BASIC ELECTRONICS

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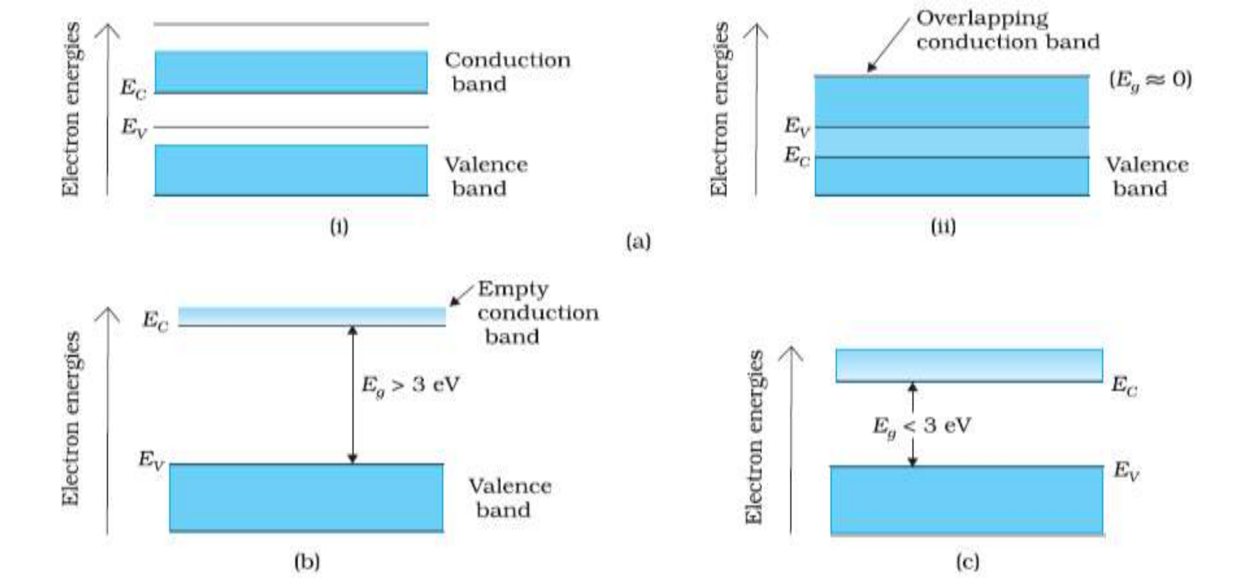
Classification of materials based On Energy Band

Metals, Insulators, Semiconductors

- **Metals**: They have free electrons and partially filled valence bands, therefore they are highly conductive.
- **Insulators:** They have filled valence bands and empty conduction bands, separated by a large band gap E g(typically >4eV), they have high resistivity.
- **Semiconductors:** They have similar band structure as insulators but with a much smaller band gap. Some electrons can jump to the empty conduction band by thermal or optical excitation. Eg=1.1 eV for Si, 0.67 eV for Ge and 1.43 eV for GaAs

Difference between energy bands of (a) metals, (b) insulators and (c) semiconductors.



Semiconductors are materials whose electrical properties lie between Conductors and Insulators. e.g. : Silicon and Germanium

Types of Semiconductor

Intrinsic Semiconductor

Semiconductors that are free of doping impurities are called ***intrinsic semiconductors***.

Extrinsic Semiconductor

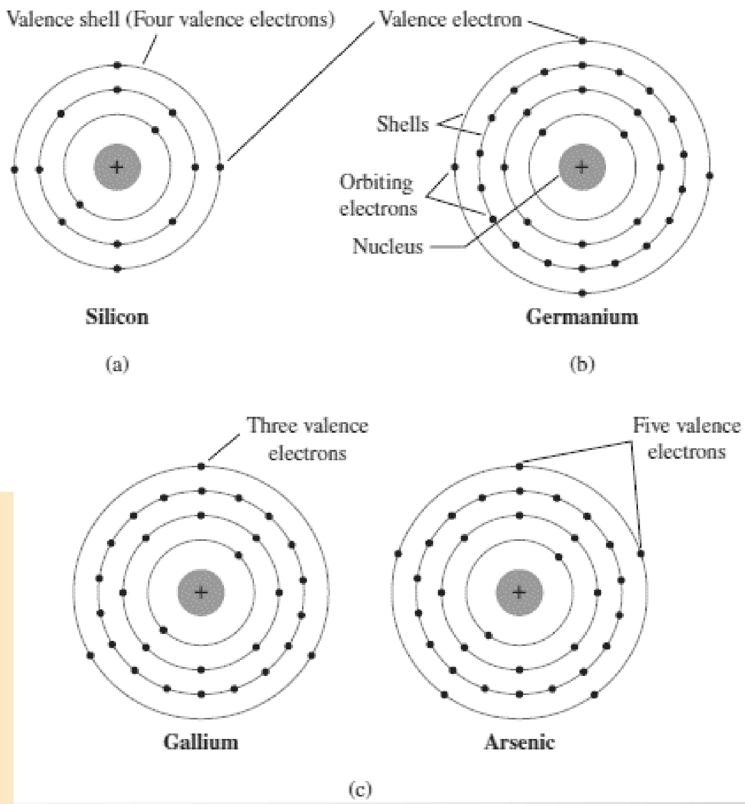
Semiconductors formed after adding impurities are called ***extrinsic semiconductors***.

Doping is a process of adding a certain amount of specific impurities called dopants to a pure semiconductor to increase its electricity conductivity.

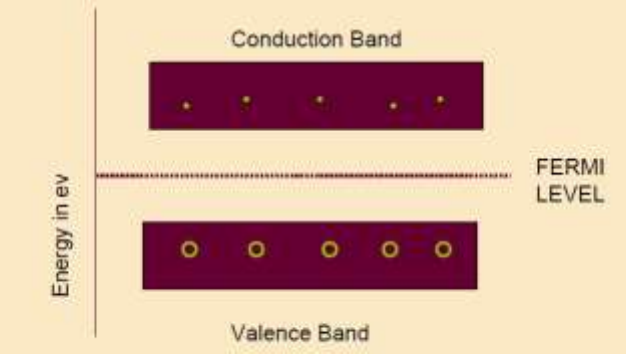
Intrinsic Semiconductor

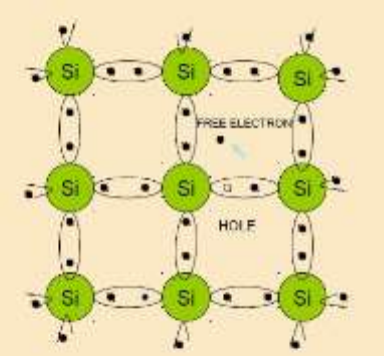
- Semiconductor in pure form is known as Intrinsic Semiconductor.
- Eg. Pure Germanium, Pure Silicon, Pure Gallilium, pure Arsenic .
- At room temp. no of electrons* equal to no. of holes*.

***Holes** and electrons are the two types of charge carriers responsible for current in **semiconductor** materials.



Energy band gap in case of intrinsic semiconductor





Extrinsic Semiconductors are further classified as:

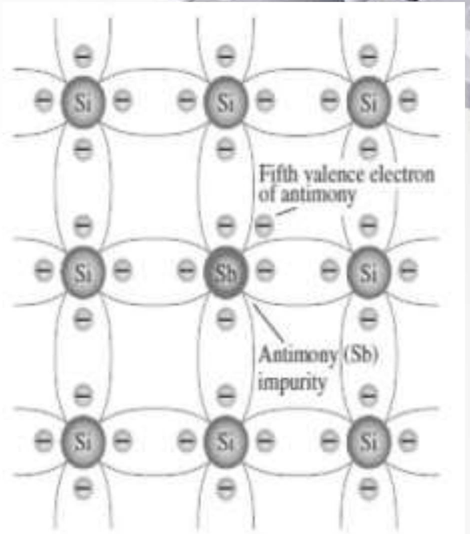
a. n-type Semiconductors.
b. p-type Semiconductors.

n - type Semiconductor

When we add a pentavalent impurity to pure semiconductor we get n-type semiconductor.

- Antimony atom has 5 valence electrons.
- Fifth electron is superfluous, becomes free electron and enters into conduction band.
- Therefore pentavalent impurity donates one electron and becomes positive donor ion. Pentavalent impurity known as donor.

Antimony impurity in *n* type material.

