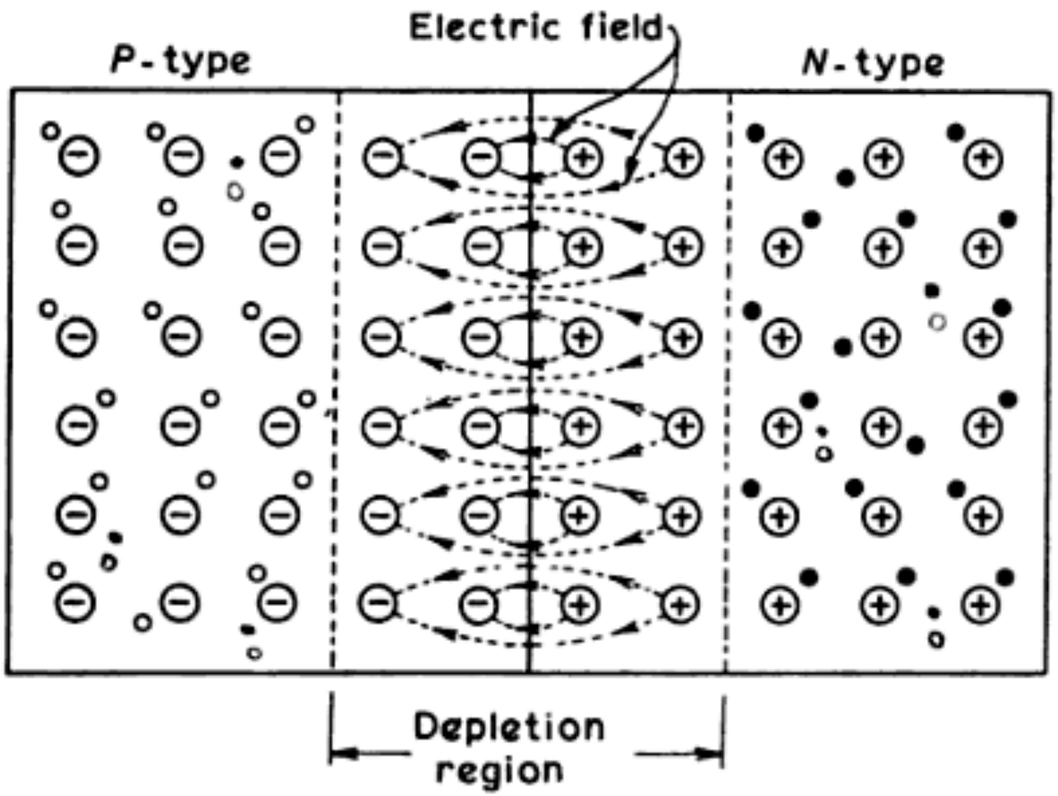
UNBIASED PN junction

- PN junction with no external voltage.



A *PN*-junction when just formed

PN junction with no external voltage.



Space-cnarge region or depletion region is formed in the vicinity of the junction

Depletion Layer

Barrier
Voltage

PN junction with no external voltage.

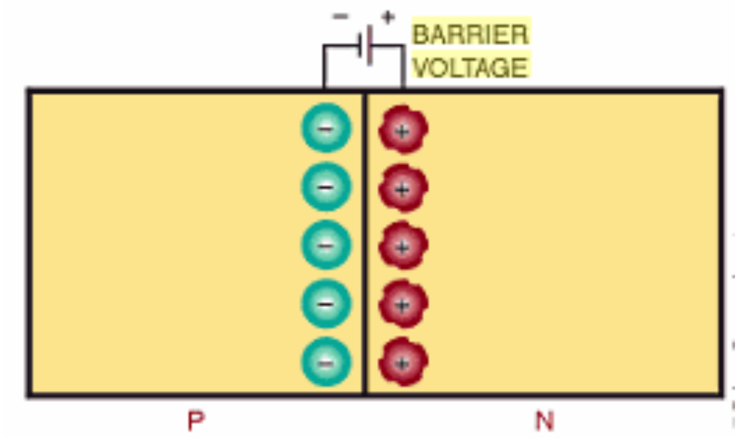
Depletion Layer

The combining of electron and holes depletes the holes in the P region and the electrons in the N region near the junction .

Barrier

A restraining force is automatically set up across the depletion layer called BARRIER

PN junction with no external voltage.



Barrier Voltage

The opposite charges that build up on each side creates a voltage across the PN junction.

The barrier voltage is the amount of electromotive force required to start conduction across the PN junction.

For Si PN junctions : 0.7 V

For Ge PN junctions : 0.3 V

The barrier voltage opposes the flow of majority carriers across PN junction and assists the flow of minority carriers across the junction.

Unequal doping density

Equal doping density : Depletion layer of equal width on either side.

If P region is heavily doped:

Depletion layer penetrates more in the lightly doped N region.

If N region is heavily doped:

Depletion layer penetrates more in the lightly doped P region.

Depletion region penetrates deepest into the more lightly doped side .

BIASED PN JUNCTION

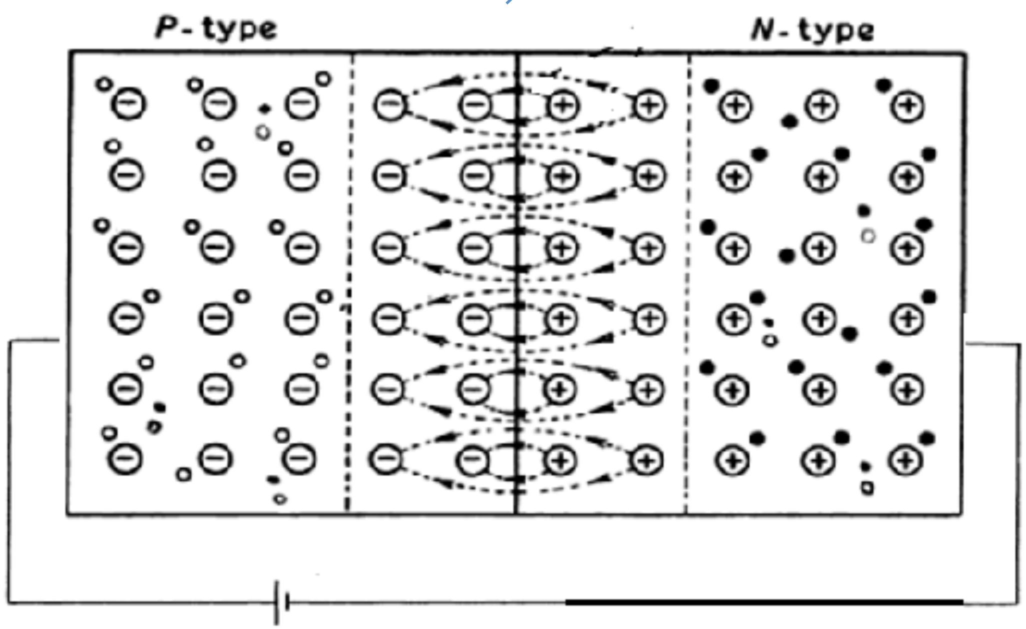
Biased PN Junction

- Forward biased PN junction
  - Battery connected with positive terminal to P side and Negative terminal to N side of the PN junction
- Reverse biased PN junction
  - Battery connected with positive terminal to N side and Negative terminal to P side of the PN junction

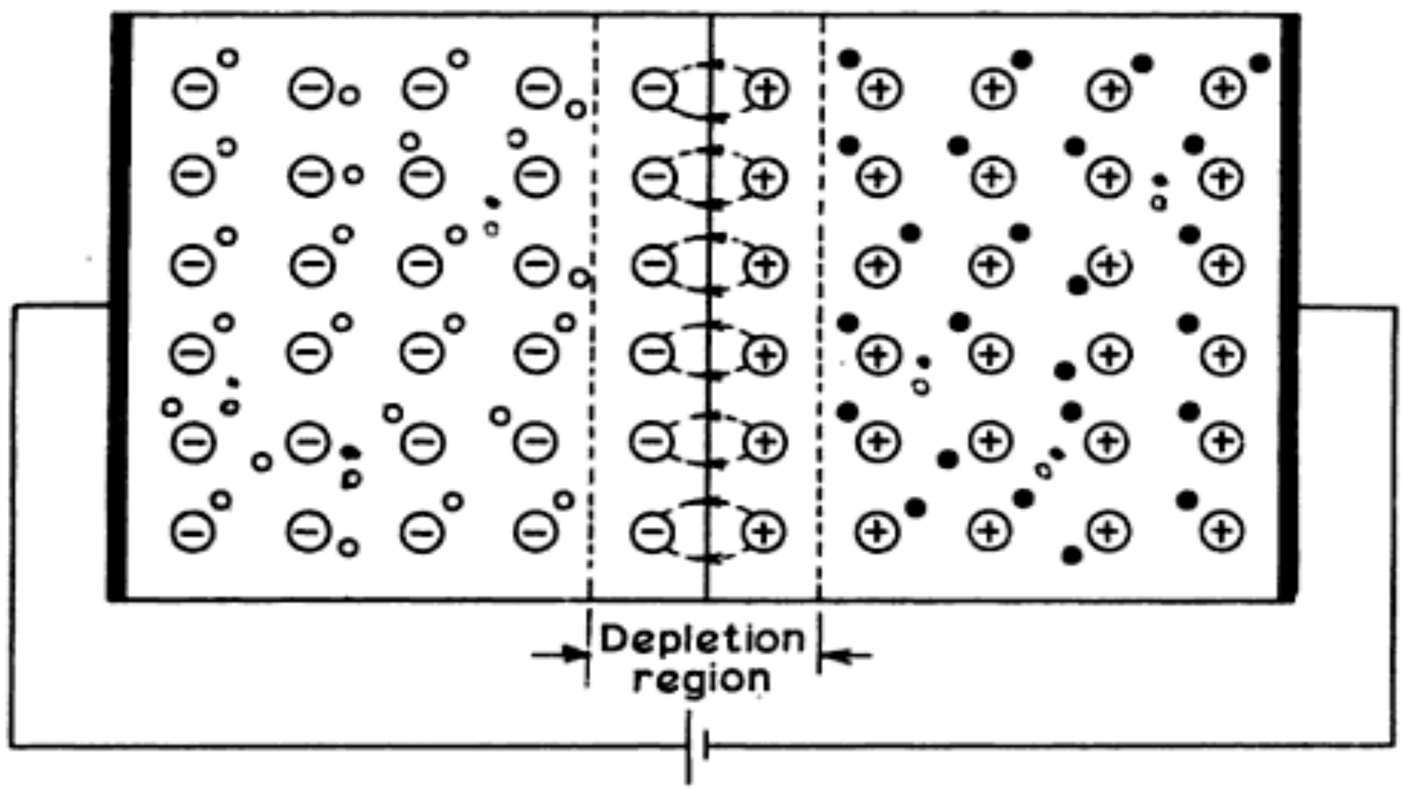
Forward Biased PN Junction

When external voltage is applied to unbiased PN junction

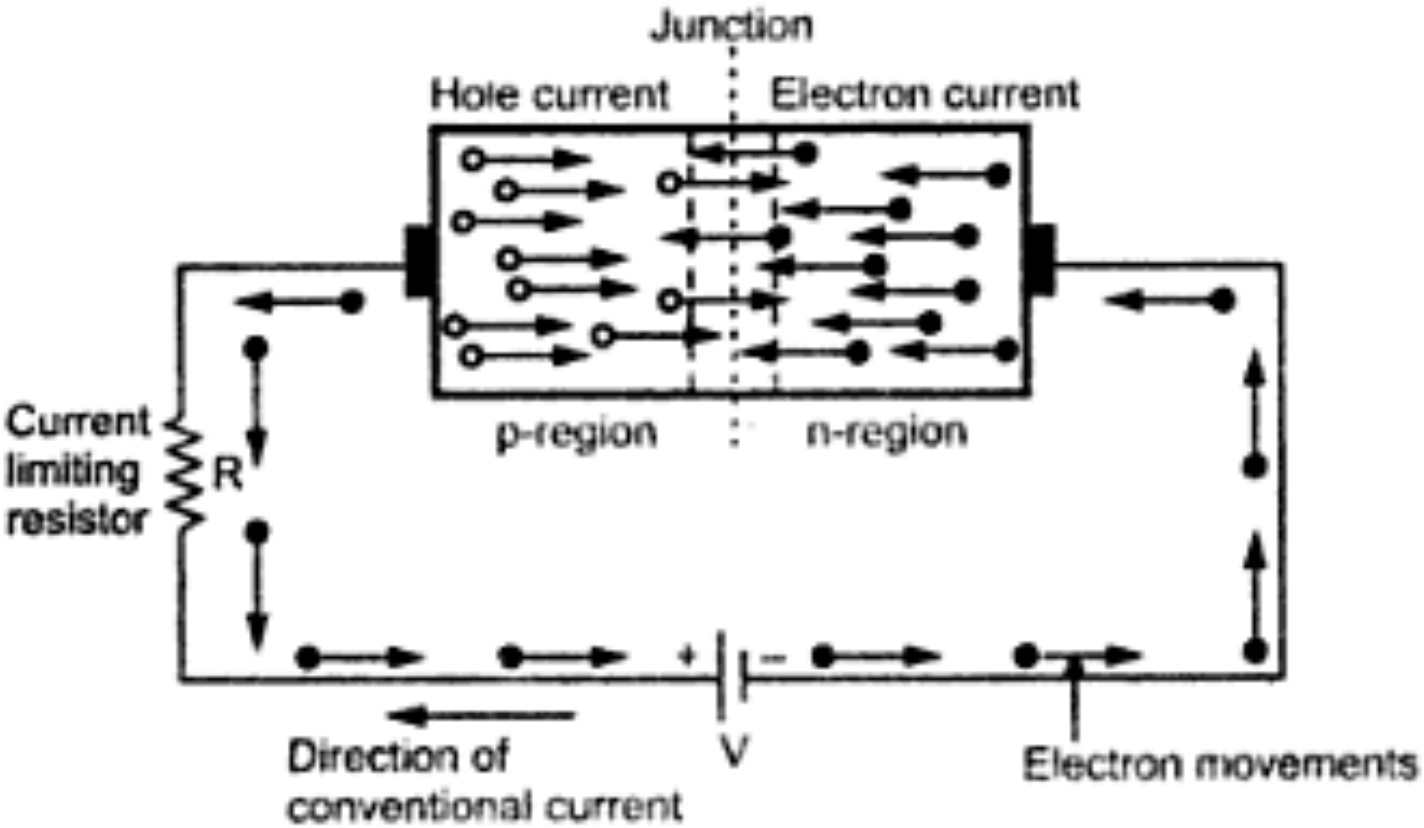
Depletion layer of Unbiased PN juction



Forward Biased PN Junction



PN-junction showing forward bias

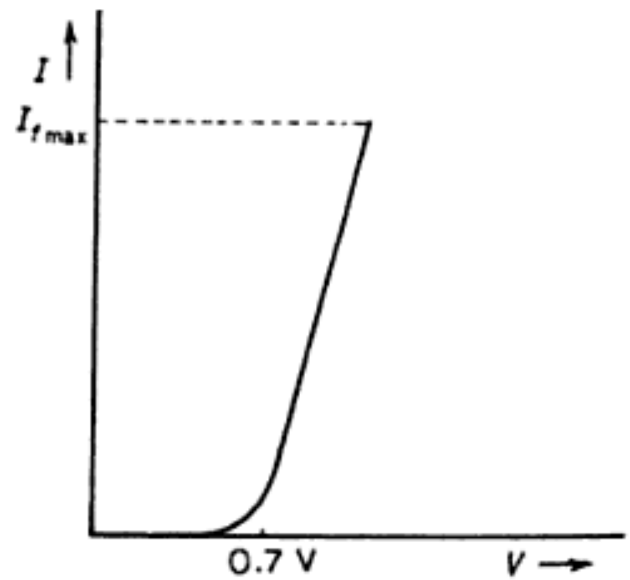


Forward current in a diode

Forward Biased PN Junction

As applied voltage is increased from 0

- Depletion width is reduced
- Barrier voltage is reduced
- Barrier voltage effectively disappears
- Majority charge carriers flows across the junction

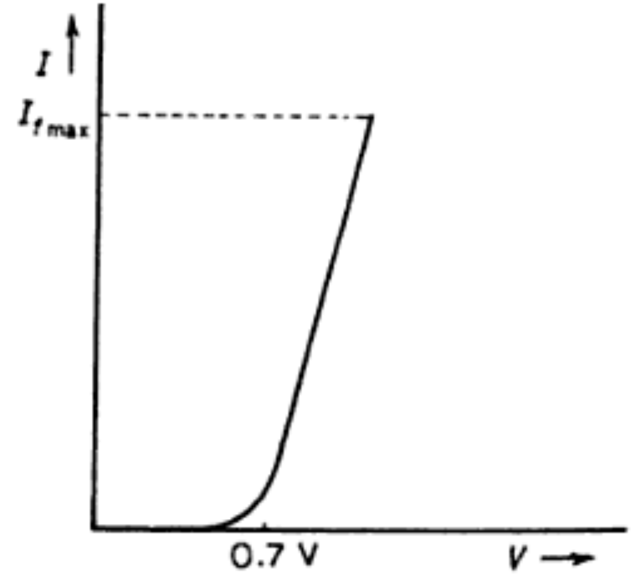


Forward characteristics of a silicon diode

Forward Characteristic

Plot of forward current (I_F) versus forward voltage (V_F)