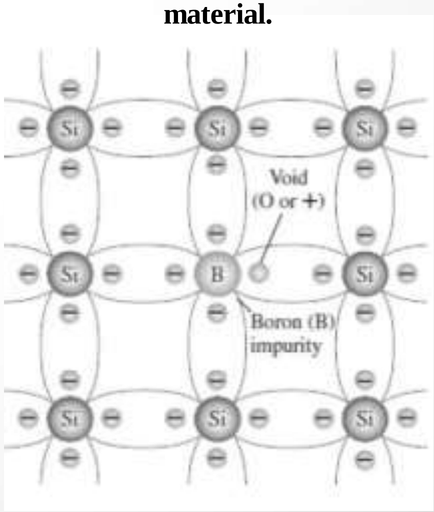


p - type Semiconductor

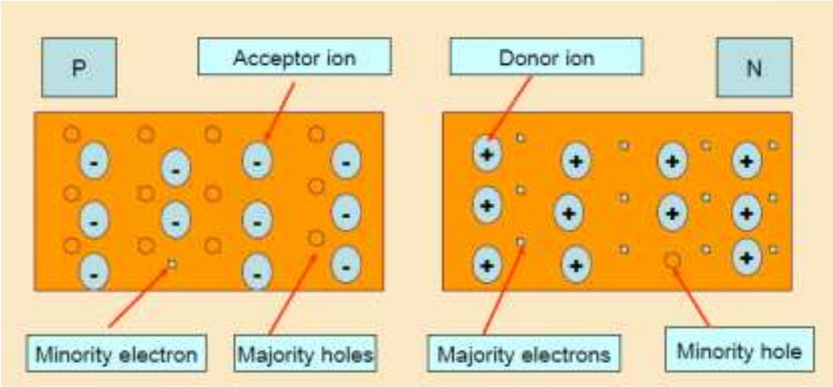
When we add a Trivalent impurity to pure semiconductor we get p-type semiconductor.

- Boron atom has 3 valence electrons.
- It makes covalent bonds with adjacent three electrons of silicon atom.
- There is a deficiency of one covalent bond and creates a hole.
- Therefore trivalent impurity accepts one electron and becomes negative acceptor ion. Trivalent impurity known as acceptor.

Boron impurity in p type material.



p - type Semiconductor and n - type Semiconductor



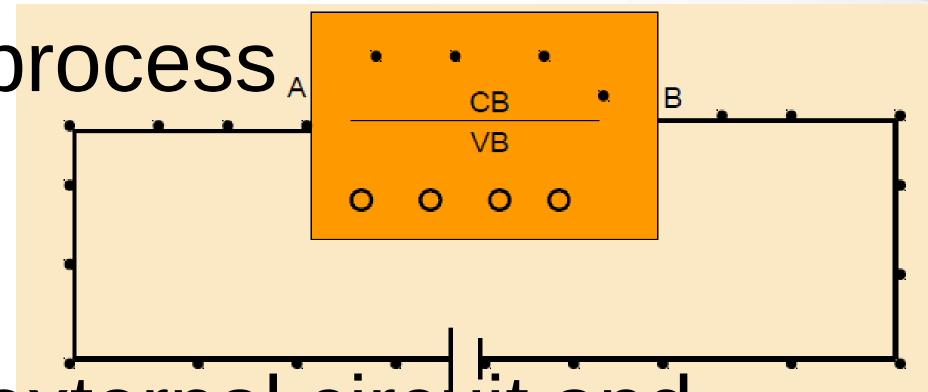
Comparison between n - type Semiconductor and p - type Semiconductor

N-type	P-type
• Pentavalent impurities are added.	• Trivalent impurities are added.
• Majority carriers are electrons.	• Majority carriers are holes.
• Minority carriers are holes.	• Minority carriers are electrons.
• Fermi level is near the conduction band.	• Fermi level is near the valence band.

Conduction in Semiconductors

Conduction is carried out by means of:

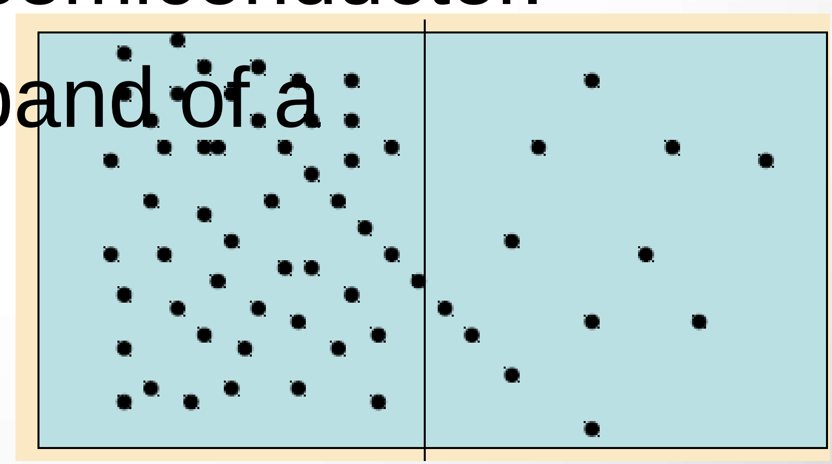
1. Drift process
2. Diffusion process



- **Drift process**
- Electrons move from external circuit and in conduction band of a semiconductor.
- Holes move in valence band of a semiconductor.

Diffusion process

•Moving of electrons from higher concentration gradient to lower concentration gradient is known as diffusion process.



What are P-type and N-type ?

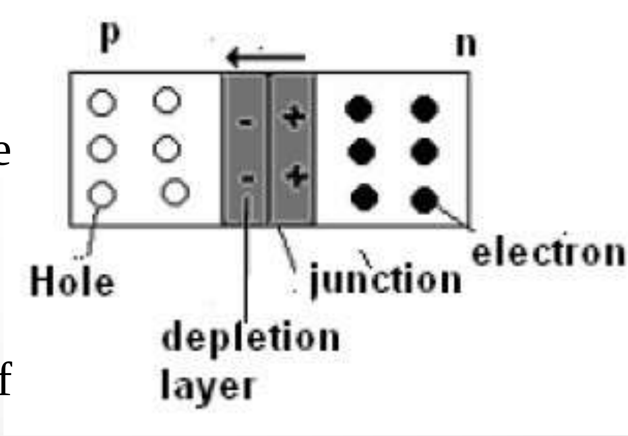
•Semiconductors are classified in to P-type and N-type semiconductor
•P-type: A P-type material is one in which holes are majority carriers i.e. they are positively charged materials (++++)
•N-type: A N-type material is one in which electrons are majority charge carriers i.e. they are negatively charged materials

What is the p-n junction?

• A p-n junction is formed when a n-type and p-type semiconductors are joined together.
• The boundary between the p-type and n-type regions is called the junction.
•At the p-n junction, electrons from the n-side move to the p-side and recombine with the holes.
• Holes from the p-side similarly move into the n- side, where they recombine with electrons.
•As a result of this flow, the n-side has a net positive charge, and the p-side has a net negative charge.

Depletion layer

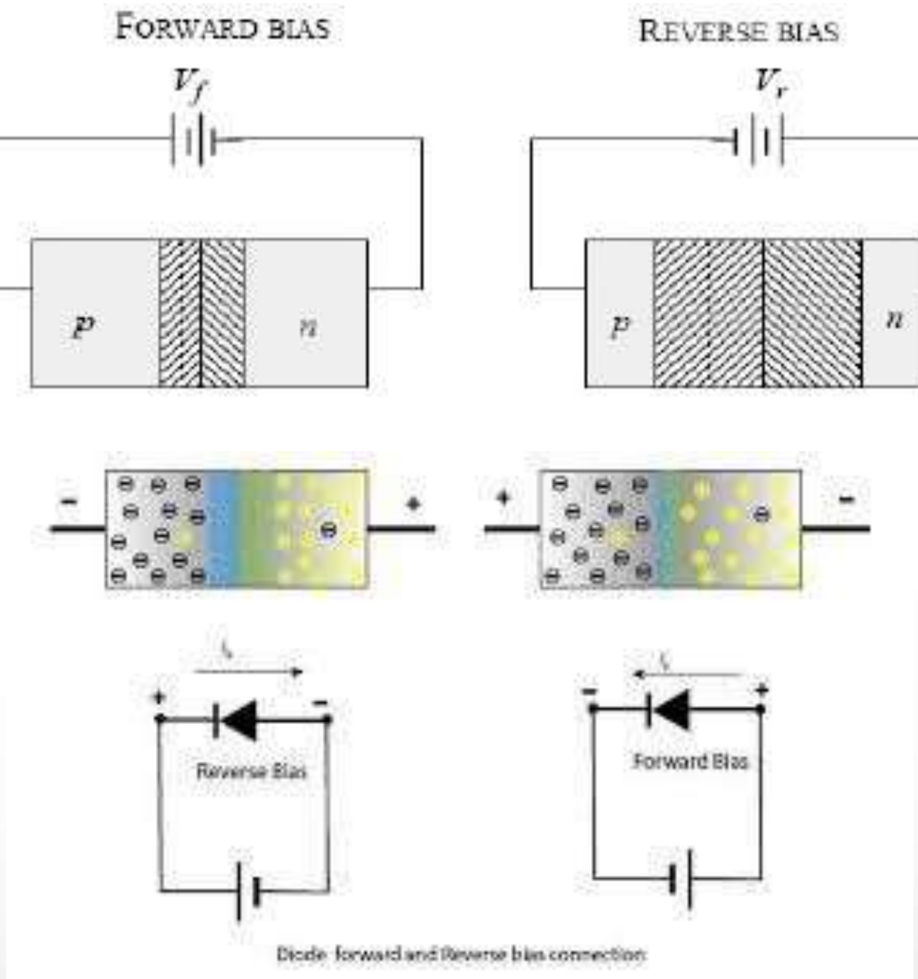
•The region around the junction is left with neither holes nor free electrons.
•This neutral region which has no charge carriers is called the depletion layer.
• This layer which has no charge carrier is a poor conductor of electricity.



Forward Bias and Reverse Bias

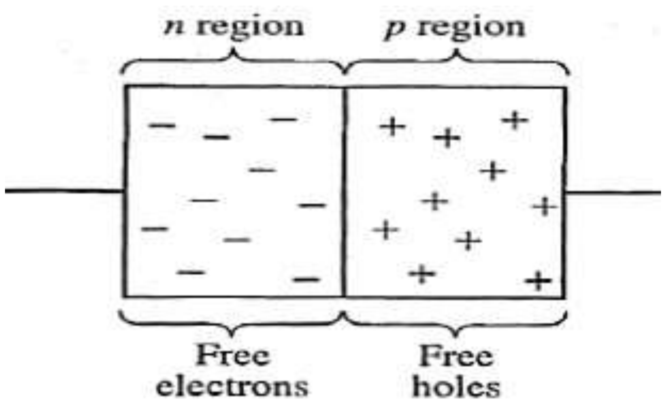
□ **Forward Bias**: Connect positive of the Diode to positive of supply…negative of Diode to negative of supply

□**Reverse Bias**: Connect positive of the Diode to negative of supply…negative of diode to positive of supply.



Diode

➢Electronic devices created by bringing together a *p-type and n-type region* within the same semiconductor lattice. Used for rectifiers, LED etc



Characteristics of Diode

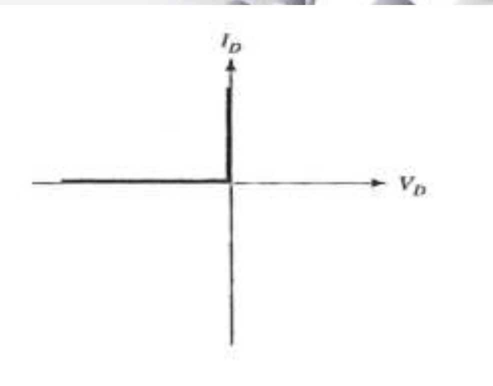
- ✓Diode always conducts in one direction.
- ✓Diodes always conduct current when "Forward Biased" (Zero resistance)
- ✓Diodes do not conduct when Reverse Biased (Infinite resistance)

➢ Electronic devices created by bringing together a p-type and n-type region within same semiconductor lattice.

➢ Diodes are used for rectifiers and LEDs

I-V characteristics of Ideal diode

When **Ideal Diode** is forward biased it acts like a perfect conductor, with zero voltage across it. Similarly, when the diode is reversed biased, it acts as a perfect insulator with zero current through it.



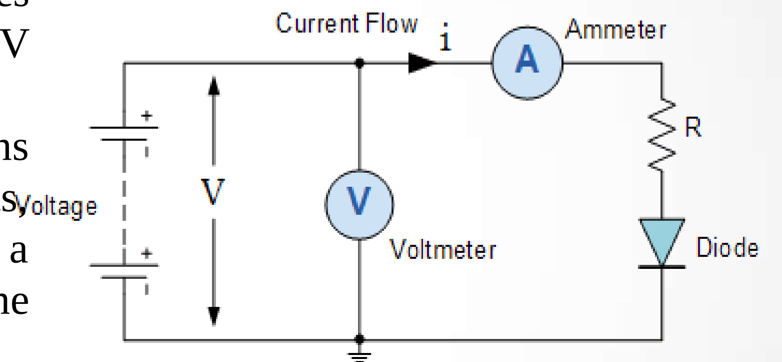
I-V Characteristics of Practical Diode

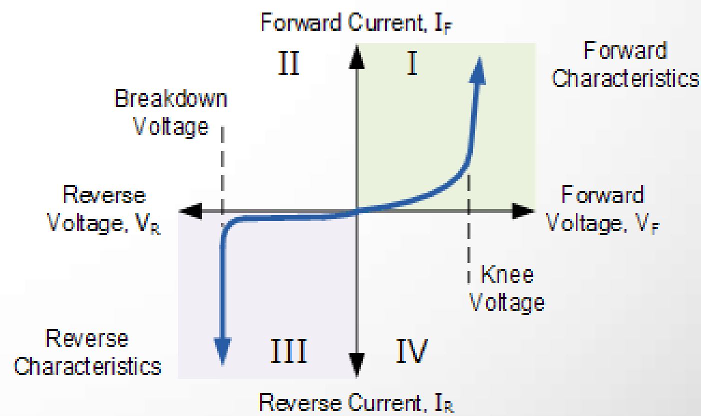
•When the diode is forward biased, a forward current passes through the diode and operates in the top right quadrant of its I-V characteristics curves.

•When the forward voltage exceeds the diodes P-N junctions internal barrier voltage, which for silicon is about 0.7 volts, avalanche occurs and the forward current increases rapidly for a very small increase in voltage producing a non-linear curve. The "knee" point on the forward curve.

•Likewise, when the diode is reversed biased, cathode positive with respect to the anode, the diode blocks current except for an extremely small leakage current, and operates in the lower left quadrant of its I-V characteristic curves.

•The diode continues to block current flow through it until the reverse voltage across the diode becomes greater than its breakdown voltage point resulting in a sudden increase in reverse current producing a fairly straight line downward curve as the voltage losses control.





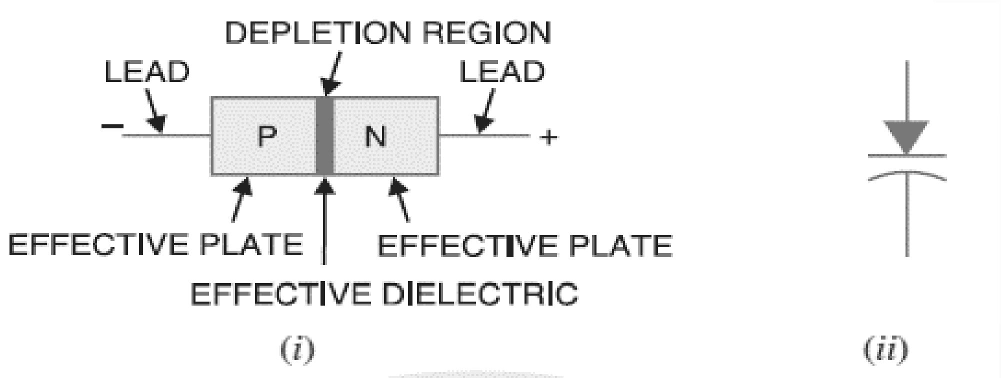
•This reverse breakdown voltage point is used to good effect with zener diodes.

Varactor diode

Introduction

Varactor diode is a special type of PN junction diode, in which PN junction capacitance is controlled using reverse bias voltage. When the diode is forward biased, current will flow through the diode. When the diode is reverse biased, charges in the P and N semiconductors are drawn away from the PN junction interface and hence forms the high resistance depletion zone.