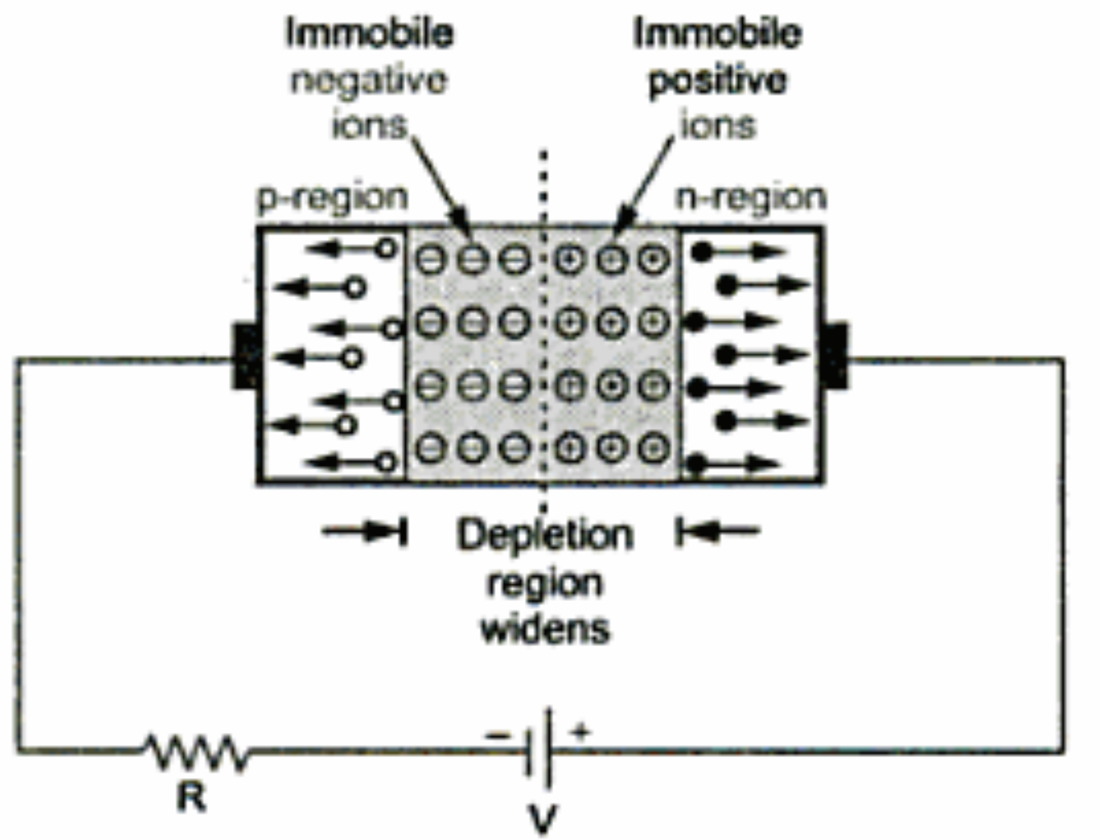
As applied voltage is increased from 0



Forward characteristics of a silicon diode

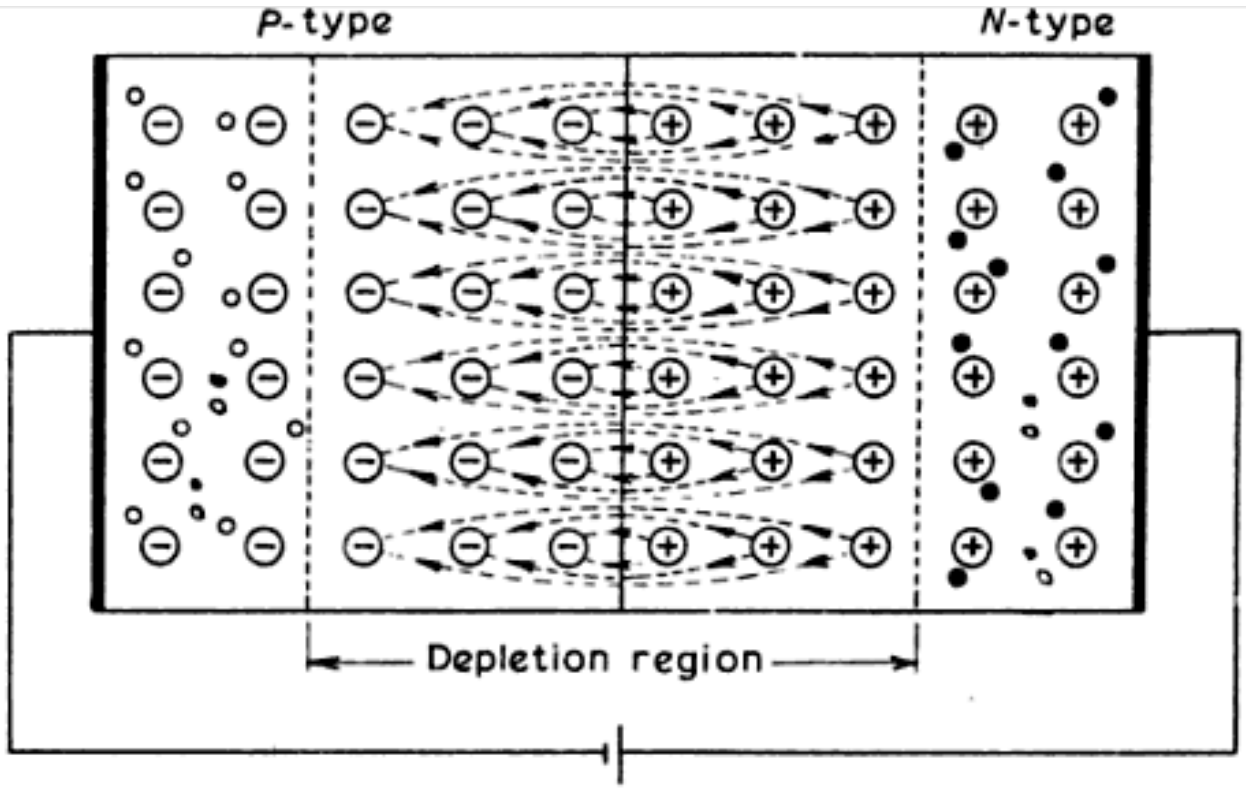
- Diode does not conduct until the external voltage overcomes the barrier voltage.
- When the applied voltage reaches 0.7V (Si), large no. of free electrons and holes cross the junction.
- Above 0.7 V, even a small increase in voltage causes a sharp rise in current.
- **The voltage at which the current starts to increase rapidly is called CUTIN or KNEE Voltage (Vγ).**

Reverse bias PN junction



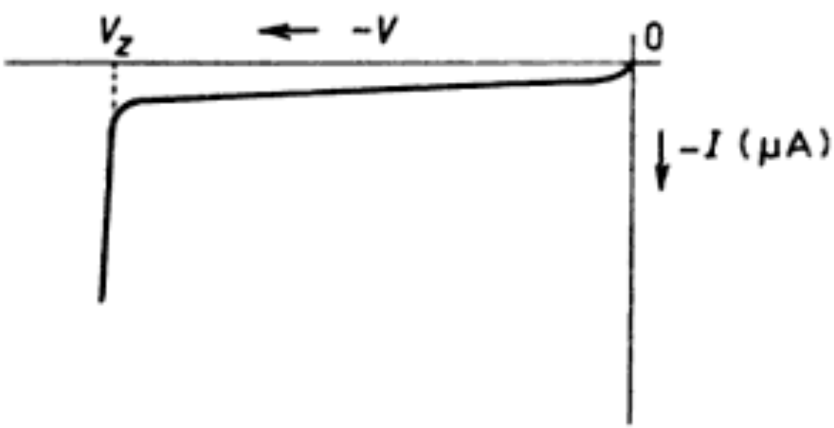
Depletion region widens in reverse bias

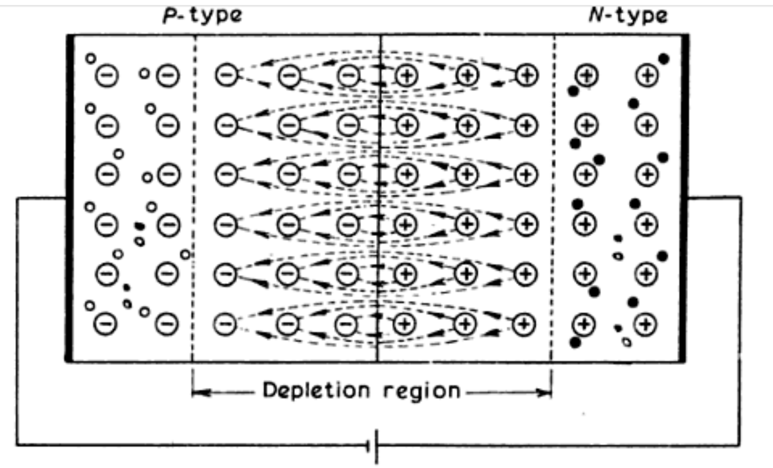
Reverse biased PN junction



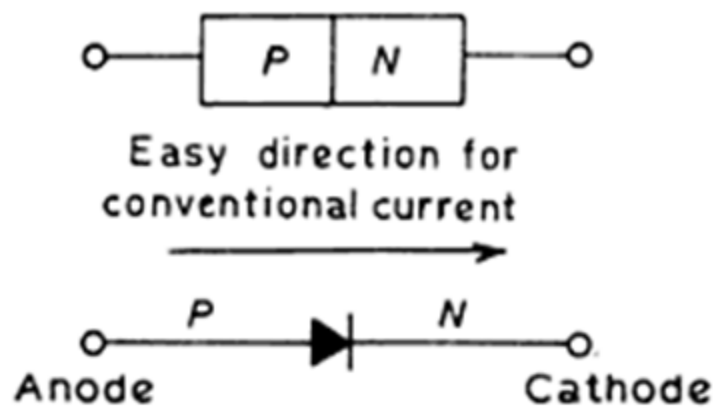
***PN*-junction showing reverse bias**

Reverse biased PN junction





PN-junction showing reverse bias



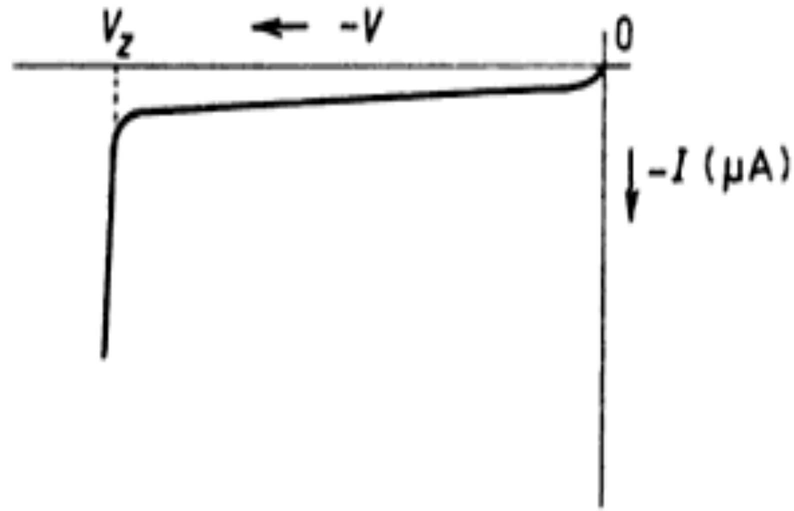
Reverse Biased PN Junction

As applied reverse voltage is increased from 0

- Depletion width is increased
- Barrier voltage is increased
- Majority charge carriers cannot flows across the junction
- Minority charge carriers can flows across the junction (Small reverse current flows)
- Rate of generation of minority carriers depends on temperature.
- At constant temperature rate of minority carrier generation is constant whether applied voltage is low or high **(REVERSE SATURATION CURRENT).**

As applied reverse voltage is too large

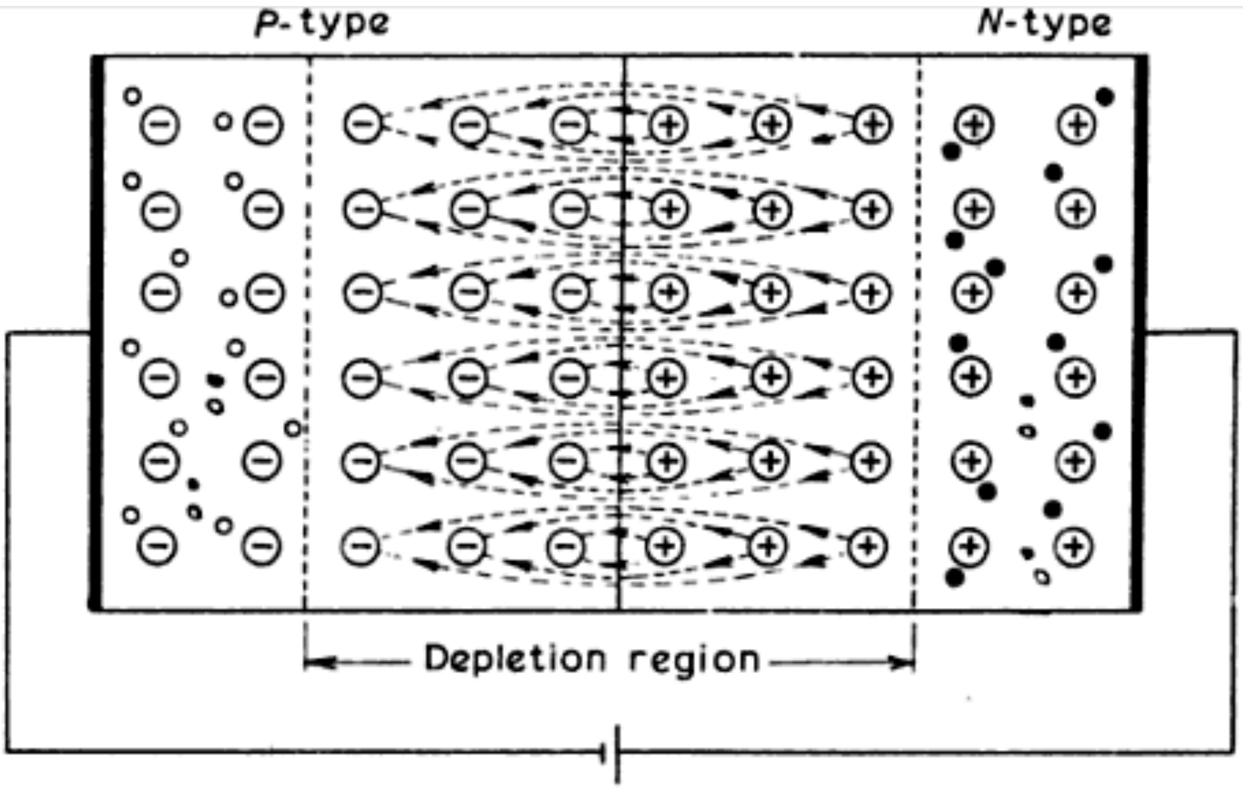
- Current increases abruptly.
- The voltage at which this phenomenon occurs is called as **BREAKDOWN VOLTAGE**.



Breakdown in
PN junction diode

Zener Breakdown
Avalanche
Breakdown

BREAKDOWN



PN-junction showing reverse bias

Zener Breakdown

Q: Explain the breakdown mechanism of zener diode

- When reverse bias is increased, the electric field at the junction also increases.
- The high electric field causes the covalent bonds to break.
- The valence electrons in the atoms are pulled out by the electrostatic force experienced at the junction.
- Thus a large number of carriers are generated.
- This causes a large current to flow.
- This mechanism of breakdown is called as zener breakdown.

Avalanche Breakdown

- Avalanche breakdown occurs when the reverse voltage across the diode is increased to a huge value
- Charge carriers (minority carriers) in the depletion region are accelerated to **gain kinetic energy,** which collides with the carriers of stable atoms.
- The high energy carriers break the covalent bonds.
- The process results in another free electron having velocity.
- The generated free electron in turn gain kinetic energy and collides with another atom to produce more and more electrons free.
- When the number of free electron increases rapidly due to the subsequent collision of free electrons with other atoms, a huge current develops at the junction which results in **damaging of the diode due to over heating.**
- **Avalanche breakdown** occurs at **high voltage** and in a **less doped diode** as compared to Zener breakdown.

Q: Differentiate between Zener Breakdown and Avalanche Breakdown

Zener Breakdown

1. This occurs at junctions which being heavily doped have narrow depletion layers

2. This breakdown voltage sets a very strong electric field across the narrow layer.

3. Here the electric field is very strong to rupture the covalent bonds thereby generating electron hole pairs. So even a small increase in reverse voltage is capable of producing a large number of current carriers. This leads to Zener Breakdown.

Avalanche Breakdown

1. This occurs at junctions which being lightly doped have wide depletion layers.

2. Here the electric field is not strong enough to produce Zener breakdown

3. Here the minority carriers collide with semiconductor atoms in the depletion region which breaks the covalent bond and electron hole pairs are generated. Newly generated carriers are accelerated by the electric field which results in collision and generates avalanche of charge carriers. This results in avalanche breakdown.

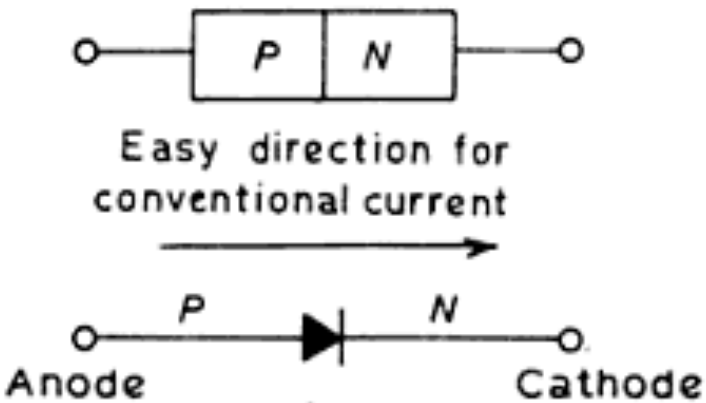
Q: Differentiate between
Zener Breakdown and Avalanche Breakdown (Contd.)

Zener Breakdown	**Avalanche Breakdown**
4. Zener breakdown occurs at low voltages	4. Avalanche breakdown occurs at high voltages.
5. Diodes are specially fabricated with a specially designed breakdown voltage inorder to operate in breakdown region. These Diodes are called as ZENER DIODES	5. Avalanche breakdown is avoided as it leads to permanent damage of the diode due to overheating.

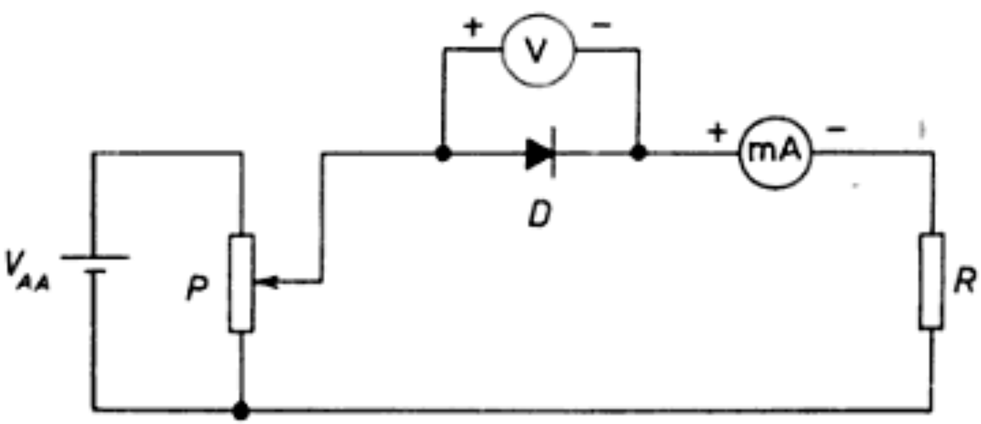
V I Characteristic of PN junction diode

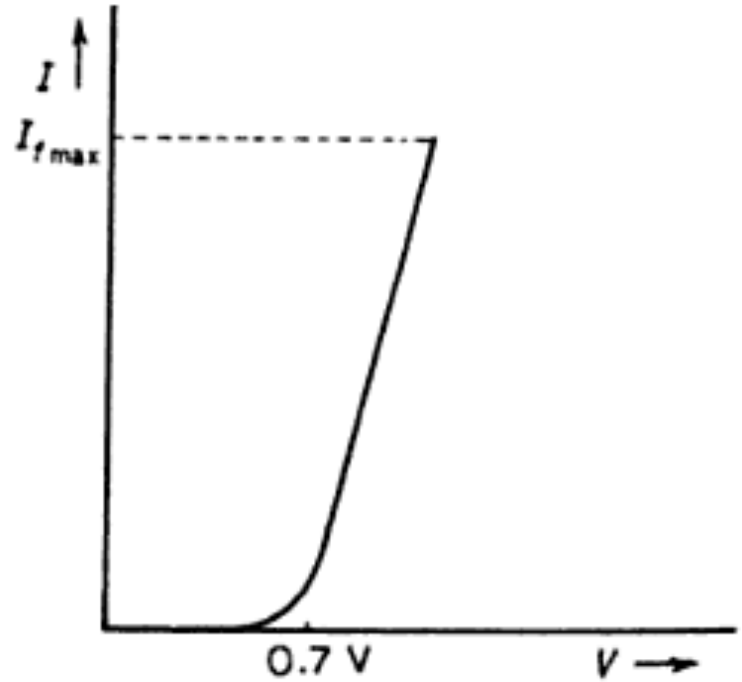
- *Forward Characteristic*
- *Reverse Characteristic*

Forward Characteristic of PN junction. diode



(b)



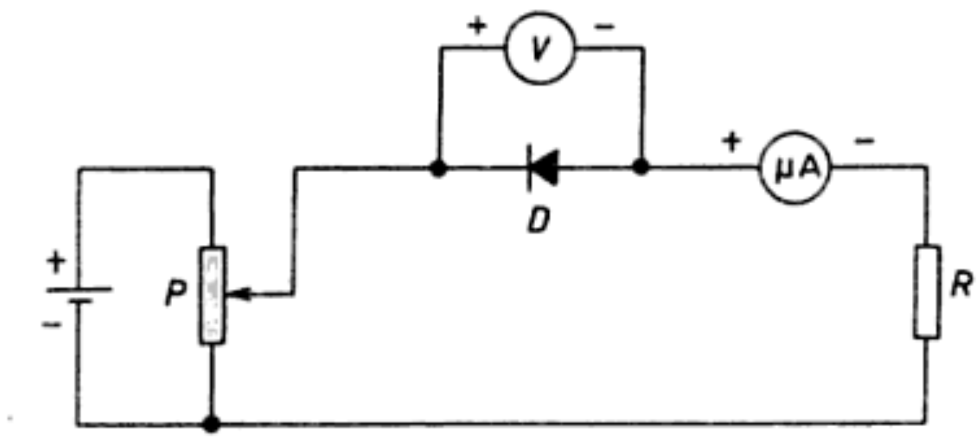


Forward characteristics of a silicon diode

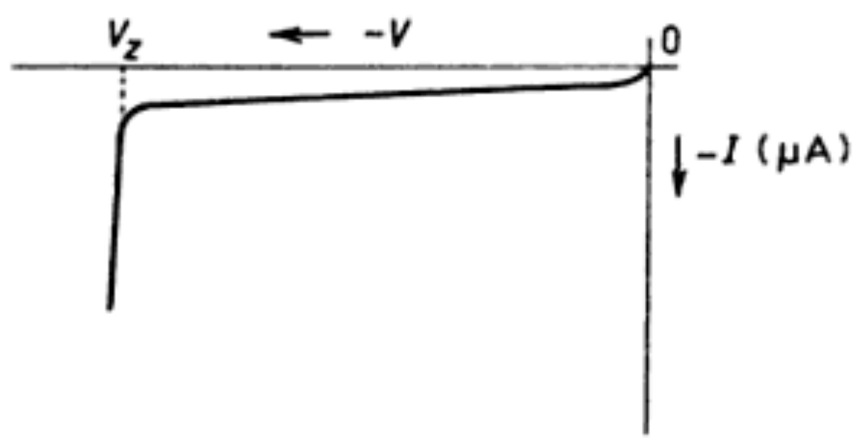
$V_0 = 0.7$ V for Si

$V_0 = 0.3$ V for Ge

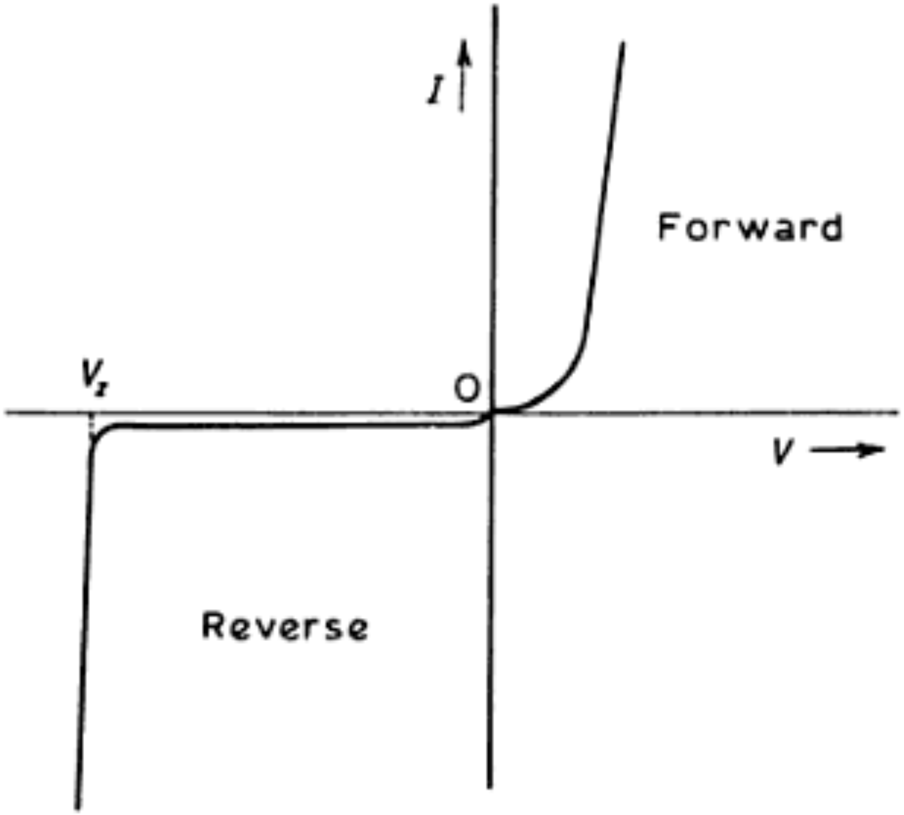
Reverse Bias Characteristic of PN jn. diode



(a)

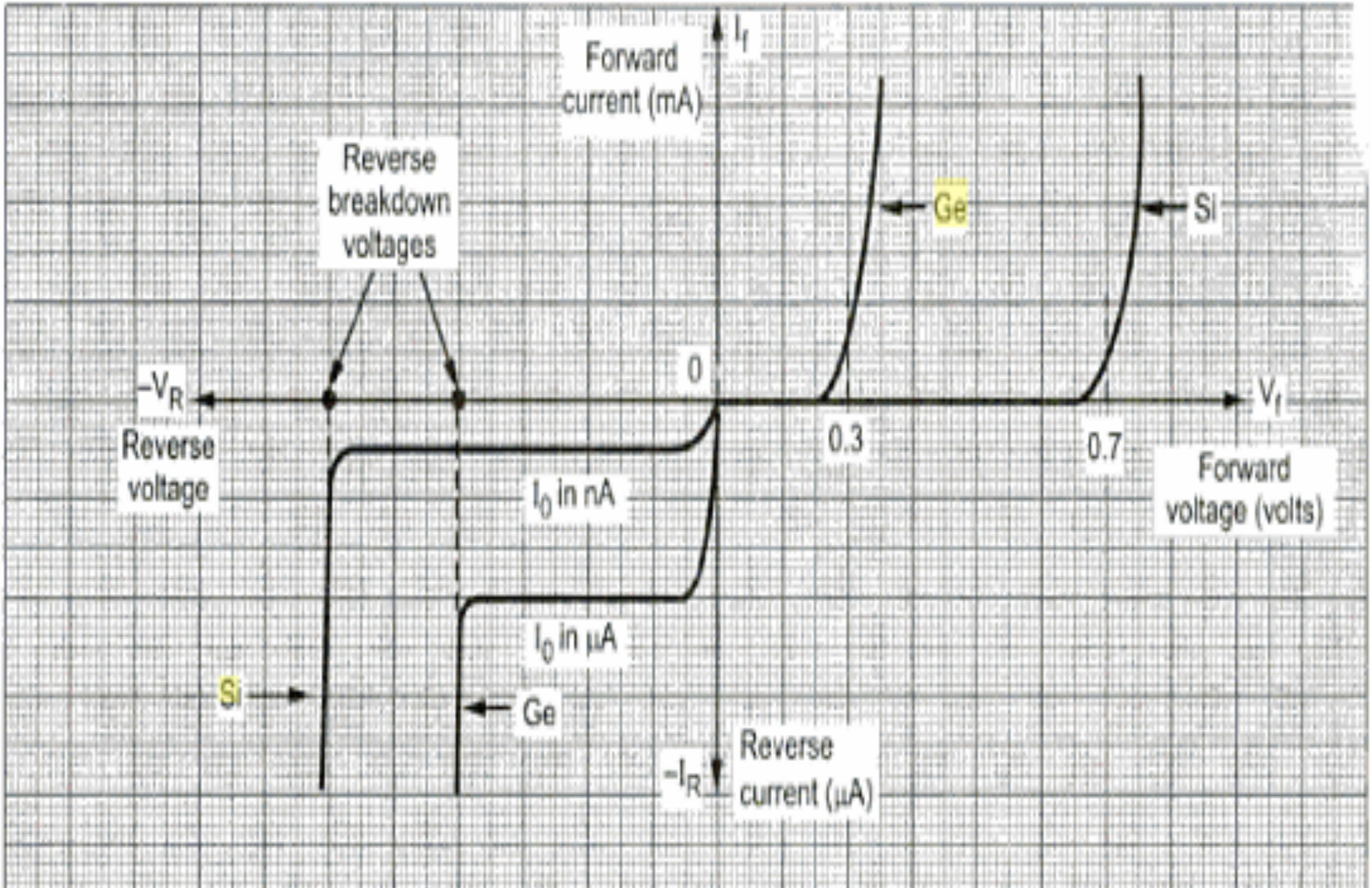


V I Characteristic of PN junction diode



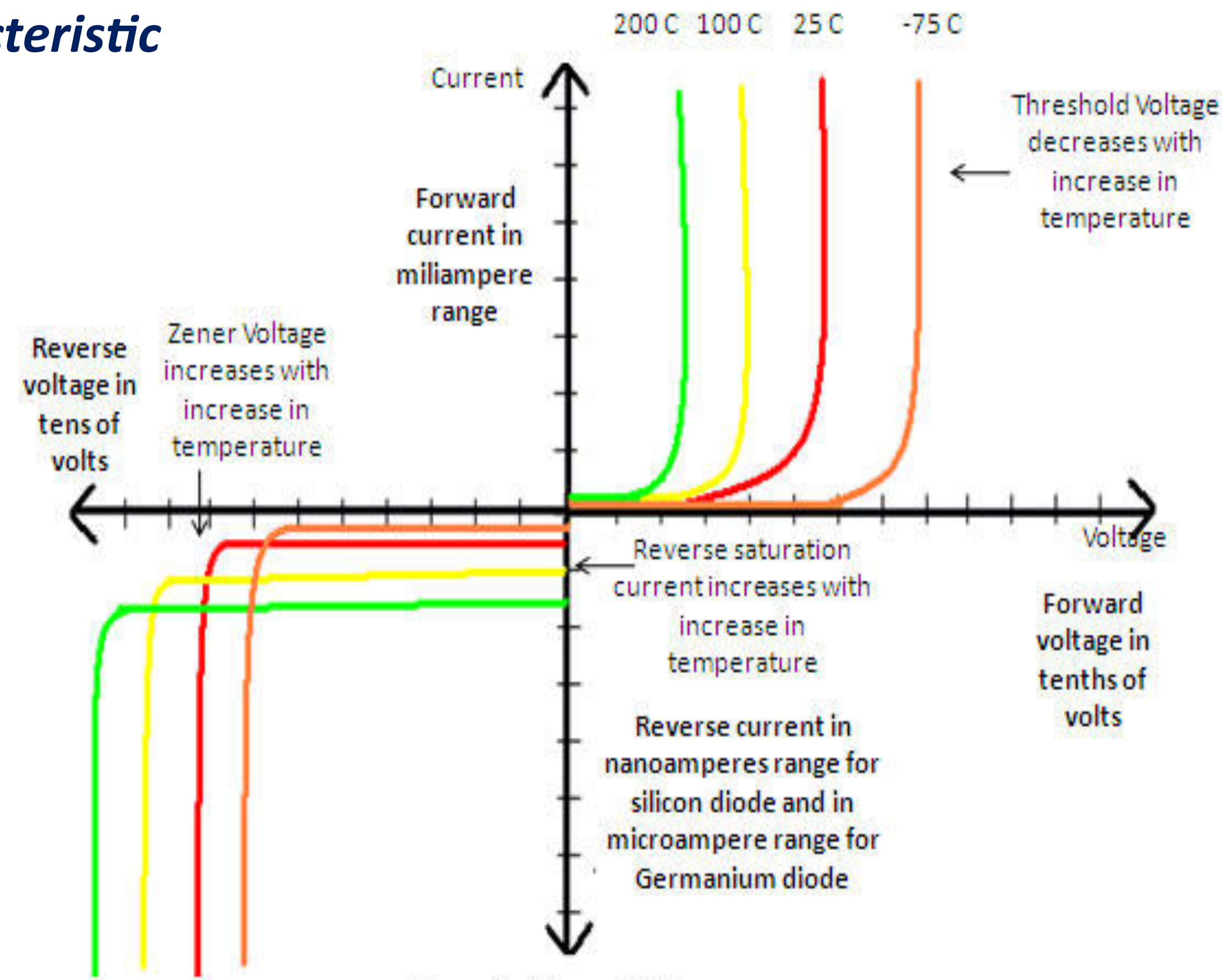
- *Diode conducts well in forward direction*
- *Diode conducts poorly in reverse direction*

V-I characteristics of typical Ge and Si diodes



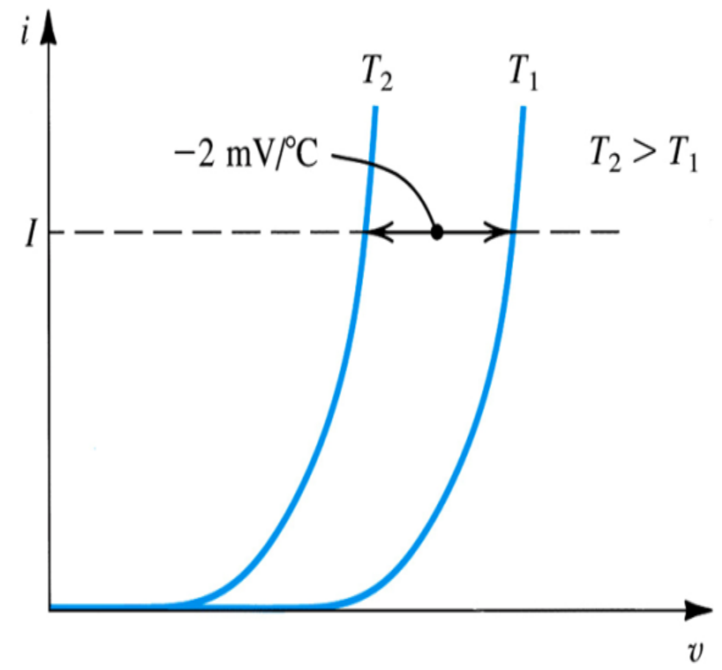
Temperature Dependence

Q: What is the effect of temperature on diode Characteristic



Characteristics of diode

Temperature Dependence



Forward Bias Region

- *The junction forward voltage drop is affected by temperature.*
- *In forward bias region the characteristic of a silicon diode shift to the left at a rate of 2 mV / ^{0} C increase in temperature*

- For **forward bias** Voltage decreases 2mV/ ^{o}C for a given current.
- Current increases with temperature for a given voltage.

Temperature Dependence

Reverse Bias Region

- *The reverse current level approximately doubles with each 10^0 C increase in temperature.*

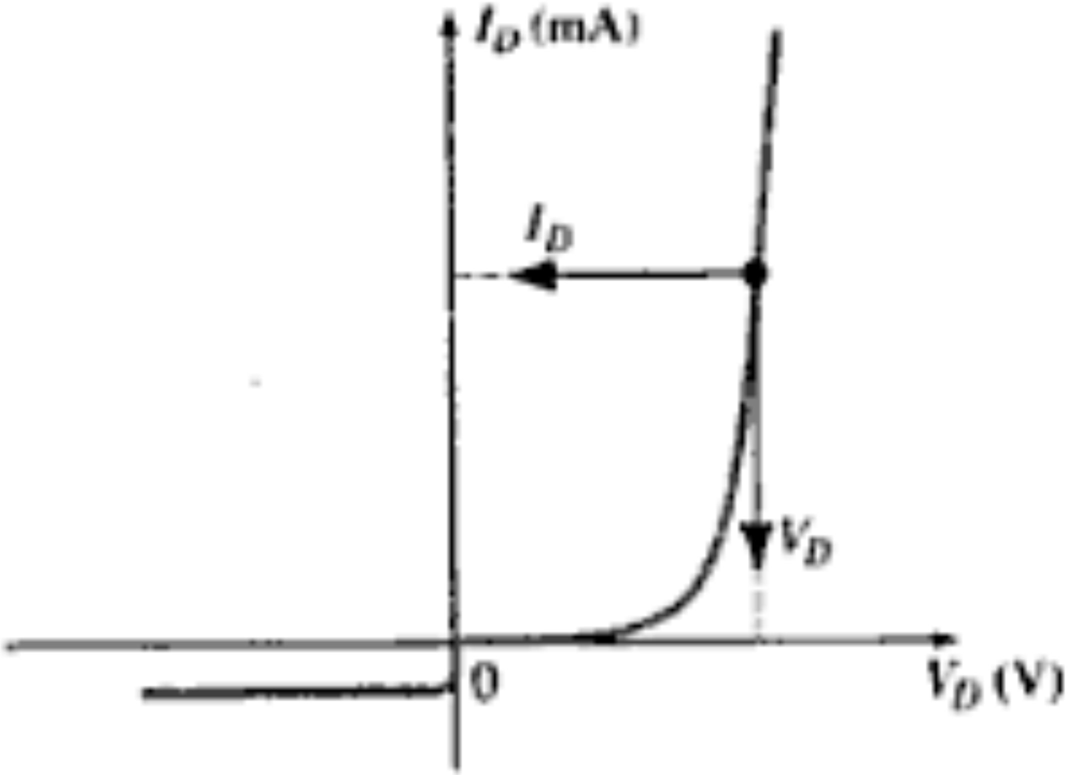
Diode Resistance

DC or Static Resistance

AC or Dynamic Resistance

Q:Explain the
DC and AC resistance of Diode

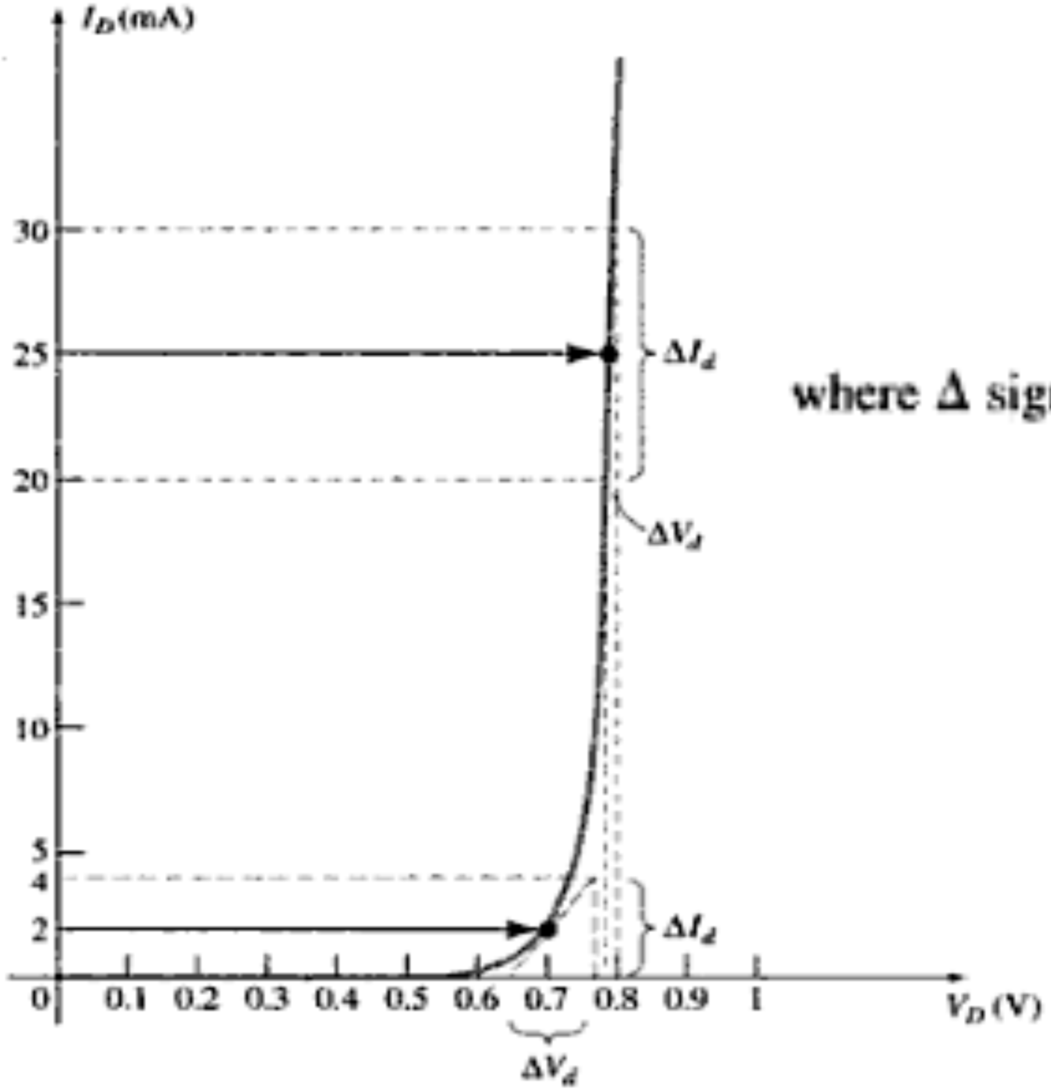
DC or Static Resistance



Determining the dc resistance of a diode at a particular operating point.