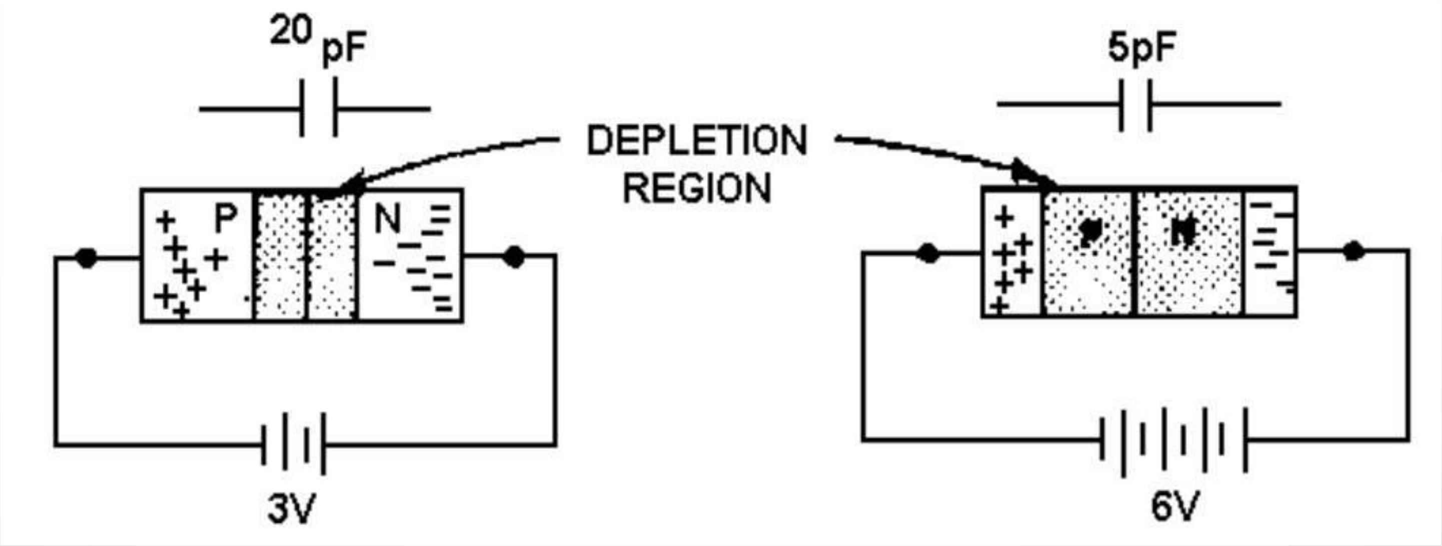
Schematic Symbol



OTHER NAMES : ● Variable capacitance (Varicap) diode ● Voltage – Variable Capacitor (VCC) diode ● Tuning diode
● Variable reactance diode

Basic Operation

- Operates in reverse bias and this gives rise to three regions. At either end of the diode are the P and N regions. However around the junction is the depletion region where no current carriers are available. As a result, current can be carried in the P and N regions, but the depletion region is an insulator.
- Same as capacitor construction. It has conductive plates separated by an insulating dielectric.
- The capacitance of a capacitor is dependent on a number of factors including the plate area, the dielectric constant of the insulator between the plates and the distance between the two plates. In the case of the varactor diode, it is possible to increase and decrease the width of the depletion region by changing the level of the reverse bias. This has the effect of changing the distance between the plates of the capacitor.



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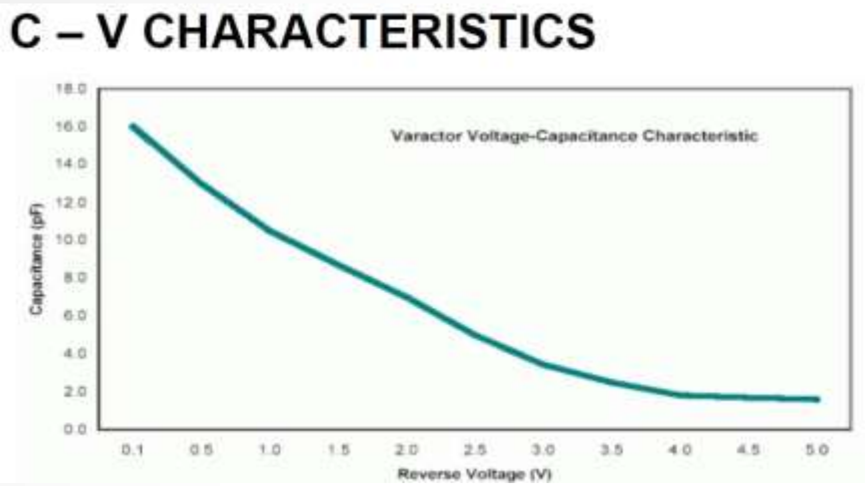
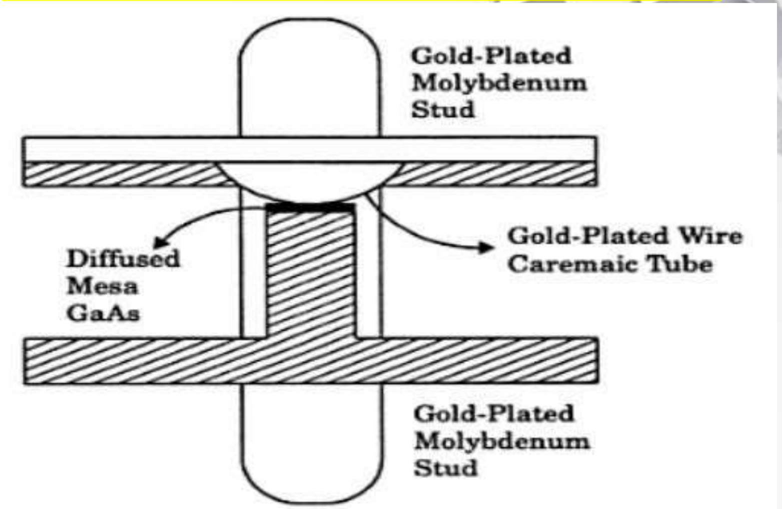
C – V CHARACTERISTICS



MATERIAL CONSTRUCTION



Varactor diodes are manufactured with gallium arsenide. GaAs has a higher operating frequency (up to nearly 1000 GHz)

APPLICATIONS

● Variable reactor in microwave circuits. ● It is used in variable resonant tank LC circuit. Here C part is varied using varactor diode. ● AFC (Automatic Frequency Control) where in varactor diode is used to set LO signal. ● Varactor is used as frequency modulator in Radios and Television sets. ● It is used as frequency multiplier in microwave receiver LO.

● It is used as RF phase shifter.

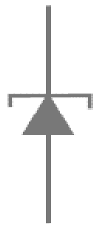
Tunnel Diode

It is heavily doped PN- junction. Doping density of about 1000 times greater than ordinary junction diode

History

- Tunnel diode was invented in 1958 by Leo Esaki.
- Also called Esaki diode.
- Leo Esaki observed that if a semiconductor diode is heavily doped with impurities, it will exhibit negative resistance.
- In 1973 Leo Esaki received the Nobel Prize in physics for discovering the electron tunneling effect used in these diodes.

Schematic Symbol



Materials commonly used to produce Tunnel doide

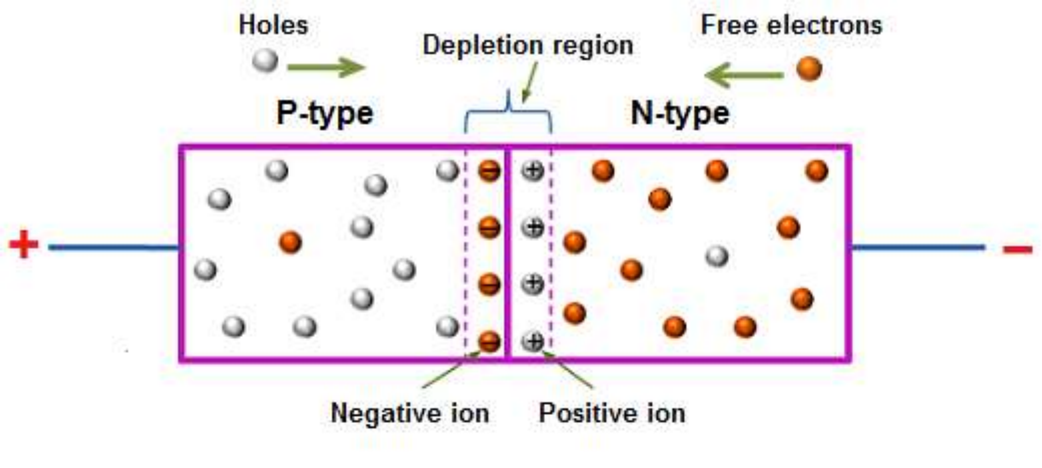
(GaSb), (GaAs), (GeAs)

Features of photodiode:

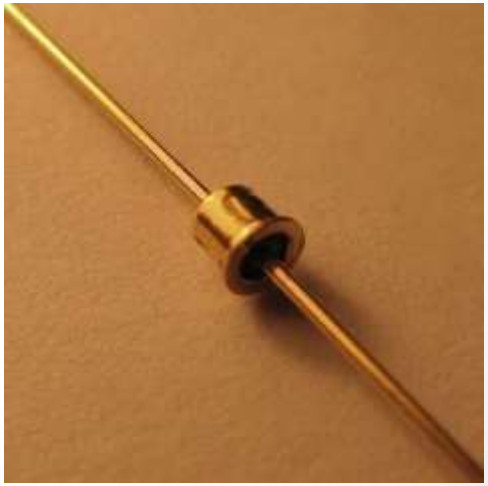
- Excellent linearity with respect to incident light
- Low noise
- Wide spectral response
- Mechanically rugged
- Compact and lightweight
- Long life

Basic principle of operation

O The operation depends upon quantum mechanics principle known as "tunneling".
O The movement of valence electrons from valence energy band to conduction band with no applied forward voltage is called "tunneling".
O Intrinsic voltage barrier (0.3V for Ge) is reduced which enhanced tunneling. O Enhanced tunneling causes effective conductivity.