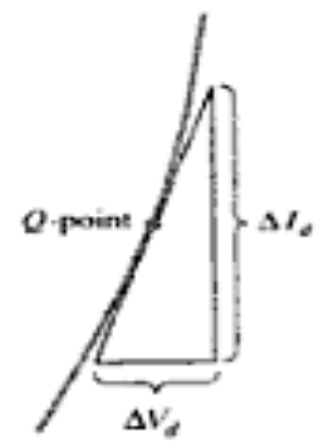
$$\boxed{R_D = \frac{V_D}{I_D}}$$

AC or Dvnamic Resistance



$$\boxed{r_d = \frac{\Delta V_d}{\Delta I_d}}$$

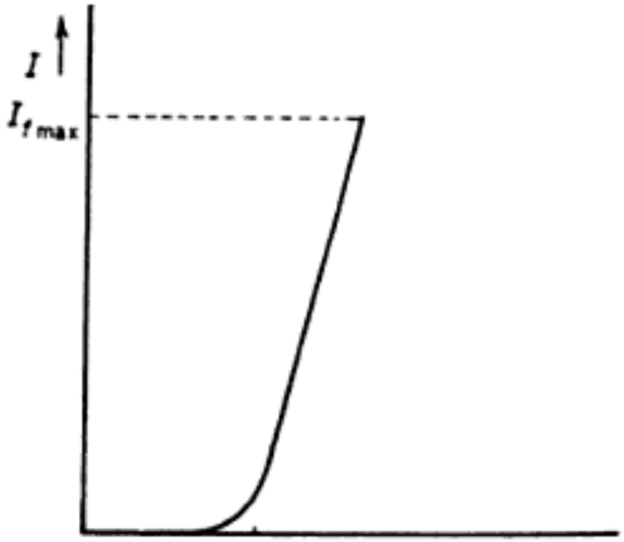
where Δ signifies a finite change in the quantity.



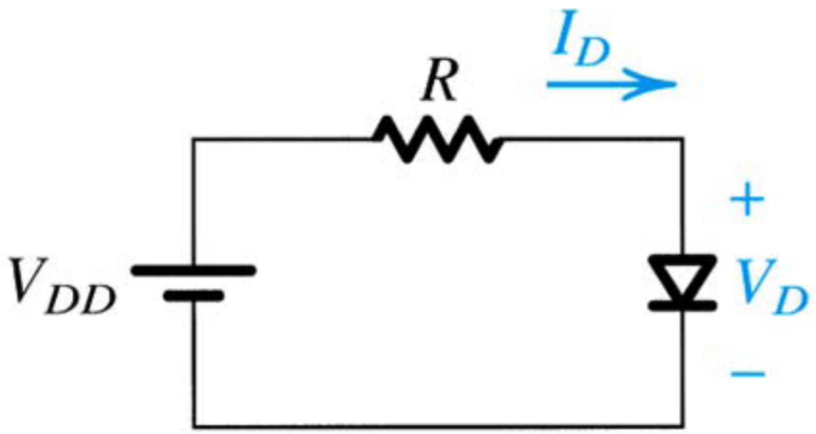
Determining the ac resistance at a Q-point.

Diode Current Equation

Diode Equation



Forward characteristics of a silicon diode



$I_D = (V_{DD} - V_D)/R$
Kirchhoff loop equation

For forward and reverse bias region the current flowing through the diode :

$\boldsymbol{I_D = I_S\,[\exp(V/\eta V_T) - 1\,]}$ ----- *doide I-V characteristics*

Diode Equation

For forward and reverse bias region:

$$I_D = I_S\,[\exp(V/nV_T) - 1]$$ *doide I-V characteristics*

- I_D is the diode current. (Positve for forward and negative for reverse)
- I_s is the constant reverse saturation current.

- V is the applied voltage (Positive for forward and negative for reverse)
- η factor dependent upon the nature of semiconductor. (1 for germanium and 2 for silicon)
- V_T - volt equivalent of temperature which is given by T/11600. (T is Temperature in Kelvin)

- *V_T (thermal voltage) = 26 mV at room temperature (300 K)*

DC Equivalent Circuit for a junction diode

Equivalent Circuit of Diode

Significance of equivalent circuit

Represents the device behavior.

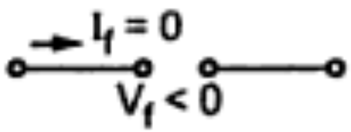
Made up of resistors and voltage cells.

A diode can be replaced by its equivalent circuit when investigating the circuit containing diode.

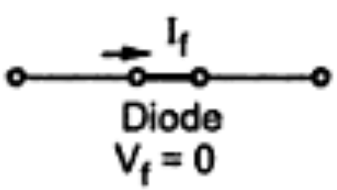
Diode Approximations

- Ideal diode approximation
- Linear Piecewise approximation

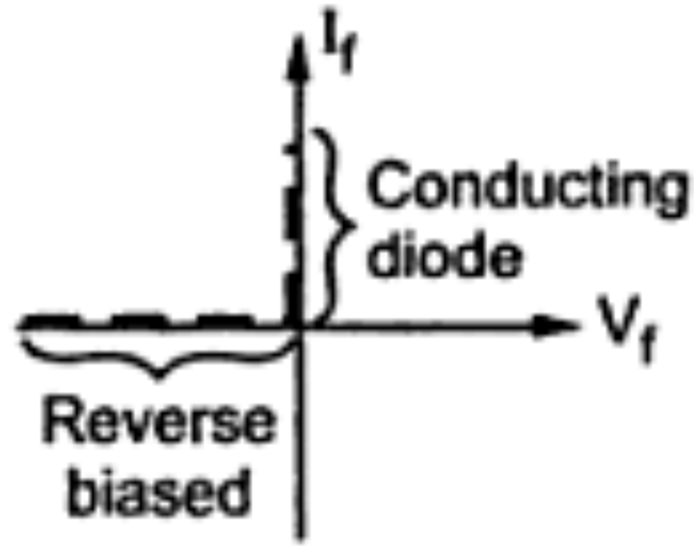
Ideal Diode Approximation



(a) Reverse biased

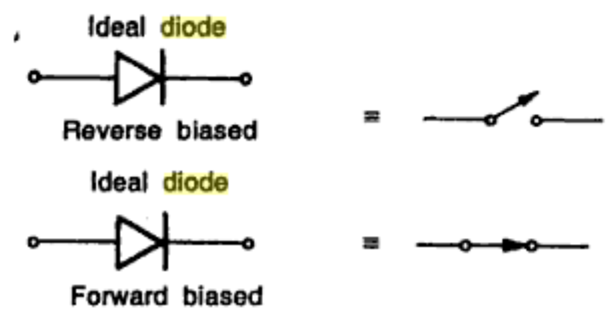


(b) Forward biased



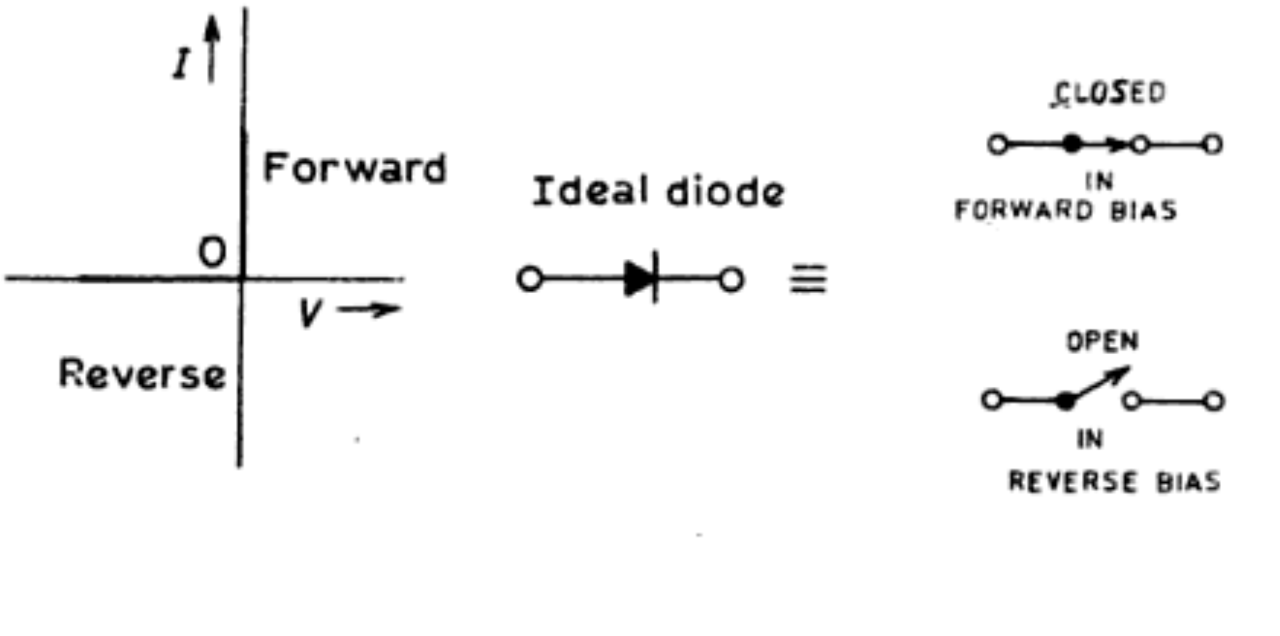
(c) V - I characteristics

Equivalent Circuit



Ideal Diode

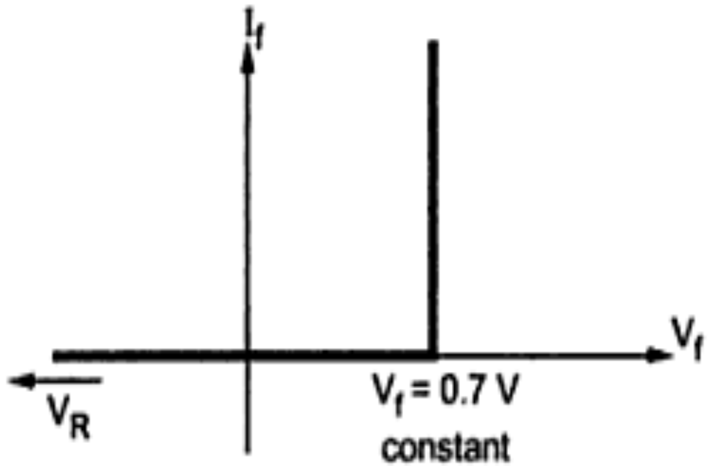
- *Ideal Diode acts as perfect conductor (zero voltage across it) in forward direction*
- *Ideal Diode acts as perfect insulator (no current through it) in reverse direction*



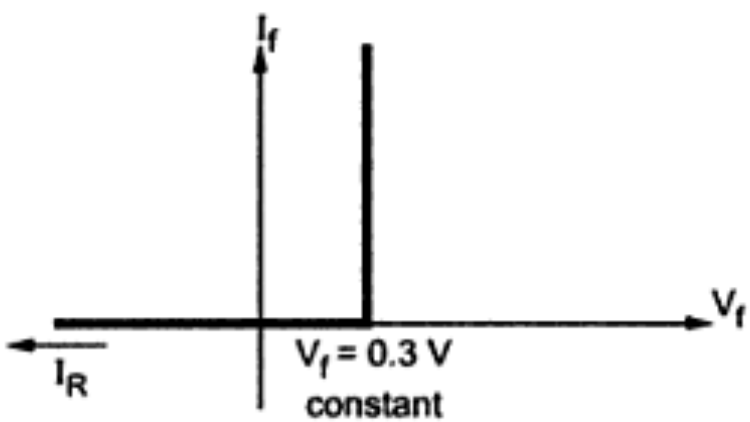
(*a*) Ideal-diode characteristics; (*b*) Switch analogy

- *Ideal Diode acts as automatic switch.*

Approximate Characteristic of Diode

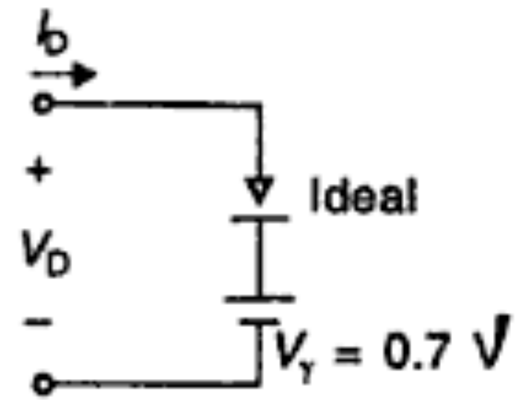


(a) Silicon diode



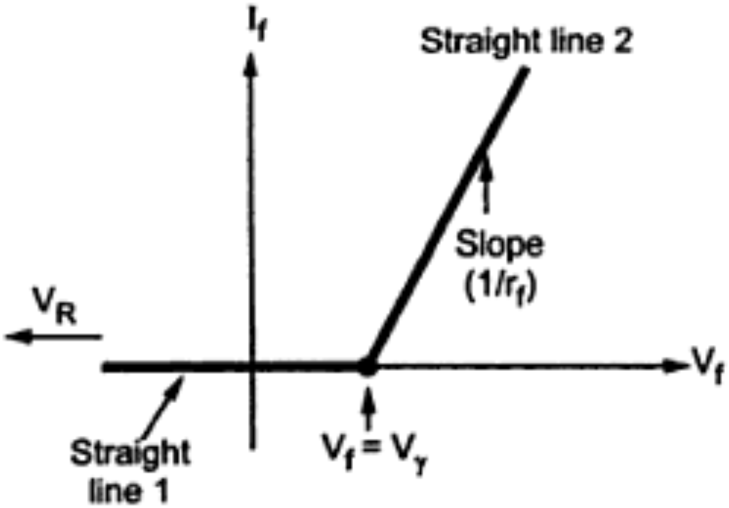
(b) Germanium diode

Equivalent Circuit



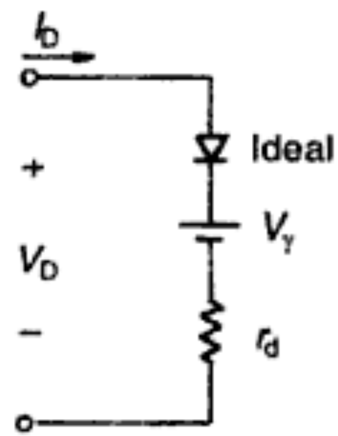
Voltage drop , Vd = Vγ

Piecewise Linear Approximation



Linear piecewise approximation

Equivalent Circuit



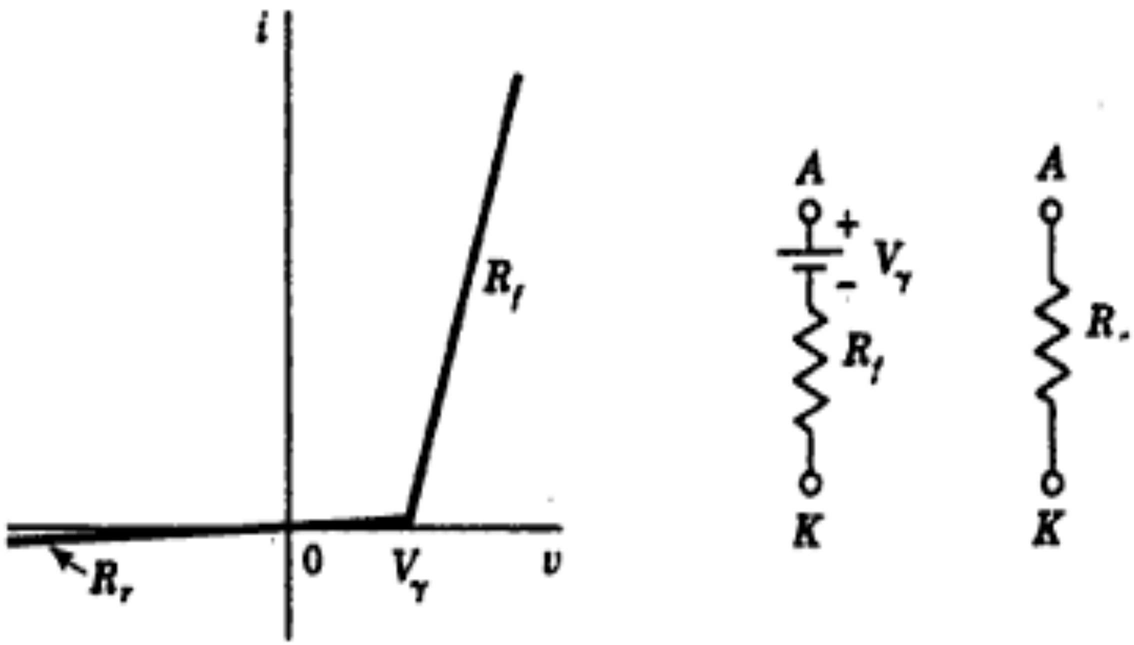
Voltage drop , $Vd = V\gamma + I_d r_d$

Taking into consideration the dynamic forward resistance

r_d is the dynamic resistance in series with the voltage cell.

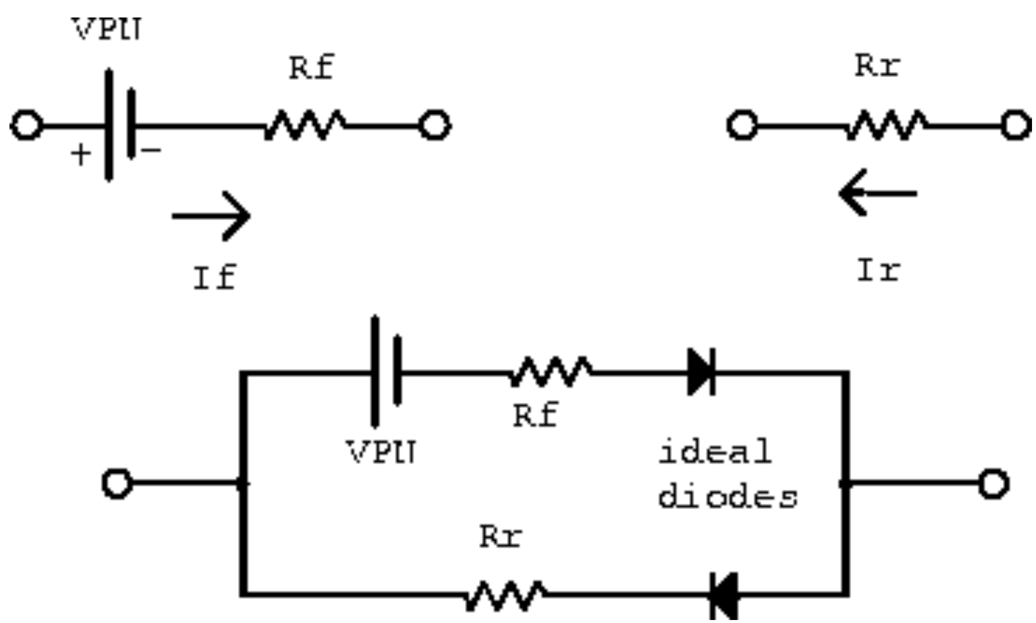
Ideal diode is also included to show that the current flows only in one direction.

Piecewise linear V I Characteristic of PN diode

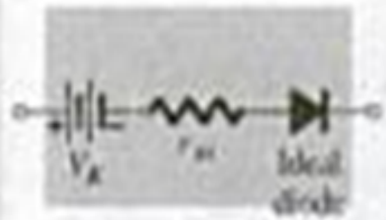
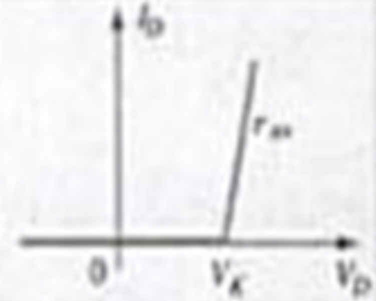
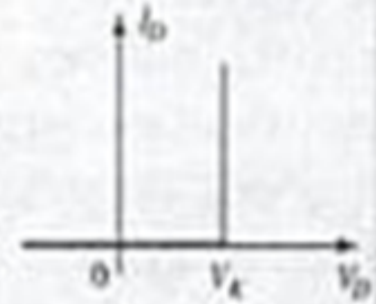
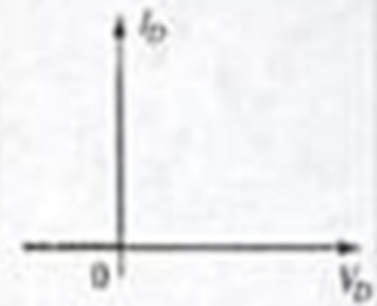


(a) (b) (c)

- If a diode is forward biased with a high voltage it acts like a resistor (R_f) in series with a voltage source (V_f).
- For reverse biasing it acts simply as a resistor (R_r).



Summary Table

Type	Model	Characteristics
Piecewise-linear model		
Simplified model		
Ideal device		

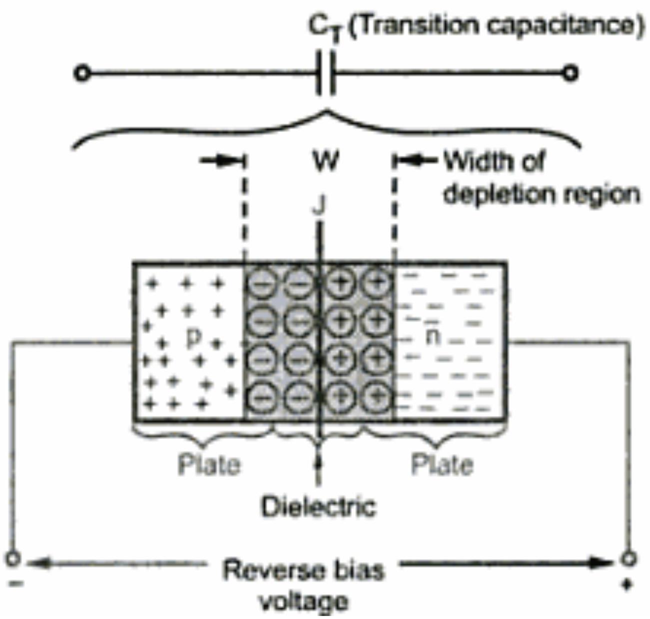
AC Equivalent of Diode

Junction Capacitances

Depending on the biasing condition, two types of capacitive effects exists in the diodes

1) Transition capacitance (C_T) is reverse biased condition.
2) Diffusion capacitance (C_D) is forward biased condition.

Transition Capacitance (C_T or C_{pn})

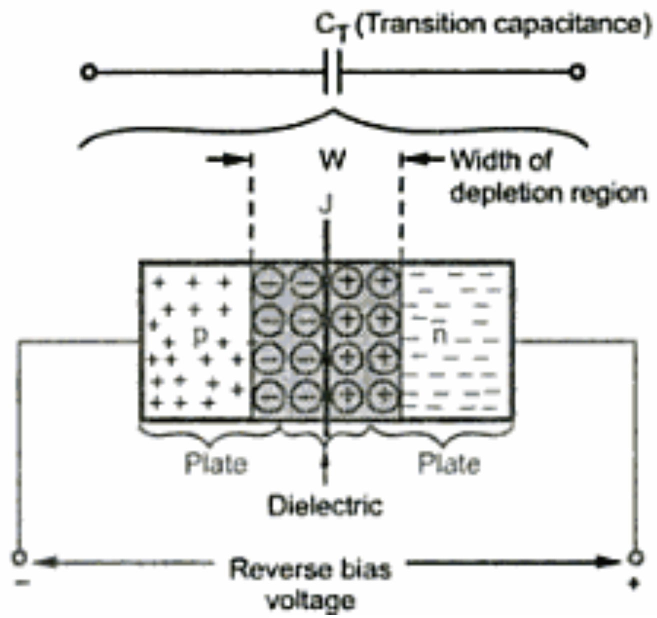


- Diode is Reverse Biased.
- Width of depletion region increases.
- P and N region acts as plates of capacitor.
- Depletion region acts as dielectric.

Thus there exist a capacitance at the pn junction called

Transition capacitance, junction capacitance, space charge capacitance, barrier capacitance, depletion region capacitance.

Transition Capacitance (C_T or C_{pn})



$$\boxed{C_T = \frac{\varepsilon A}{W}}$$

ε = permittivity of semiconductor = $\varepsilon_0 \varepsilon_r$

$$\varepsilon_0 = \frac{1}{36\pi \times 10^9} = 8.849 \times 10^{-12} \text{ F/m}$$

ε_r = relative permittivity of semiconductor = 16 for Ge, 12 for Si

A = area of cross section

W = width of depletion region

Diffusion Capacitance (C_D)

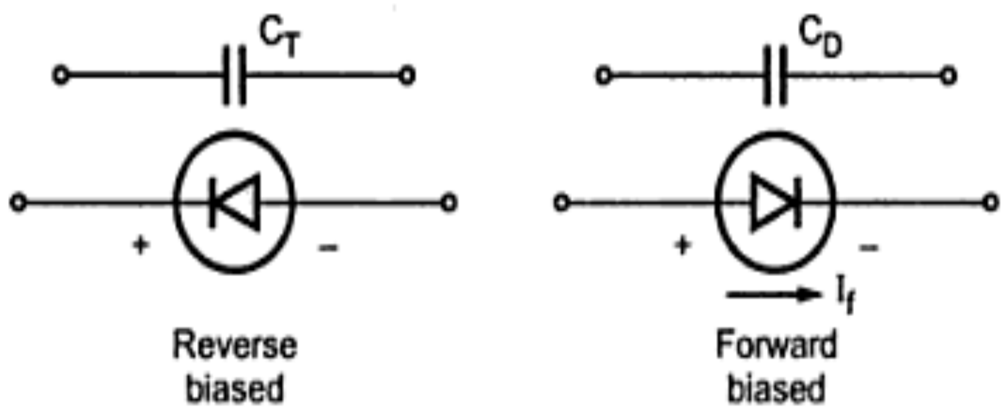
- Diode is Forward Biased.
- Width of depletion region decreases.
- Holes in P diffuse in N side and Electrons in N diffuse to P side.
- As applied voltage increases, concentration of the injected charged particles increases.

This rate of change of injected charge with applied voltage is defined as **DIFFUSION CAPACITANCE**.

$$C_D = \frac{dQ}{dV}$$

Junction Capacitances

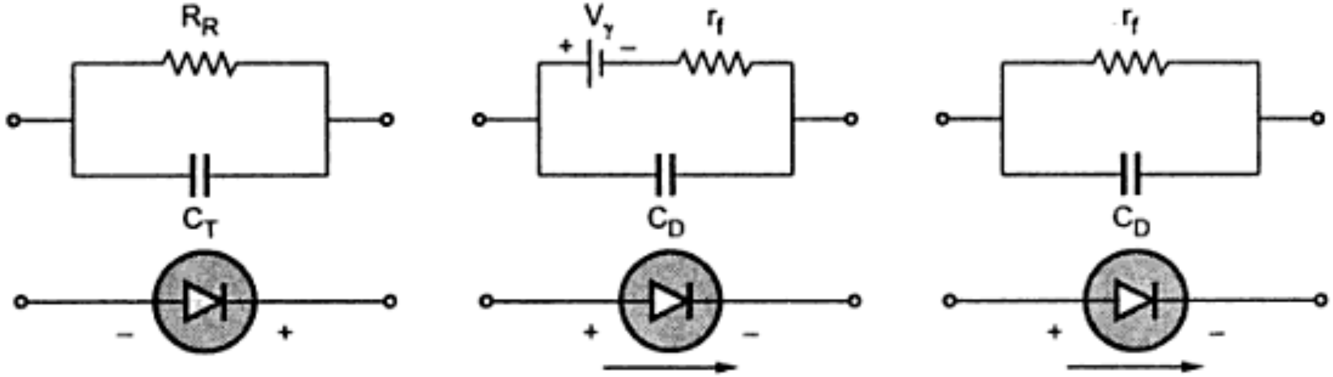
- The capacitance existing in reverse biased is called transition capacitance (C_T) or depletion layer capacitance (C_{pn}).
- The capacitance existing in forward biased is called diffusion capacitance (C_D).



Junction capacitances

C_D is much larger than C_T.

AC Equivalent Circuits

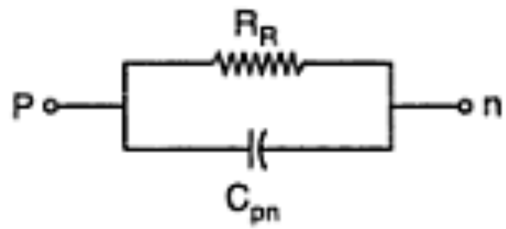


(a) A.C. equivalent circuit of reverse biased. **(b) Complete equivalent circuit of forward biased.** **(c) A.C. equivalent circuit of forward biased.**

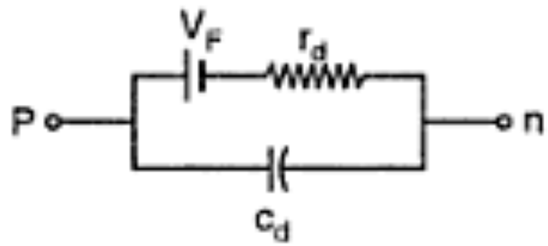
- In Reverse Biased
  - Very high resistance R_r in parallel with Transition Capacitance C_T .
- In forward Biased
  - Battery of V_γ and series dynamic resistance ri are in parallel with diffusion capacitance $C_{D.}$ (Completer Equivalent Circuit)
- In AC equivalent the dc voltage drop V_γ is not included.

An equivalent circuit

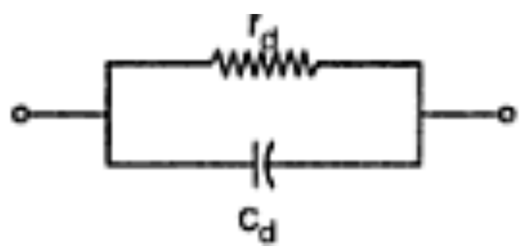
(a) Equivalent circuit for reverse- biased diode



(b) Equivalent circuit for forward-biased diode



(c) AC equivalent circuit for forward-biased diode



Why are Silicon semiconductor material preferred

Silicon diodes have a

greater ease of processing

lower cost

greater power handling

less leakage

more stable temperature characterics

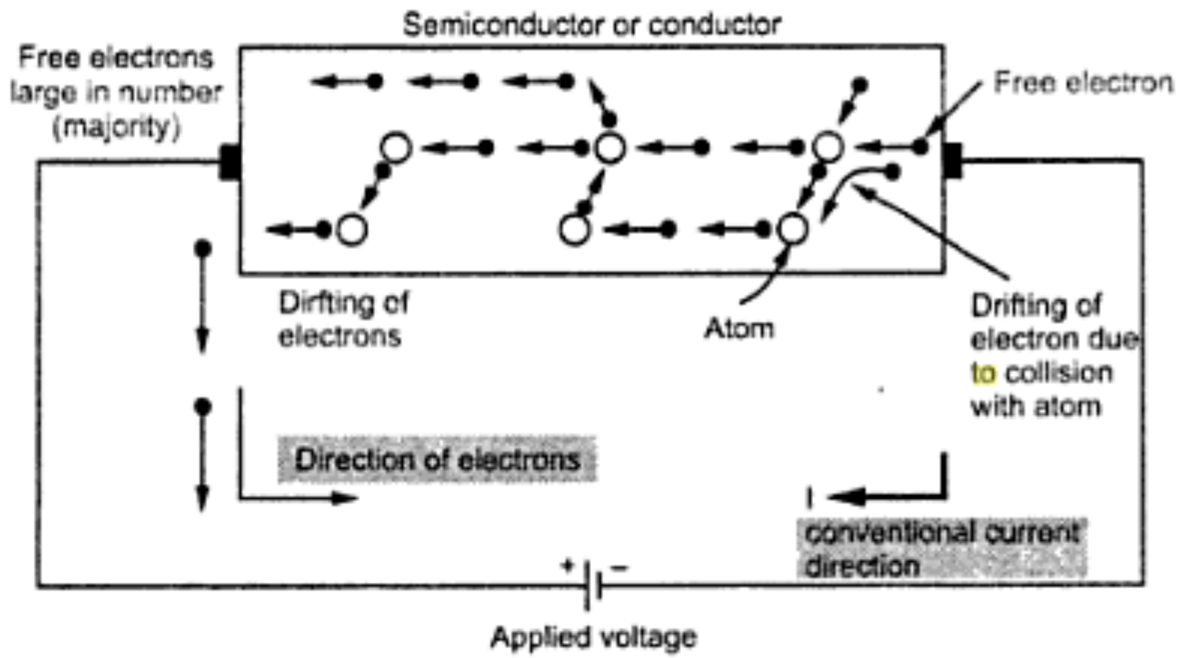
Q: Explain Drift and Diffusion Current

→ The flow of charge (i.e.) current through a semiconductor material are of two types namely drift & diffusion.

→ (i.e.) The net current that flows through a (PN junction diode) semiconductor material has two components

- Drift current
- Diffusion current

Drift Current



Drift mechanism causing drift current

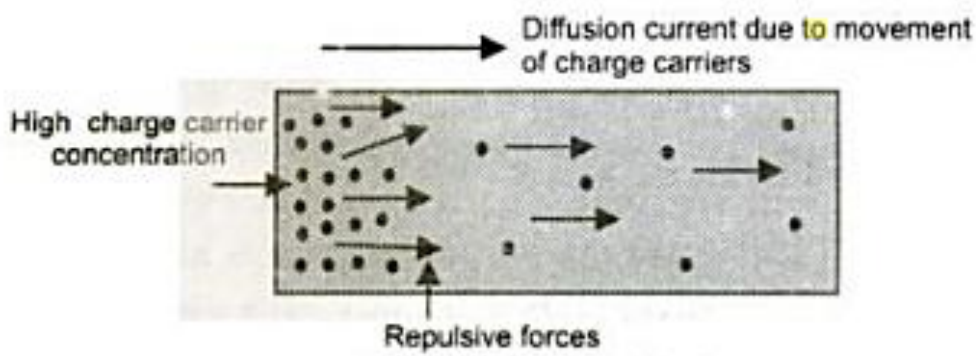
Drift Current

→ When an electric field is applied across the semiconductor material, the charge carriers attain a certain drift velocity V_d , which is equal to the product of the mobility of the charge carriers and the applied Electric Field intensity E.

→ Holes move towards the negative terminal of the battery and electrons move towards the positive terminal of the battery. This combined effect of movement of the charge carriers constitutes a current known as “ the drift current “ .

→ Thus the drift current is defined as the flow of electric current due to the motion of the charge carriers under the influence of an external electric field

Diffusion current



(b) Process of diffusion

Diffusion current

Diffusion Current

→ It is possible for an electric current to flow in a semiconductor even in the **absence of the applied voltage provided a concentration gradient exists in the material**.

→ A concentration gradient exists if the number of either electrons or holes is greater in one region of a semiconductor as compared to the rest of the Region.

→ In a semiconductor material the change carriers have the tendency to move from the region of higher concentration to that of lower concentration of the same type of charge carriers. Thus the movement of charge carriers takes place resulting in a current called diffusion current.

Differentiate between Drift current and Diffusion current

Drift Current

- Drift current is due to potential gradient
- Drift current is the response of electrons and holes to the electric field. This occurs until the carriers available. Holes moves in the direction of electric field while electrons moves in the opposite direction of field.
- Drift current is depends on electric field. Only appears when we apply voltage.

Diffusion Current

- Diffusion current is due to concentration gradient.
- Diffusion current is holes and electrons moving from areas of high concentration to the area of lower concentration. This occurs until they are uniformly distributed.
- Diffusion current can be there even if we don't apply voltage

Diode Parameters

- V_F – Forward voltage drop
- I_F – Reverse Saturation current
- V_{BR} – Reverse breakdown voltage
- r_d – dynamic resistance
- $I_{F(max)}$ - maximum forward current

No.	Symbol	Specifications
1.	V_f	The forward voltage mentioned at specific current and temperature.
2.	I_f	The maximum forward current mentioned at specific temperature.
3.	I_R	The maximum reverse saturation current mentioned at specific temperature.
4.	PIV/PRV or V_{BR}	It is maximum reverse voltage rating at specific temperature. It is also called **Peak Inverse Voltage, Peak Reverse Voltage** or **Reverse Breakdown Voltage.**
5.	$P_{D\,max}$	The maximum power dissipation capacity at specific temperature
6.	C_D, C_T	The capacitance levels of diffusion and transition capacitances.
7.	t_{rr}	Reverse recovery time.
8.	T_J, T_{stg}	Operating junction temperature and storage temperature ranges.

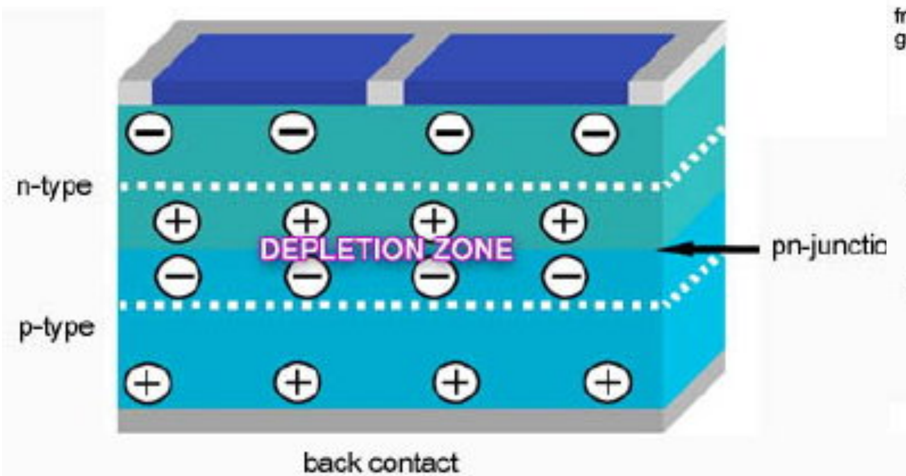
Diode Types

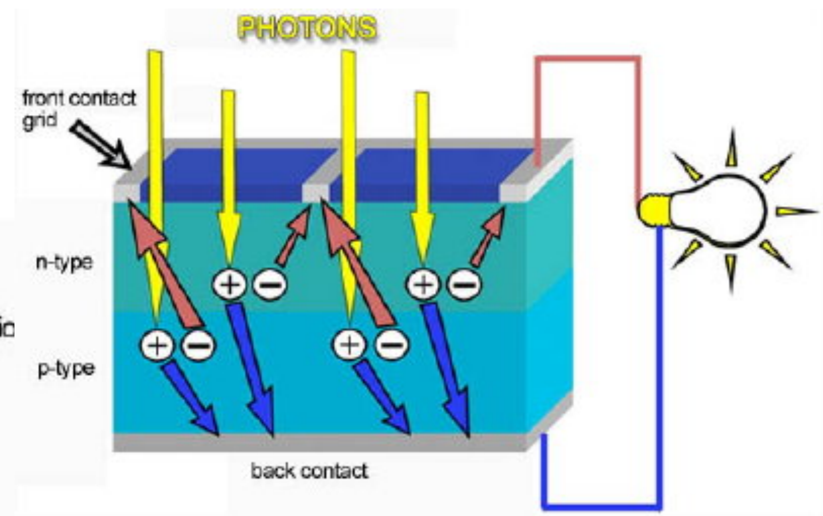
- Solar Cell
- Photo Diode
- Light Emitting Diode
- Schottky Barrier Diode
- Zener Diode

Solar Cell

Q: Explain the working of solar cell with application?