Forward bias tunnel diode



Working

- In a conventional diode, forward conduction occurs only if the forward bias is sufficient to give charge carriers the energy necessary to overcome the potential barrier.
- When the tunnel diode is slightly forward biased, many carriers are able to tunnel through narrow depletion region without acquiring that energy.
- The carriers are able to tunnel because the voltage barrier is reduced due to high doping.

Forward Bias operation:

At first voltage begin to increase:

- Electrons tunnel through pn junction.
- 2. Electron and holes states become aligned.

Voltage increases further:

- 1. States become misaligned.
- 2. Current drops.
- 3. Shows negative resistance (V increase, I decrease).

As voltage increase yet further:

- 1. The diode behave as normal diode.
- 2. The electrons no longer tunnel through barrier.

Reverse Bias Operation:

- When used in reverse direction, they are called as Back Diodes. In this, i. The electrons in valence band of p-side tunnel directly towards the empty states present in the conduction band of n-side. ii. Thus, creating large tunneling current which increases with application of reverse voltage.

I/V Characteristics

As forward bias is applied, significant I is produced. After continuous increase of V, the current achieves its minimum value called as Valley Current. After further increase in V, current start increasing as ordinary diode.

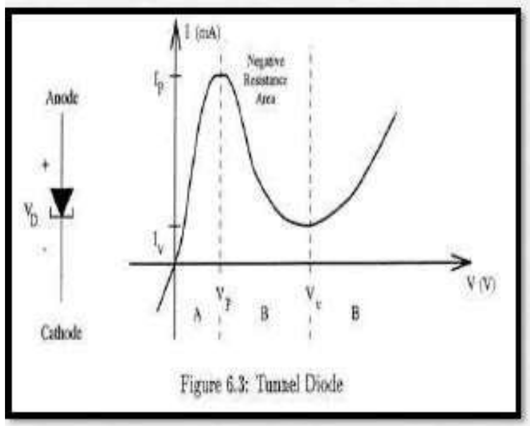
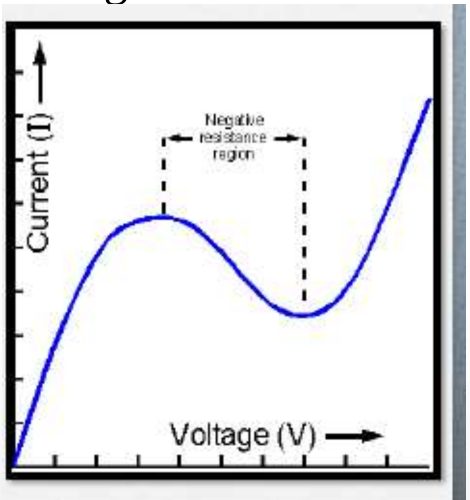


Figure 6.3: Tunnel Diode

- The Tunnel diode reverse I-V is similar to the Zener diode.
- The Zener diode has a region in its reverse bias characteristics of almost a constant voltage regardless of the current flowing through the diode.



APPLICATIONS

- It is used as an ultra-high speed switch due to tunneling (which essentially takes place at speed of light). It has switching time of nanoseconds or picoseconds.
- Used as logic memory storage device.
- In satellite communication equipment, they are widely used.
- Due to its feature of –ive resistance, it is used in relaxation oscillator circuits.
- Tunnel diodes are resistant to the effects of magnetic fields, high temperature and radioactivity. That‟s why these can be used in modern military equipments, NMR machines.
- Due to low power requirement, they are used in FM receivers.

Photo diode

A **photo-diode** is a reverse-biased silicon or germanium p-n junction in which reverse current increases when the junction is exposed to light. The reverse current in a photo-diode is directly proportional to the intensity of light falling on its p-n junction. This means that greater the intensity of light falling on the p-n junction of photo-diode, the greater will be the reverse current.

Schematic Symbol

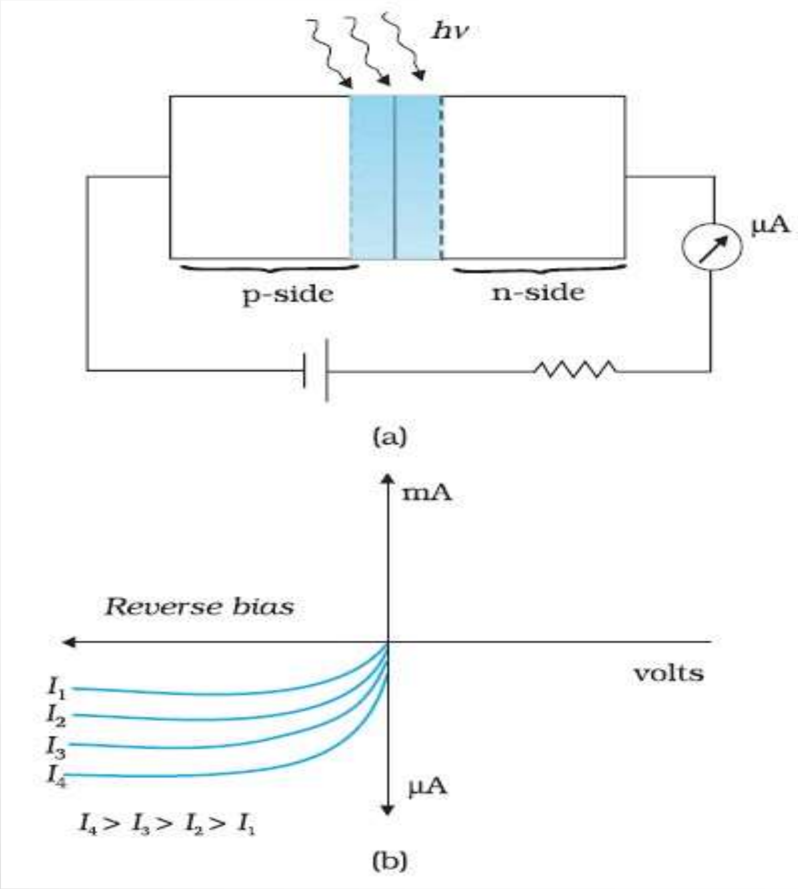
Materials commonly used to produce photodoide

MATERIALS	ELCTROMAGNETIC SPECTRUM WAVELENGTH RANGE (NM)
SILICON	190-1110
GERMANIUM	400-1700
INDIUM GALLIUM ARSENIDE	800-2600
LEAD SUFIDE	100-3500

Principle of Photodoide

An illuminated (a) photodiode under reverse bias,
(b) *I-V* characteristics of a Photodiode for different illumination intensity $I_4 > I_3 > I_2 > I_1$.

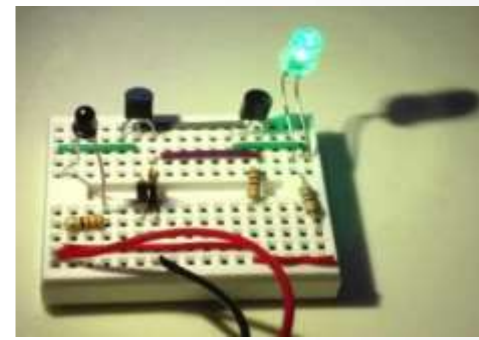
Principle of Photodoide



When a rectifier diode is reverse biased, it has a very small reverse leakage current. The same is true for a photo-diode. The reverse current is produced by thermally generated electron hole pairs which are swept across the junction by the electric field created by the reverse voltage. In a rectifier diode, the reverse current increases with temperature due to an increase in the number of electron-hole pairs. A photo-diode differs from a rectifier diode in that when its p-n junction is exposed to light, the reverse current increases with the increase in light intensity and vice-versa. This is explained as follows. When light (photons) falls on the p-n junction, the energy is imparted by the photons to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current. As the intensity of light incident on the p-n junction increases, the reverse current also increases. In other words, as the incident light intensity increases, the resistance of the device (photo-diode) decreases.

APPLICATIONS

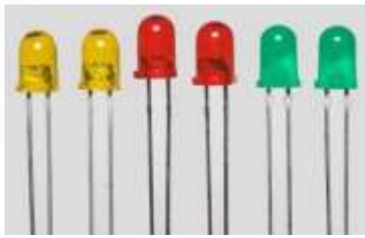
- Photodiodes are used in consumer electronics devices such as CD players, smoke detectors, and the receivers for infrared remote control devices used to control equipment from televisions to air conditioners.
- Photodiodes are used as a light sensors.
- Photodiodes are often used for accurate measurement of light intensity in science and industry.
- They are also widely used in various medical applications, such as detectors for computer tomography, instruments to analyze samples, and pulse oximeters.



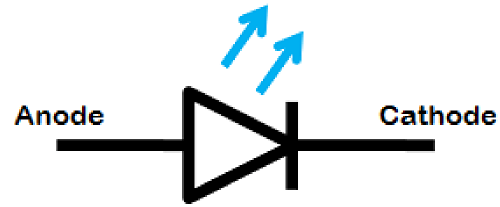
Light emitting diode

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

- LEDs convert electrical energy into light energy.



LED



LED symbol

- LEDs are available in red, orange, amber, yellow, green, blue and white. LEDs are made from gallium-based crystals that contain one or more additional materials such as phosphorous to produce a distinct color.

History

Paris, France 1962 - Nick Holonyack Jr. develops the red LED, the first LED of visible light.

1972 - Herbert Maruska and Jacques Pankove develop the violet LED using Mg-doped GaN films.

New Jersey 1976 - Thomas P. Pearsall develops special high brightness LEDs for fiber optic use.

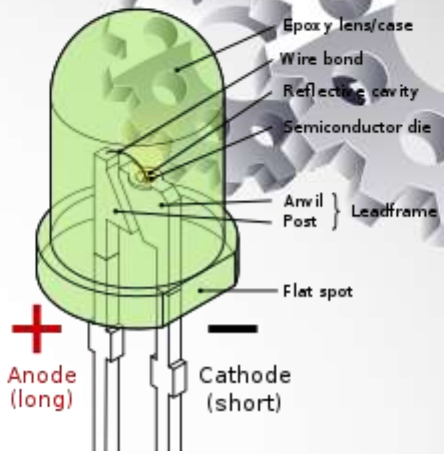
Construction of LED

➢The LED consist of a chip of semiconductor material doped with impurities to create a *P N junction.*

➢The chips are mounted in a reflecting tray order to increase the light output.

➢The contacts are made on the cathode side by means of conductive adhesive and on the anode side via gold wire to the lead frame.

➢ The plastic case encloses the chip area of the lead frame

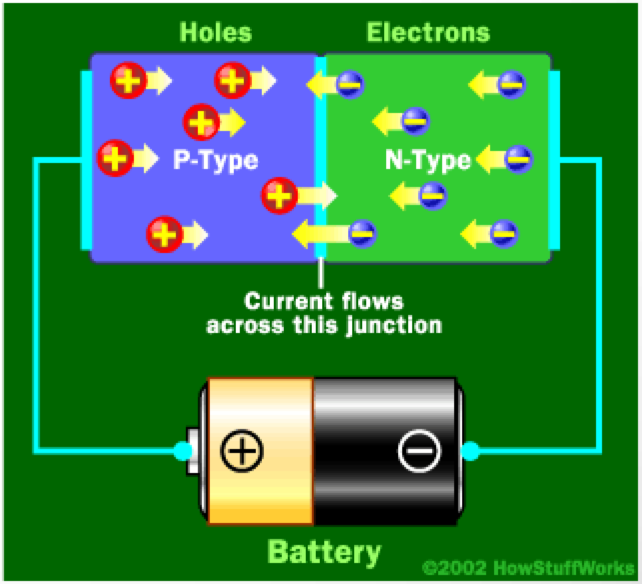


Working

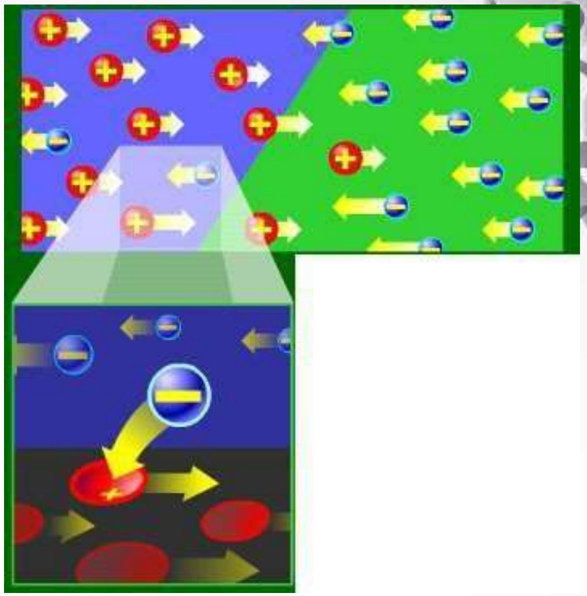
•When the negative end of a circuit is hooked up to the N-type layer and the positive end is hooked up with P-type layer than electron and holes start moving.

•If we try to pass current the other way, with the P-type side connected to the negative end of the circuit and the N-type side connected to the positive end, current will not flow.

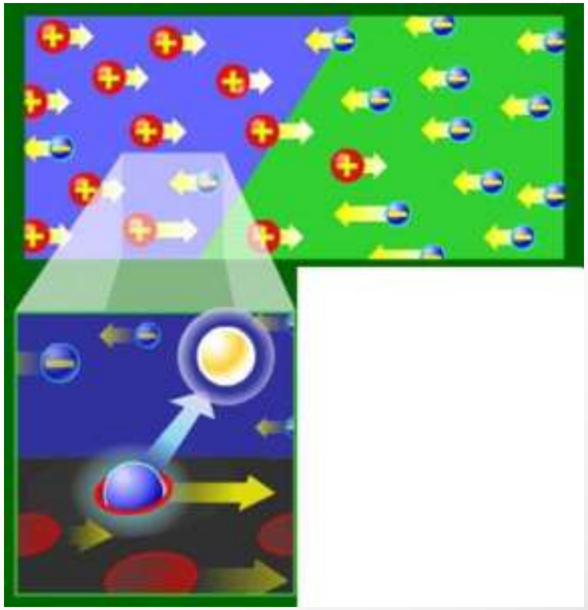
•No current flows across the junction because the holes and the electrons are each moving in the wrong direction.



➢The holes exist at a lower energy level than the free electrons
➢Therefore when a free electrons falls it losses energy



➢This energy is emitted in a form of a photon, which causes light.
➢The color of the light is determined by the fall of the electron and hence energy level of the photon



APPLICATIONS

•**SENSOR APPLICATIONS:** Medical Instrumentation, Bar Code Readers, Color & Money Sensors, Encoders, Optical Switches, Fiber Optic Communication

•**MOBILE APPLICATIONS:** Mobile Phone, PDA's, Digital Cameras,Lap Tops, General Backlighting

•**AUTOMATIVE APPLICATIONS:** Interior Lighting - Instrument Panels & Switches, Courtesy Lighting, Exterior Lighting - CHMSL, Rear Stop/Turn/Tail, Truck/Bus Lighting - Retrofits, New Turn/Tail/Marker Lights

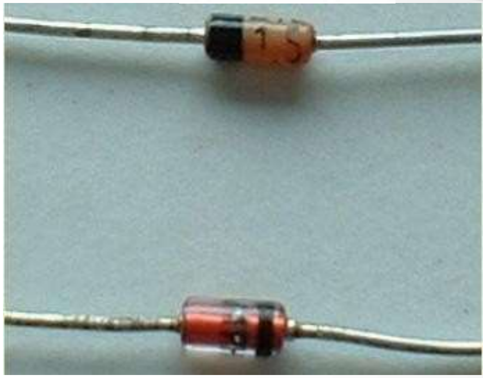
•**SIGNAL APPICATIONS:** Traffic Rail Aviation, Tower Lights, Runway Lights, Emergency/Police Vehicle Lighting,LEDs offer enormous benefits over traditional incandescent lamps, including: Energy savings (up to 85% less power than incandescent), Reduction in maintenance costs, Increased visibility in daylight and adverse weather conditions

•**ILLUMINATION:** Architectural lightening, Machine Vision Retail Displays, Emergency Lighting (Exit Signs) Neon Replacement, Bulb Replacements, Flashlights,Outdoor Accent Lighting - Pathway, Marker Lights, Studies have shown that the use of LEDs in illumination applications can offer: Greater visual appeal, Reduced energy costs, Increased attention capture, Savings in maintenance and lighting replacements

•**INDICATION:** Household appliances, VCR/ DVD/ Stereo and other audio and video devices,Toys/Games



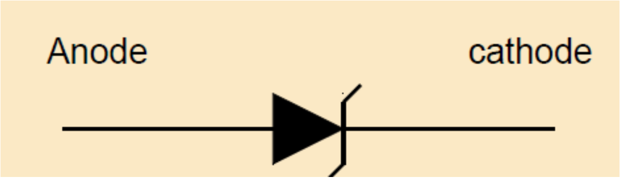

Zener Diode



Characteristics

- Zener diode is invented by "C. Zener".
- It is a heavily doped diode.
- Thin depletion region.
- Sharp break down voltage called zener voltage Vz.
- Its forward characteristics are same as pn diode characteristics.