Solar cell: **Solar cell is a photovoltaic device that converts the light energy into electrical energy based on the principles of photovoltaic effect**

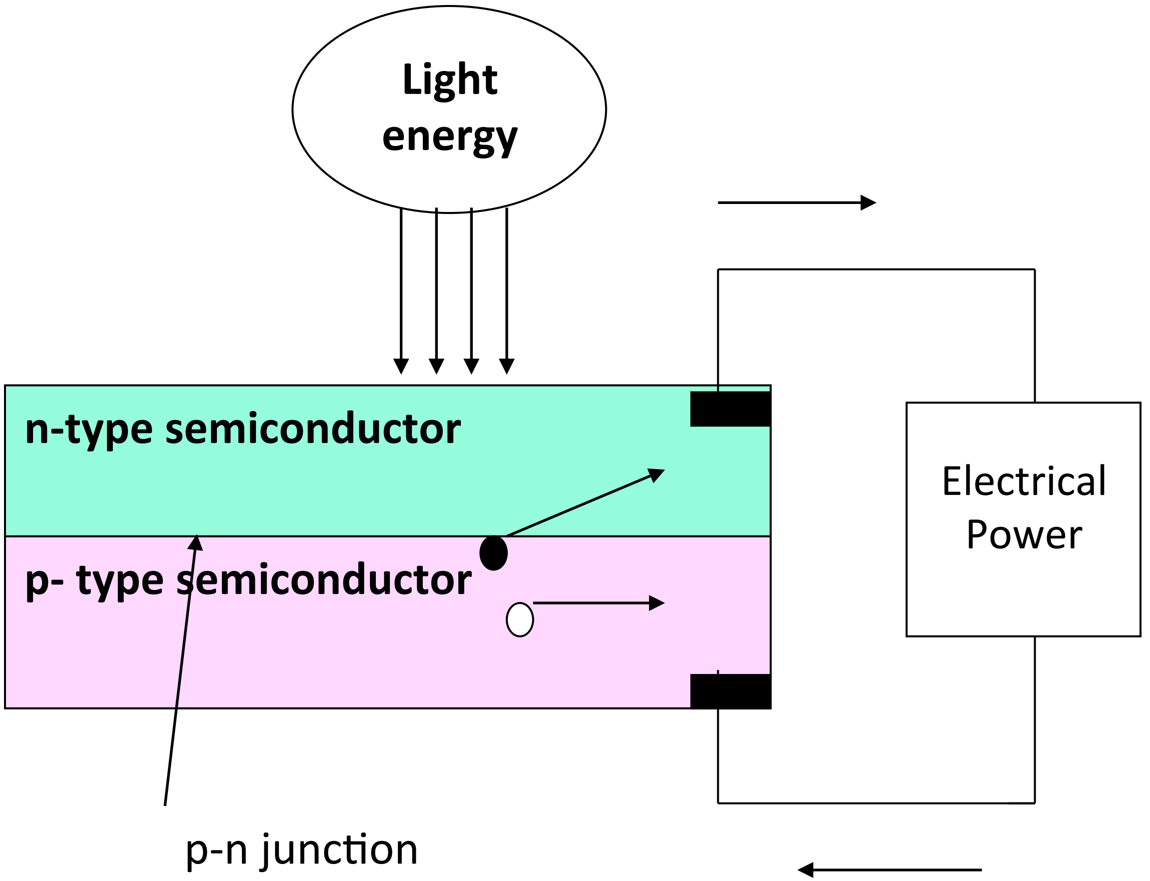




Photovoltaic effect

Definition:

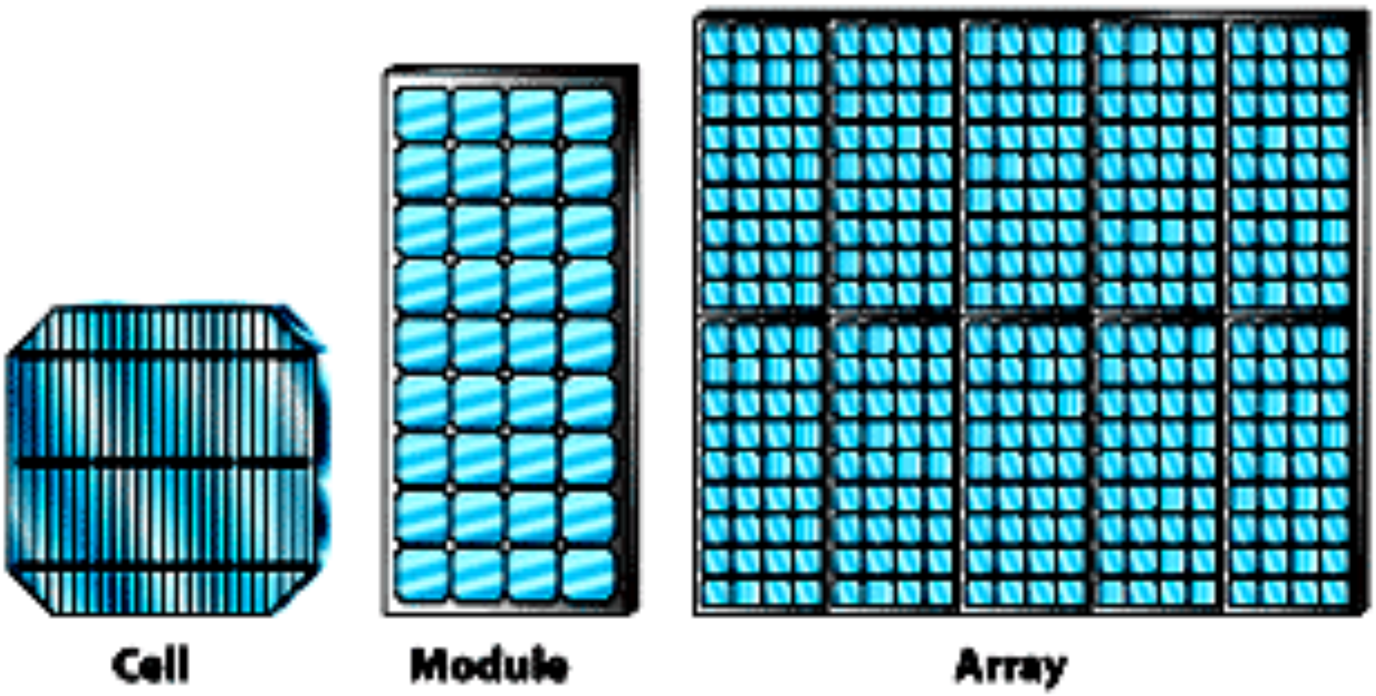
The generation of voltage across the PN junction in a semiconductor due to the absorption of light radiation is called photovoltaic effect. The Devices based on this effect is called photovoltaic device.



Solar panel (or) solar array (or) Solar module

The solar panel (or) solar array is the interconnection of number of solar module to get efficient power.

- A solar module consists of number of interconnected solar cells.
- These interconnected cells embedded between two glass plate to protect from the bad whether.
- Since absorption area of module is high, more energy can be produced.


Cell
Module
Array

Materials for Solar Cell

Solar cells are composed of various **semiconducting** materials

1. Crystalline silicon
2. Cadmium telluride
3. Copper indium diselenide
4. Gallium arsenide
5. Indium phosphide
6. Zinc sulphide

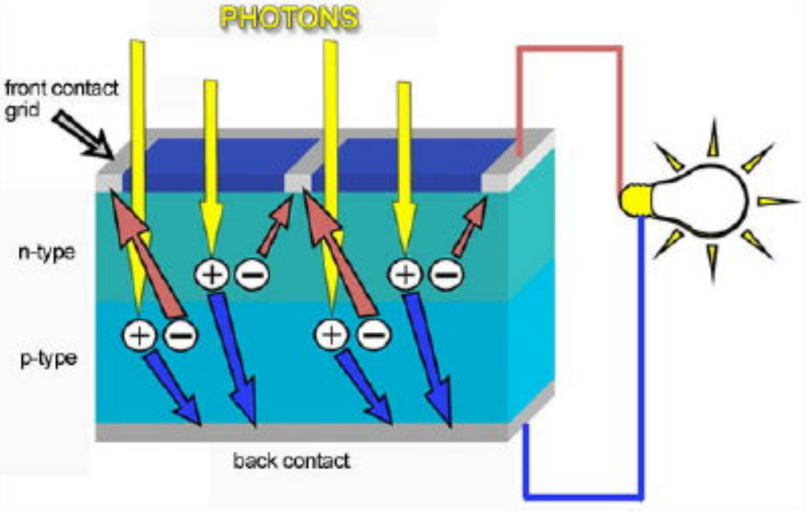
Note: Semiconductors are materials, which become electrically conductive when supplied with light or heat, but which operate as insulators at low temperatures

Construction of Solar Cell

- Solar cell (crystalline Silicon) consists of a *n-type semiconductor (emitter)* layer and *p-type semiconductor layer (base).* The two layers are sandwiched and hence there is formation of p-n *junction.*
- The surface is coated with *anti-refection coating* to avoid the loss of incident light energy due to reflection.
- A proper *metal contacts* are made on the n-type and p-type side of the semiconductor for electrical connection

Working of solar cell

- When a solar *panel exposed to sunlight* , the light energies are absorbed by a semiconductor materials.
- Due to this absorbed energy, the electrons are liberated and produce the external DC current.
- The DC current is converted into 240-volt AC current using an inverter for different applications.



Working of solar cell

- It is a pn junction device with no voltage directly applied across the junction.

- When light hits the space charge region, electrons and holes are generated.

- They are then quickly seperated and swept out of the space charge region by the electric field, thus creating *PHOTON CURRENT*.

Application

Soar pumps are used for water supply.

Domestic power supply for appliances include refrigeration, washing machine, television and lighting

Ocean navigation aids: Number of lighthouses and most buoys are powered by solar cells

Telecommunication systems: radio transceivers on mountain tops, or telephone boxes in the country can often be solar powered

Electric power generation in space: To providing electrical power to satellites in an orbit around the Earth

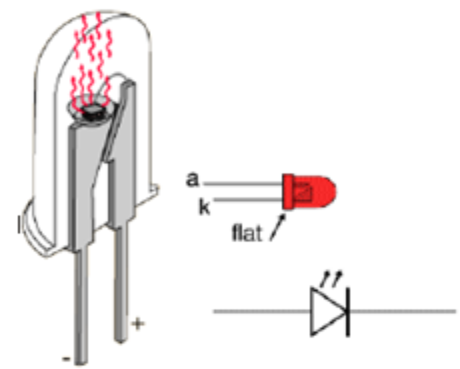
LED

Q: Draw and Explain LED along with one area of application

- Light Emitting Diode

  - A light emitting diode (LED) is essentially a PN junction opto semiconductor that emits monochromatic (single color) light when operated in a **forward biased** direction.

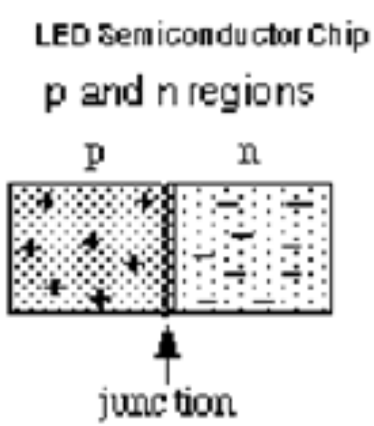
  - A LED converts electrical energy into light energy

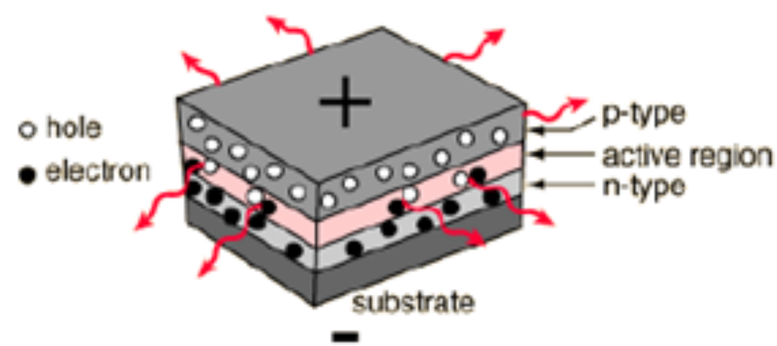


LED

Q: Draw and Explain LED along with one area of application

- A LED chip has two regions separated by a junction.
- The junction acts as a barrier to the flow of electrons between the p and the n regions.
- With sufficient voltage is applied to the chip across the leads of the LED, electrons can move easily in only one direction across the p and n regions.
- When a voltage is applied and the current starts to flow, electrons in the n region have sufficient energy to move across the junction into the p region.



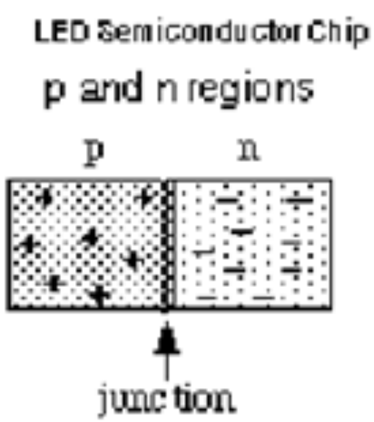


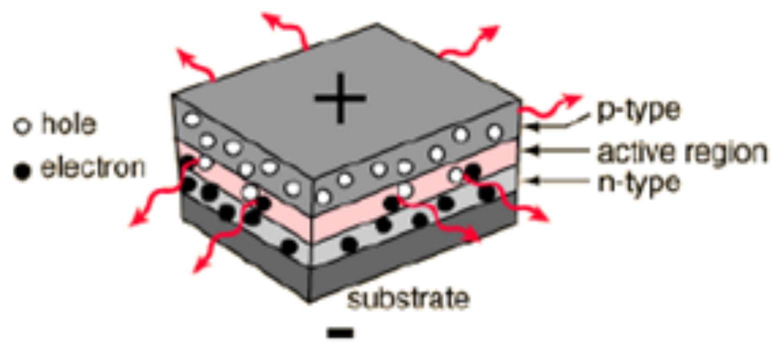
LED

Q: Draw and Explain LED along with one area of application

• Each time an electron recombines with a positive charge, electric potential energy is converted into electromagnetic energy.

• For each recombination of a negative and a positive charge, a quantum of electromagnetic energy is emitted in the form of photon of light with a frequency characteristic of the semiconductor material.





How much energy does an LED emit?

- The energy (*E*) of the light emitted by an LED is related to the electric charge (*q*) of an electron and the voltage (*V*) required to light the LED by the expression $E=qV$ Joules.

- The expression says that the voltage is proportional to the electric energy.

- The constant *q* is the electric charge of a single electron, -1.6×10^{-19} *Coulomb*.

Finding energy from voltage

- Let us say that you have a red LED, and the voltage measured between the leads is 1.71 Volts. So the energy required to light the LED is :

$$E=qV \text{ Joules}$$

$$E= - 1.6 \times 10^{-19} \ (1.71) = 2.74 \times 10^{-19} \text{ Joules}$$

Applications

- Sensor Applications
  - Medical Instrumentation, Bar Code readers ,Optical Switches ,Fiber Optic Communication, Etc.
- Mobile Applications
  - Mobile Phone , PDA's , Digital Cameras, Laptops, etc.
- Sign Applications
  - Monocromatic Message Boards, Trafific , Transportation- Passenger Information
- LED signals
  - Traffic, Rail, Aviation, Tower Light , Runway Lights ,

    Emergency/Police Vehicle Lighting , etc.
- Indicators
  - Household Appliances , DVD/VCR/Stereo and other audio and video devices ,

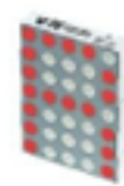
    Toys/Games , Instrumentation , Security Equipments , Switches
- Illuminations

Some types of LEDs

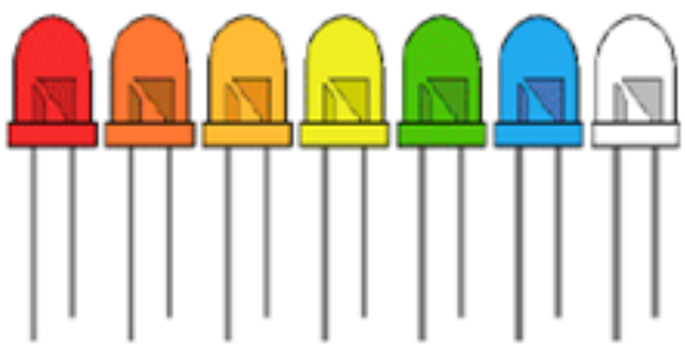
Bargraph

7-segment

Starburst

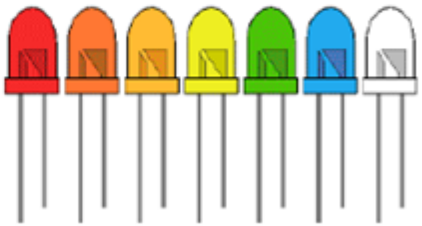


Dot matrix



LED

Q: List the materials used for different colors of LED.



- LEDs are available in red, orange, yellow, green, blue and white.

- LEDs are made from gallium-based crystals that contain one or more additional materials such as phosphorous, Arsenide, Phosphide to produce a distinct color.

LED

Q: List the materials used for different colors of LED.

- The color of an LED is a function of the material used to make the junction. There are two main flavors used in visible light LED junctions:

- Indium gallium nitride (InGaN) is used to make up the blue, white, true green, and UV types.

- Aluminum gallium indium phosphide (AlGaInP or AlInGaP) is used to make the red, yellow, and orange types.

Problem:

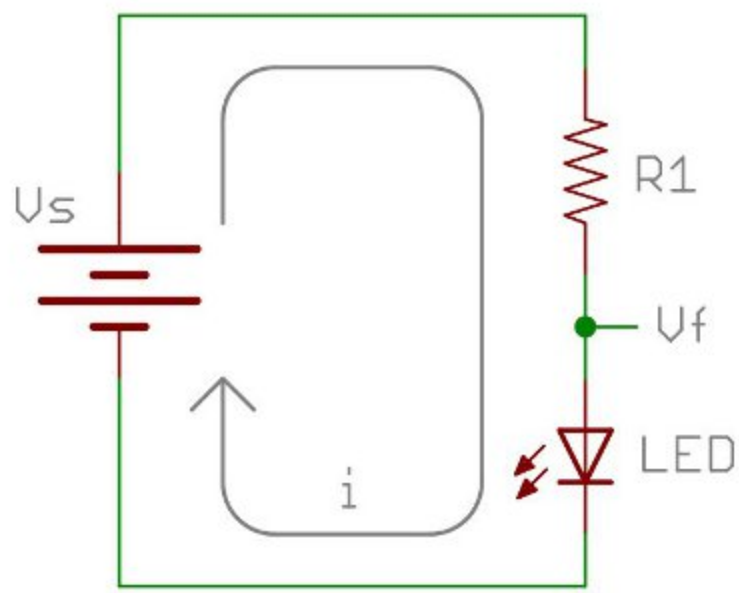
What value of Series Resistor is required to limit the current through the LED to 20mA with a forward voltage drop of 1.6V when connected to a 10 V supply?