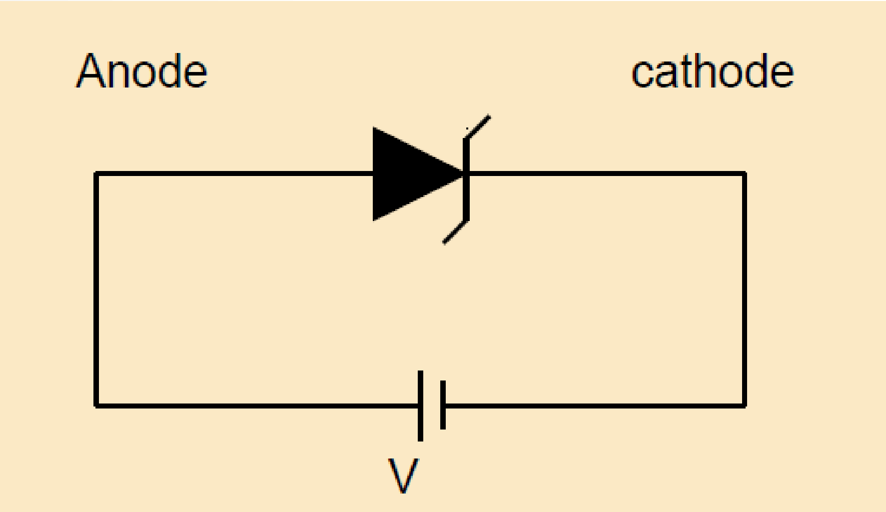
Circuit Symbol

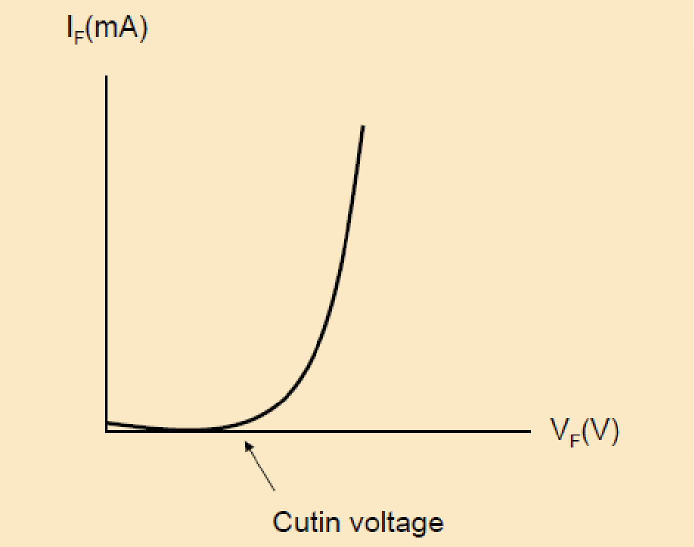


- Arrow head indicates the direction of conventional current flow.
- "Z" symbol at cathode is a indication for zener diode.

VI characteristics of Zener diode

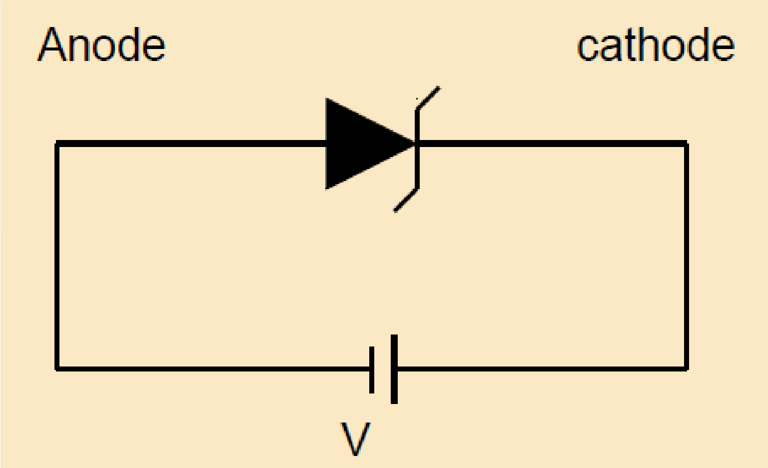
Zener diode forward biased characteristics

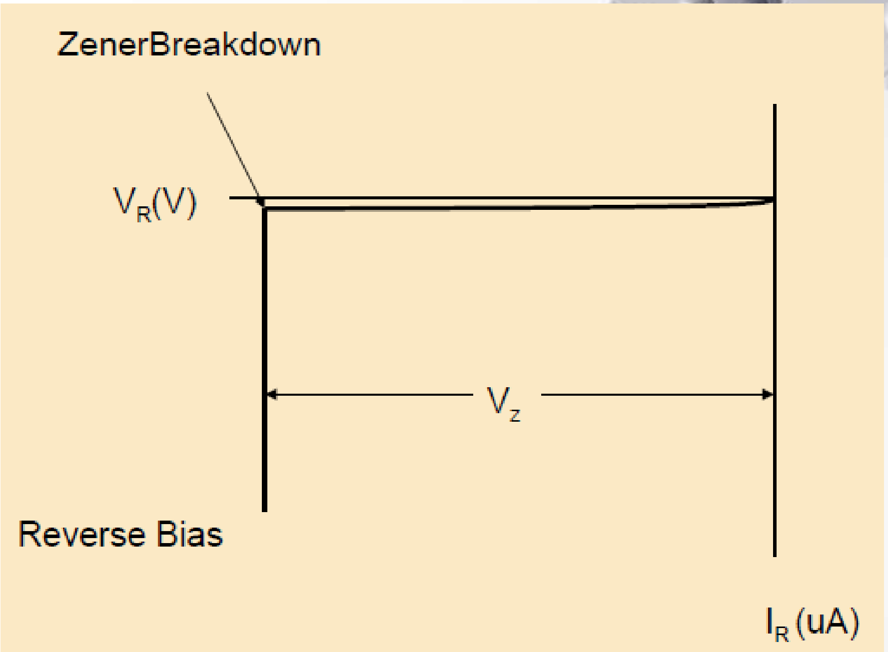




- Characteristics same as pn diode.
- Not operated in forward bias.

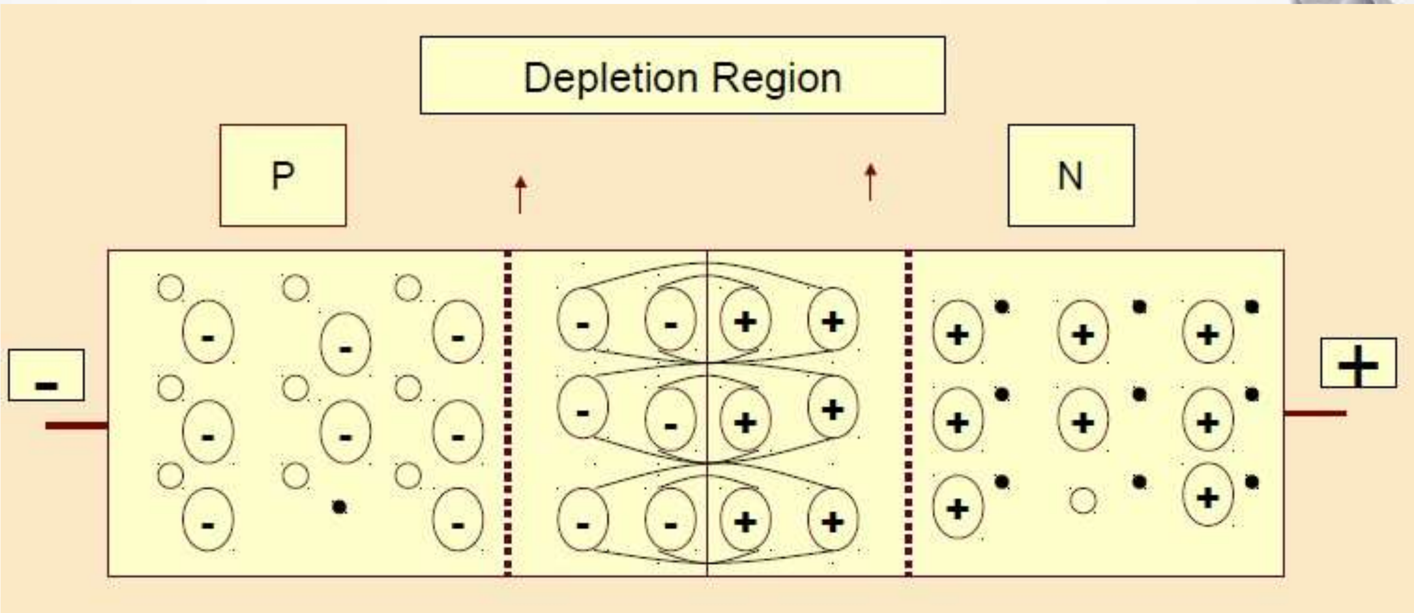
Zener diode reversed biased characteristics





- Always operated in reverse bias.
- Reverse voltage at which current increases suddenly and sharply
- known as Zener break down voltage.
- Zener break down occurs lower voltages than avalanche break down voltage.
- After break down the reverse voltage VZ remains constant.