Vf = 1.6V

Vs = 10V

i = 20mA

$$R = \frac{Vs - Vf}{i}$$



Problem:

What current limiting resistor value should you use if you have one LED and want to power it with a supply of 3.8V (Vf = 3.1V, if = 30mA)

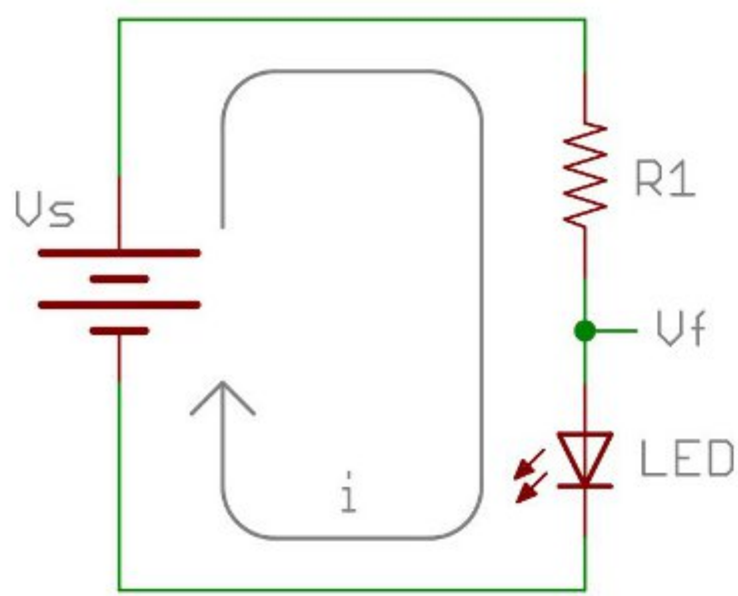
Vf = 3.1V

Vs = 3.8V

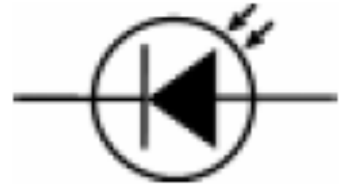
i = 30mA

$$R = \frac{Vs - Vf}{i}$$

R = 23.3 ohms



Photodiodes



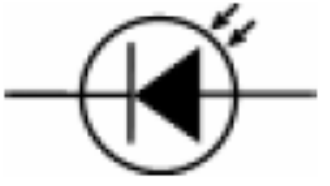
- Photodiode (pn junction) operated in reverse bias.
- In a reverse biased p-n junction a Reverse Saturation Current flows due to minority carriers which are thermally generated.
- Increasing the reverse bias does not increases the reverse current significantly.
- TEMPERATURE and ILLUMINATION increases number of minority carriers (reverse) current.

• The photons impacting the junction cause covalent bonds to break.

• The electric field in the depletion layer sweeps Minority electrons in p side to n side and minority holes in n side to the p-side.

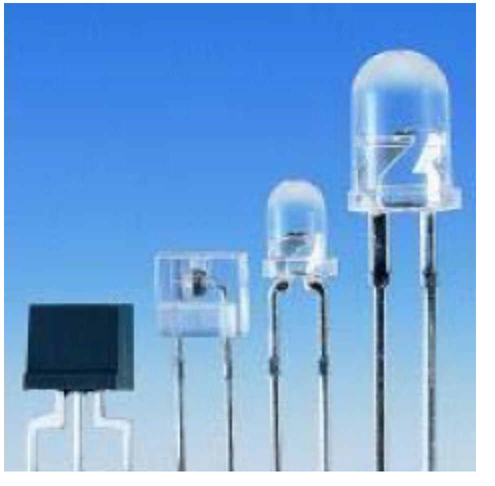
• Reverse current across junction- photocurrent is proportional to the intensity of the incident light.

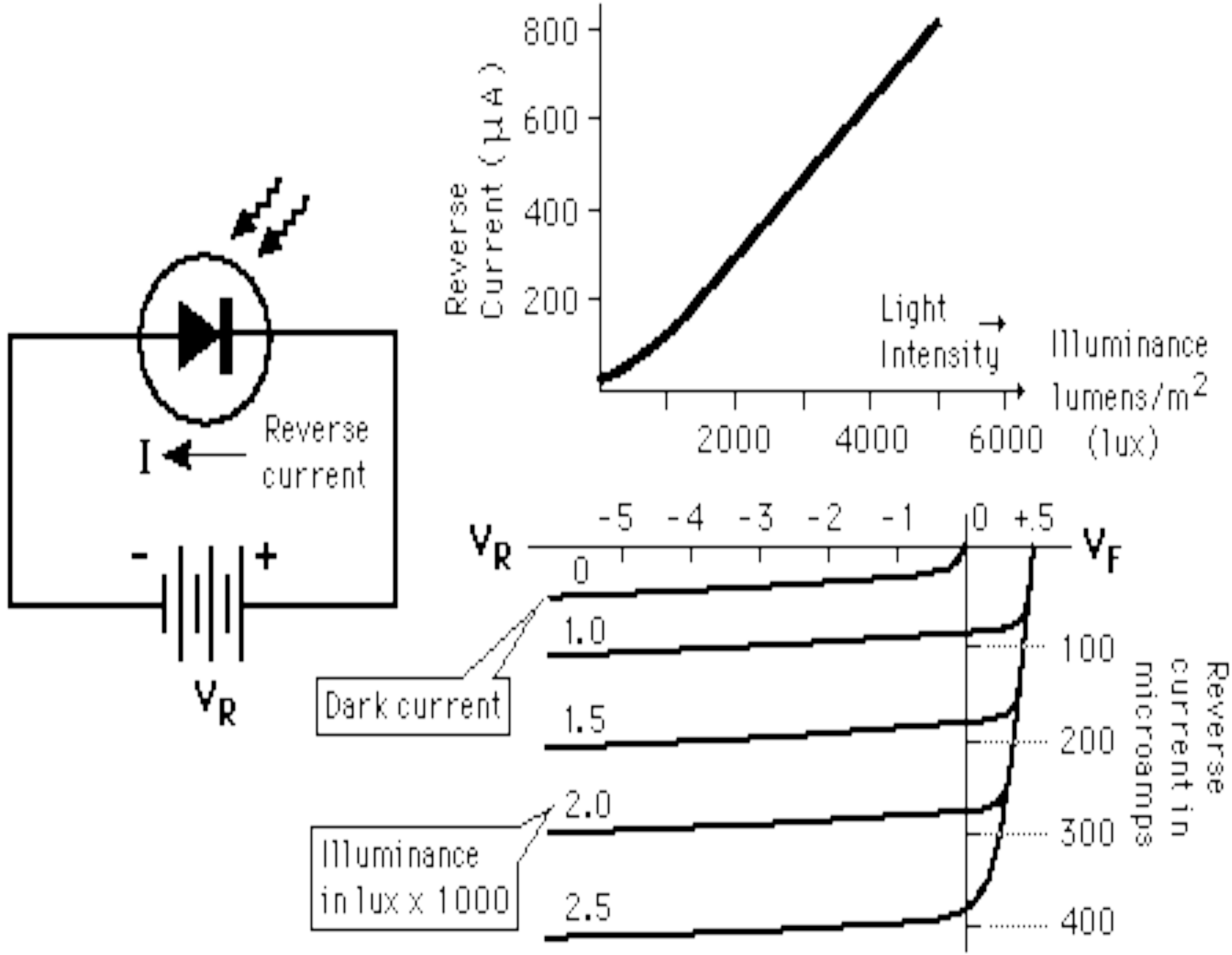
• Response time is fast (nanoseconds)



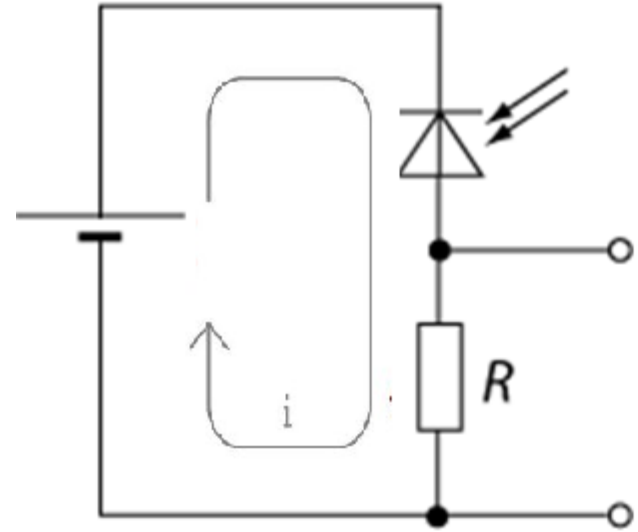
Materials used to produce photodiodes

- Silicon
- Germanium
- Indium Gallium Arsenide
- Lead Sulphide




Reverse current
I
-
+
V_R
Reverse Current (μA)
800
600
400
200
Light Intensity →
Illuminance lumens/m^2 (lux)
2000
4000
6000
-5 -4 -3 -2 -1 0 +.5
V_R
V_F
0
1.0
1.5
2.0
2.5
Dark current
Illuminance in lux x 1000
100
200
300
400
Reverse current in microamps

Photodiode Circuit



- If photon intensity is zero.
  - Only current flowing is the reverse saturation current.

    (Dark current , normally small).
- Photon intensity of sufficient energy strikes the diode.
  - Photoelectric effect (electron hole pair in

    space charge region)
  - Photocurrent flows in reverse direction.
  - Photocurrent is sum of dark current and the light current.
  - Photocurrent creates voltage drop across R.

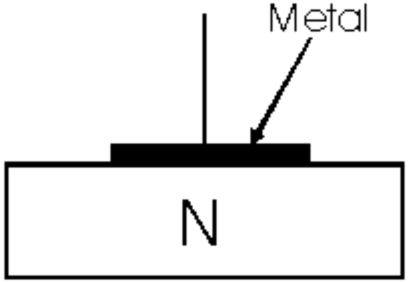
Schottky Diode

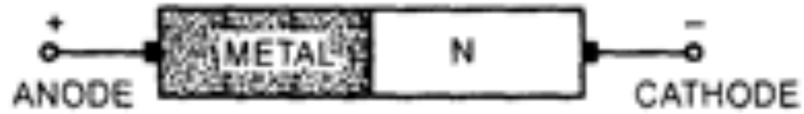
Q: Explain the construction, working and characteristic of Schottky diode.

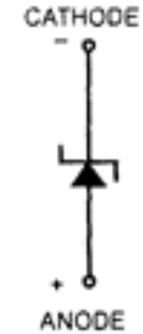
- Schottky diode is a special purpose device with no depletion layer elliminating the stored charges at the junction.

- Construction is different from the normal p-n junction.

Construction of Schottky Diode







- It is a metal semiconductor junction.

- On one side of the junction a metal (gold, silver, molybdenum, chrome or tungsten) is used and on other side of the junction n type doped Si is used.

Working of Schottky diode

- When diode is unbiased.
  - Electrons on the n side have low energy levels then the electrons in the metal and so cannot cross the junction barrier called Schottky barrier.
- When diode is Forward biased.
  - Electrons on the n side gain enough energy to cross the junction and enter metal.
  - Electrons plunge into the metal with very large energy, they are called hot carriers and hence the name HOT CARRIER DIODE.
- Schottky diode is a unipolar device and there is no deletion region.

Characteristic of Schottky diode

- It has low barrier potential (0.2 – 0.25 V) whereas normal diode has 0.7 V (Si)
- It has higher leakage currents and lower reverse breakdown voltage.

- It is more efficient for high power applications.

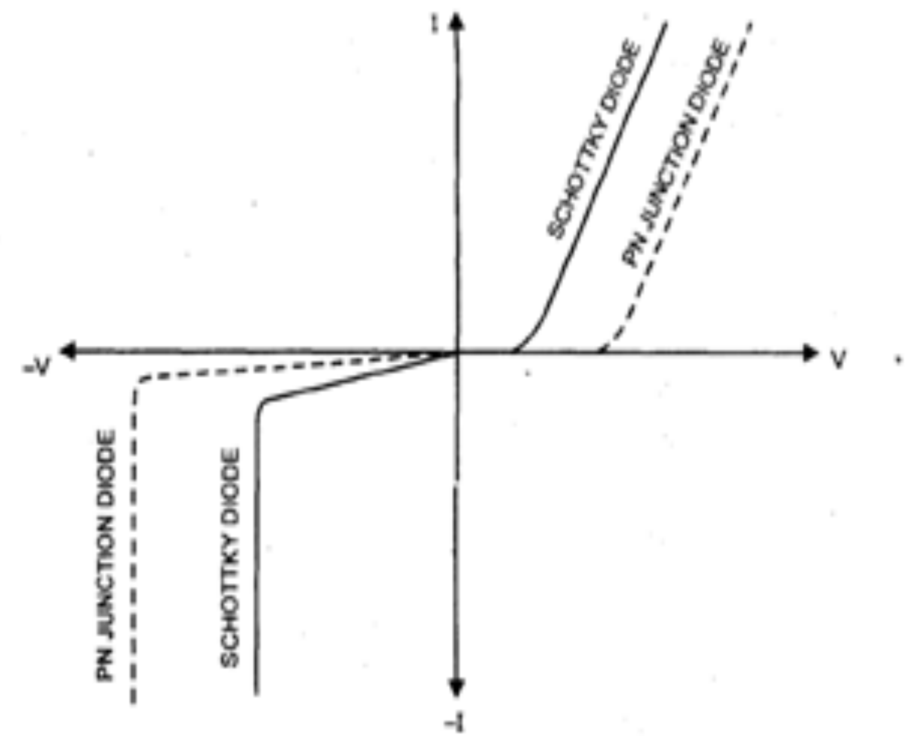


Fig. 37. Comparison of VI characteristics of Schottky and p-n junction diode.

Applications of Schottky diode

The Schottky barrier diodes are widely used in the electronics industry finding many uses as diode rectifier. Its unique properties enable it to be used in a number of applications where other diodes would not be able to provide the same level of performance. In particular it is used in areas including:

RF mixer and detector diode

Power rectifier

Solar cell applications

Clamp diode

Schottky diode

Advantages:

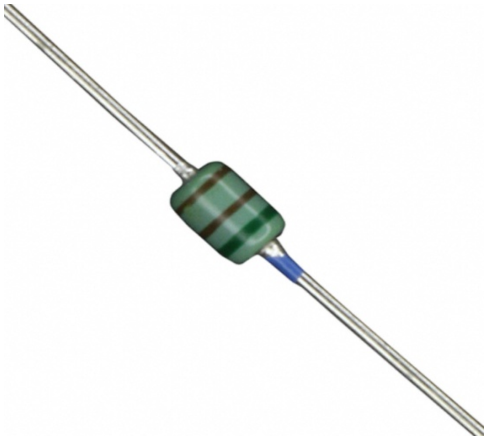
High speed, high frequency, low forward voltage drop, low heat dissipation, low loss.

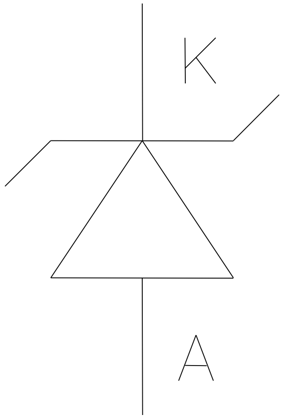
Disadvantages:

Size and cost.

ZENER DIODES

Zener diodes





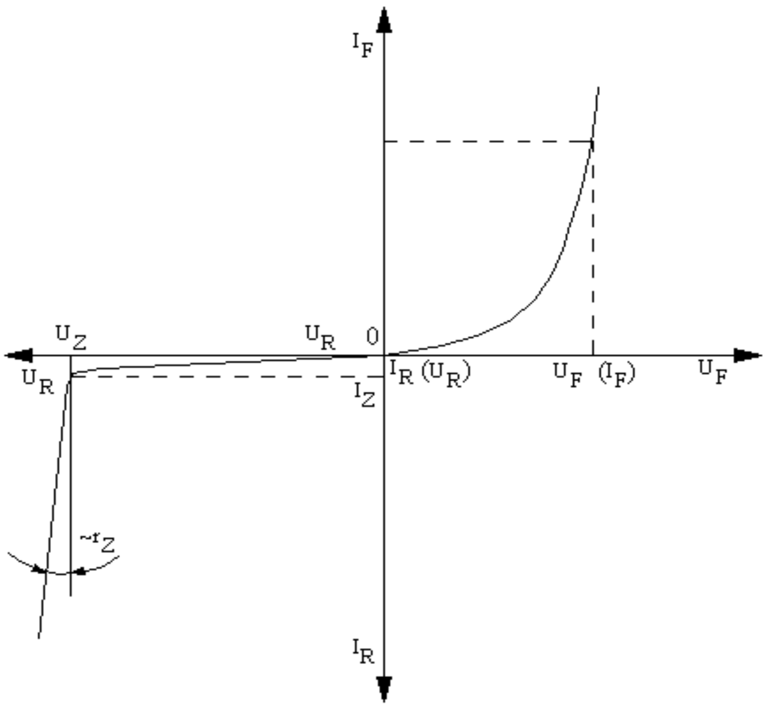
(Zener) diodes are designed to stabilize voltage.

It is a special kind of diode which permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above a certain value - the breakdown voltage known as the Zener voltage.

A Zener diode is a special diode that is optimized for operation in the breakdown region

Zener diode

The V-I characteristics

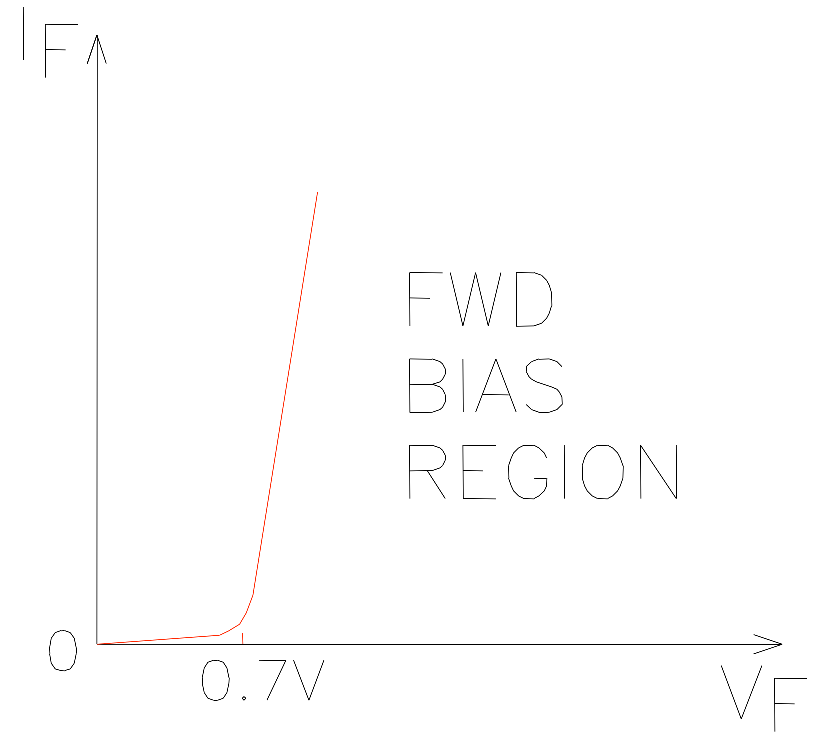


V_Z – breakdown voltage
V_F – forward voltage

I_R – reverse current

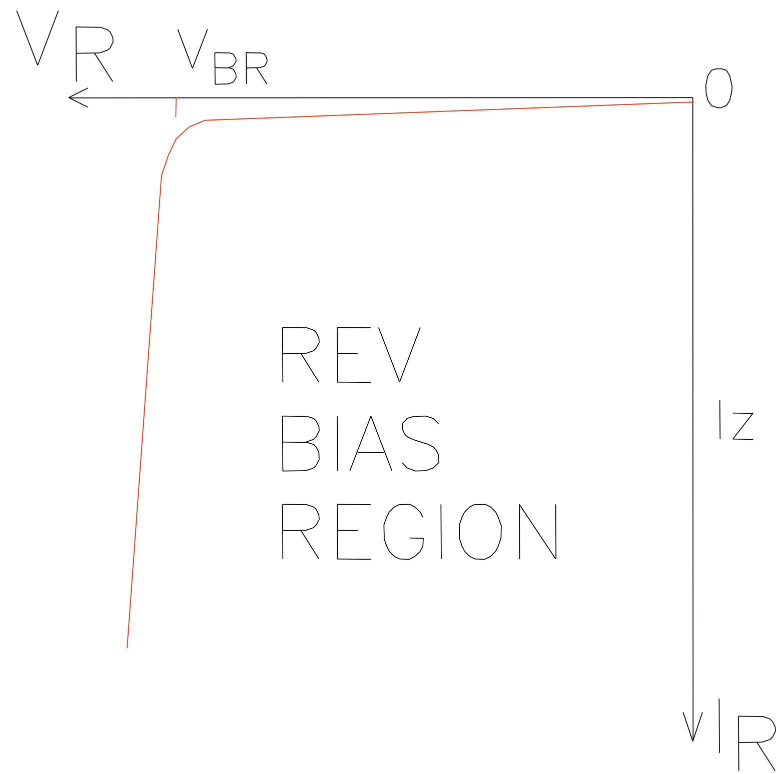
ZENER DIODE CHARACTERISTICS

- In the forward region, the Zener diode acts like a regular silicon diode, with a 0.7 volt drop when it conducts.



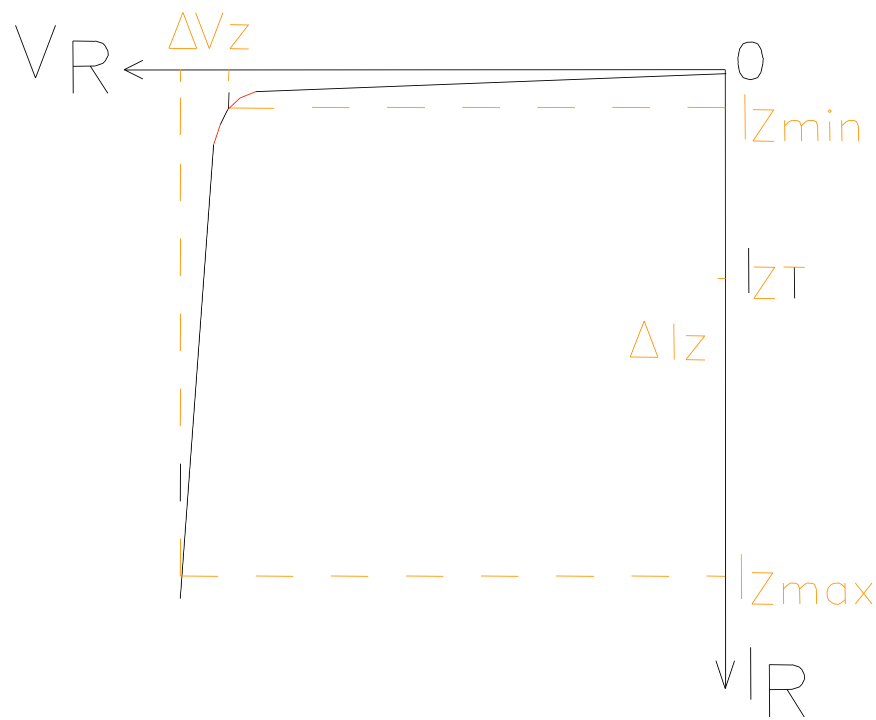
ZENER DIODE CHARACTERISTICS

- In the reverse bias region, a reverse leakage current flows until the breakdown voltage is reached.
- At this point, the reverse current, called Zener current Iz, increases sharply.



ZENER DIODE CHARACTERISTICS

- **Voltage after breakdown is also called Zener voltage Vz.**
- **Vz remains nearly a constant, even though current Iz varies considerably.**



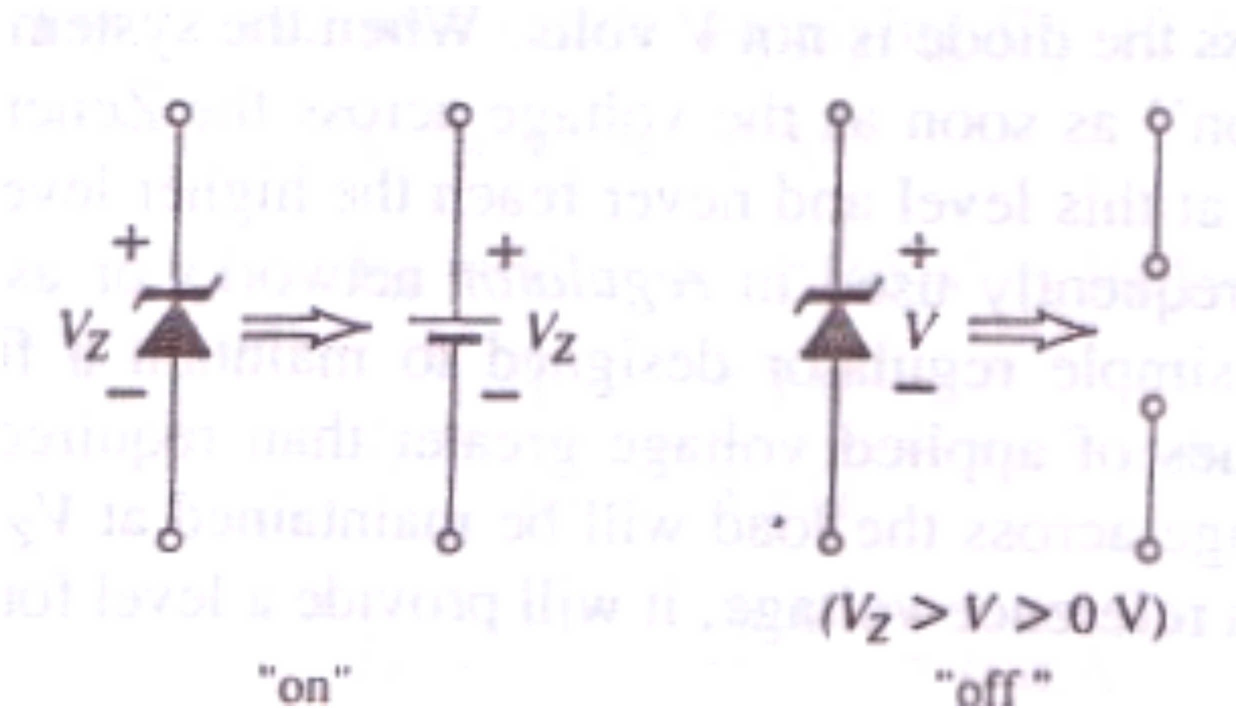
ZENER DIODE RATINGS

- A Zener data sheet typically provides
  - the maximum power rating P_{ZM}
  - the nominal zener voltage V_Z at test current I_{ZT}
  - the maximum DC zener current I_{ZM}

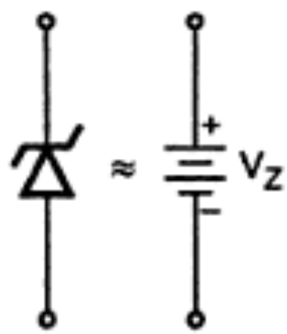
Example:

- 1N752 has a power rating of 500mW, a nominal Zener voltage of 5.6V at a test current of 20 mA, a maximum Zener current of 80 mA.

ZENER DIODE MODEL

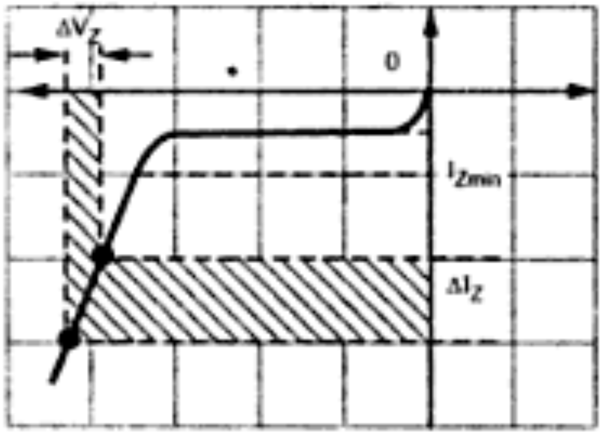


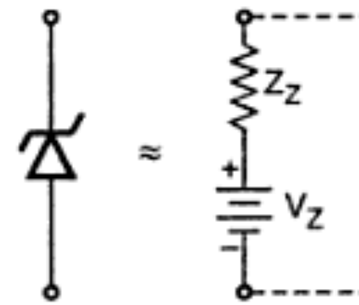
Equivalent Circuit of Zener Diode



Ideal equivalent circuit of zener diode

Practical Zener diode





A.C. equivalent circuit

From the graph the dynamic resistance is defined as,

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z} = \frac{1}{\left[\dfrac{\Delta I_Z}{\Delta V_Z}\right]} = \frac{1}{\left[\begin{array}{l}\text{Slope of the reverse}\\ \text{characteristics in}\\ \text{zener region}\end{array}\right]}$$

This value is specified generally at zener test current I_{ZT}.

Key Point: *In most of the cases this value is almost constant over the full range of zener region i.e. from I_{Zmin} to I_{Zmax}. It is of the order of few tens of ohms.*

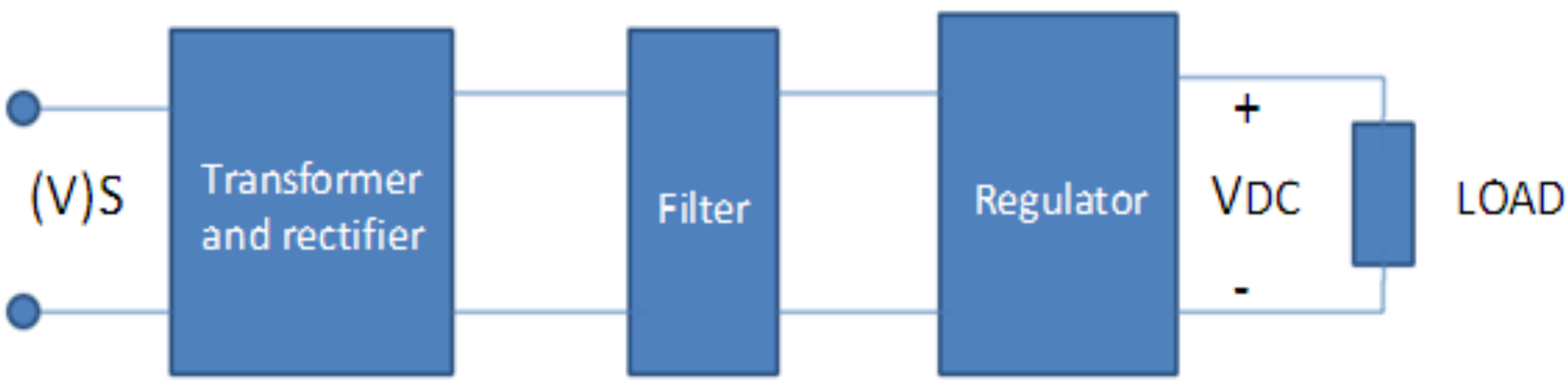
Zener diode Regulator

VOLTAGE REGULATION

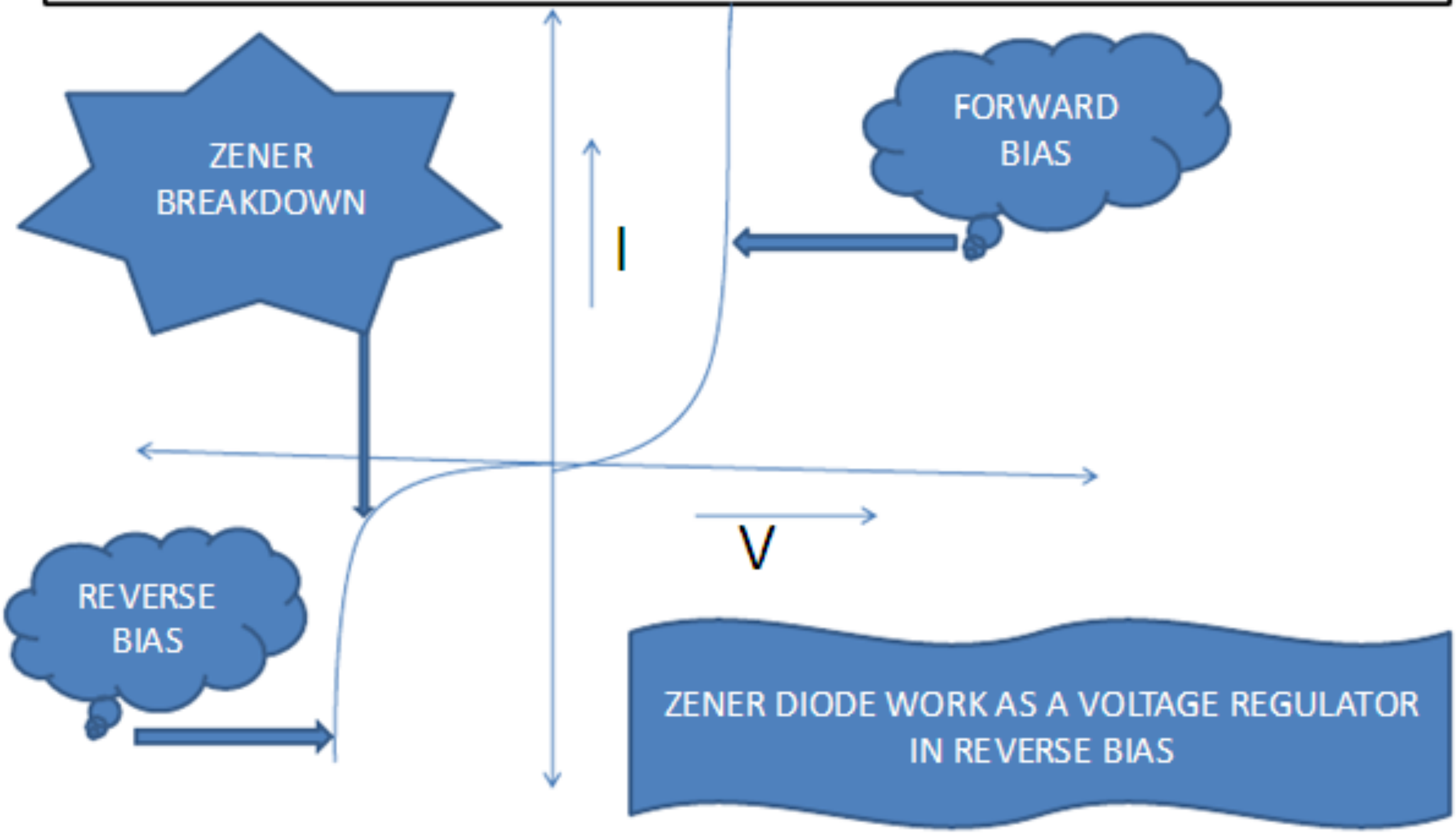
- ✓ A voltage regulator circuit automatically maintains the output voltage of a power supply constant, regardless of

i) a change in the load

ii) a change in the source voltage

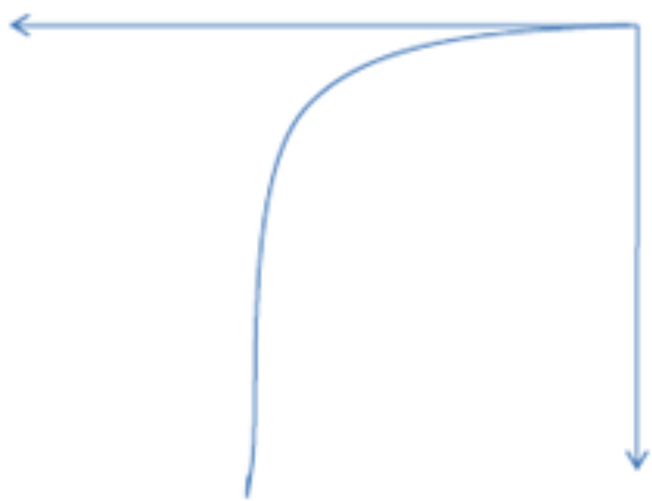


OUTPUT CHARECTERISTICS OF ZENER DIODE



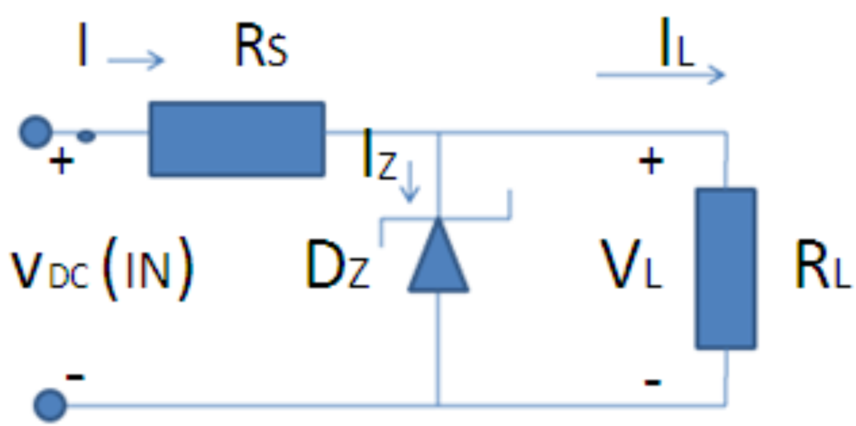
ZENER DIODE CHARCETERISTICS

- Voltage after breakdown is also called zener voltage V_{FZ}
- V_Z remains nearly a constant, even though current IZ varies considerably.



ZENER DIODE AS A VOLTAGE REGULATOR

- The zener diode is typically connected reverse biased, in parallel with the load.
- Resistor Rs limits current to zener.



Component functions

Rs Limits the zener current to a safe value.

Vz maintains a constant voltage across the load unit by controlling the current through the series resistor.

Zener Breakdown

Q: Explain the breakdown mechanism of zener diode

- Zener breakdown occurs in diodes **specially designed** to withstand the damaging caused by the Avalanche breakdown.
- Zener diodes are **heavily doped** to reduce the depletion region width.
- On applying reverse potential across a Zener diode, due to the reduced width of the depletion region, the valence electrons in the atoms are pulled out by the electrostatic force experienced at the junction.
- Which inturn results in the breakdown of the junction, since the diode is **specially designed to have a breakdown at lower voltages as compared to normal Avalanche breakdown.**
- Therefore, a **Zener diode has a controlled breakdown** in reverse biased condition over the zener region.

Q: Compare the extrinsic and the intrinsic semiconductor material

Q: Explain energy band diagram for semiconductor and conductor

Q: Explain breakdown mechanism of zener diode

Q:Differentiate between energy levels of insulator, conductor and semiconducor

Q: Differentiate between avalanche and zener breakdown

Q: Explain the dc and ac resistance of diode.

Q: Explain the piecewise linear equivalent circuit for diose with characteristics.