Zener break down



Mechanism

•Break down in Zener Diode.
•In heavily doped diode field intensity is more at junction.
• Applied reverse voltage setup strong electric field.
•Thin depletion region in zener diode.
•Applied field enough to break covalent bonds in the depletion region.
•Extremely large number of electrons and holes results. •Produces large reverse current.
•Known as Zener Current IZ

Avalanche break down

•Break down in PN Diode.
•In lightly doped diode field intensity is not strong to produce zener break down
•Depletion region width is large in reverse bias.

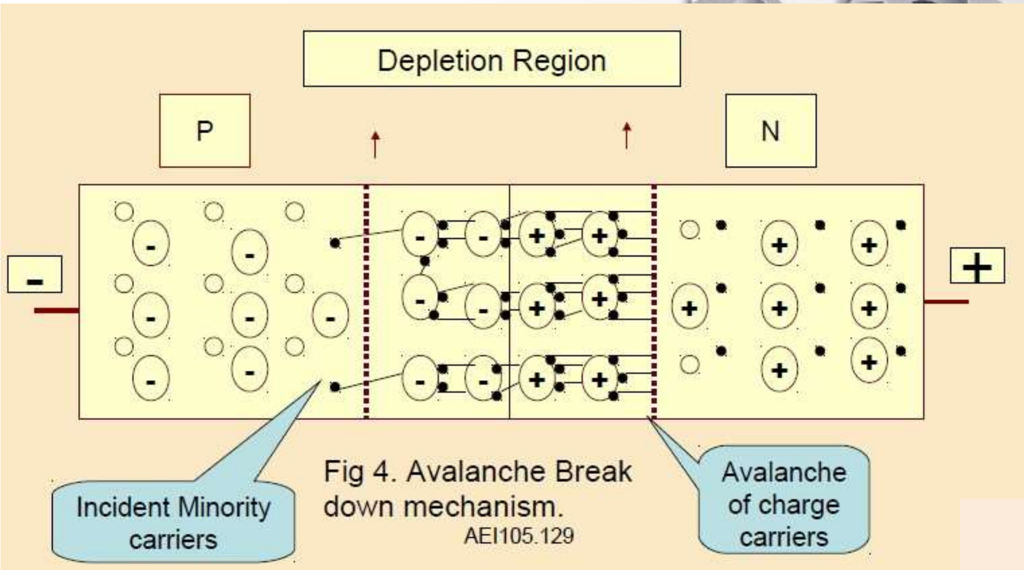


Fig 4. Avalanche Break down mechanism.

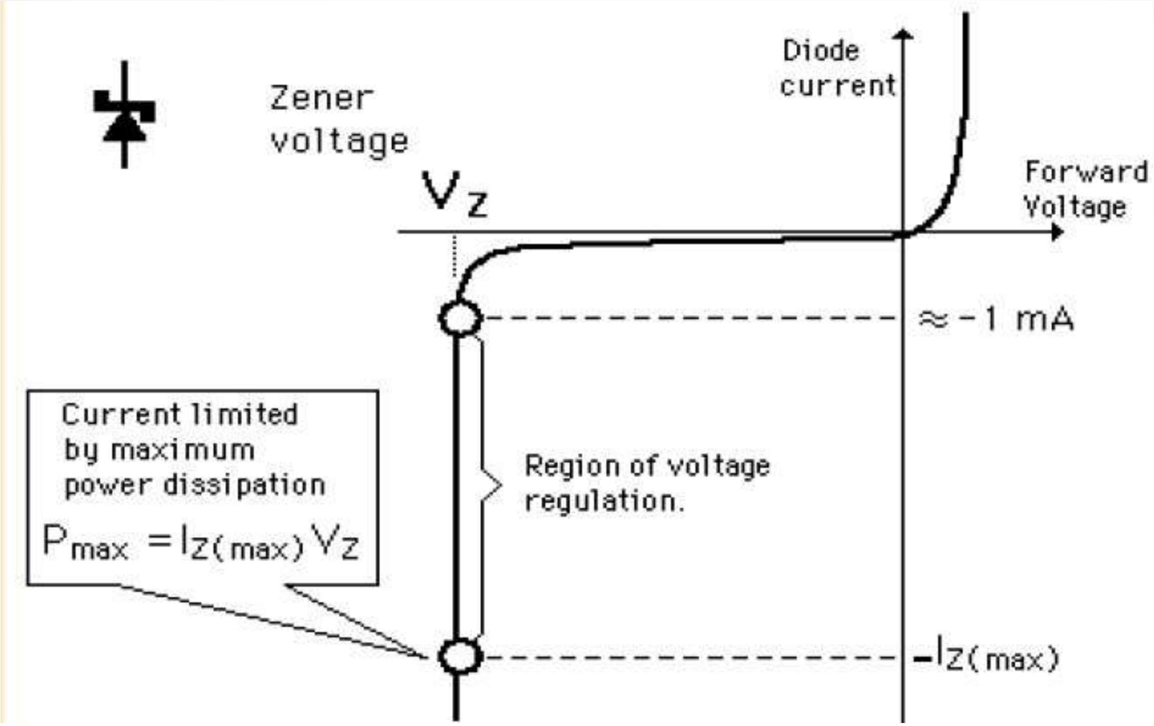
Mechanism

- Velocity of minority carriers increases with reverse bias.
- Minority carriers travels with great velocity and collides with ions in depletion region.
- Many covalent bonds breaks and generates more charge carriers.
- Generated charge carriers again collides with covalent bonds and again generates the carriers
- Chain reaction established.
- Creates large current.
- This effect is known as “Ionization by Collision”. • Damages the junction permanently.

Difference between Zener and Avalanche breakdown

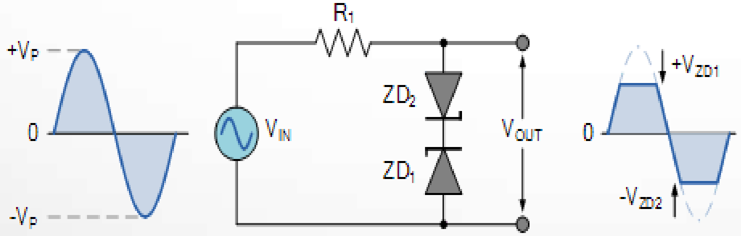
1. Occurs in heavily doped diodes.	1. Occurs in lightly doped diodes.
2. Ionization takes place by electric field.	2. Ionization takes place by collisions.
3. Occurs even with less than 5V.	3. Occurs at higher voltages.
4. After the breakdown voltage across the zener diode is constant.	4. After breakdown voltage across the pn diode is not constant.

VI characteristics of Zener diode



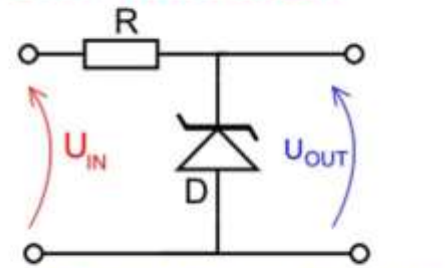
Applications of zener diode

- Used as voltage regulator.
- Also used in clipper circuits



Zener as clipper circuits

Zener Diode Circuit



Zener Diode Voltage Regulator

Summary

1. Semiconductors are the basic materials used in the present solid state electronic devices like diode, transistor, ICs, etc.
2. Metals have low resistivity (10^{-2} to 10^{-8} Ωm), insulators have very high, while semiconductors have intermediate values of resistivity.
3. Semiconductors are elemental (Si, Ge) as well as compound (GaAs,CdS, etc.).
4. Pure semiconductors are called „intrinsic semiconductors‟. The presence of charge carriers (electrons and holes) is an „intrinsic‟property of the material and these are obtained as a result of thermal excitation. The number of electrons (n_e) is equal to the number of holes (n_h) in intrinsic conductors. Holes are essentially electron vacancies with an effective positive charge.
5. The number of charge carriers can be changed by „doping‟ of a suitable impurity in pure semiconductors. Such semiconductors are known as extrinsic semiconductors. These are of two types (n-type and p-type).

6. There are two distinct band of energies (called valence band and conduction band) in which the electrons in a material lie. Valence band energies are low as compared to conduction band energies. All energy levels in the valence band are filled while energy levels in the conduction band may be fully empty or partially filled. The electrons in the conduction band are free to move in a solid and are responsible for the conductivity. The extent of conductivity depends upon the energy gap (E_g) between the top of valence band (E_V) and the bottom of the conduction band E_C. The electrons from valence band can be excited by heat, light or electrical energy to the conduction band and thus, produce a change in the current flowing in a semiconductor.
7. For insulators $Eg > 3$ eV, for semiconductors Eg is 0.2 eV to 3 eV, while for metals $Eg \approx 0$.
8. p-n junction is the „key‟ to all semiconductor devices. When such a junction is made, a „depletion layer‟ is formed consisting of immobile ion-cores devoid of their electrons or holes. This is responsible for a junction potential barrier.

9. By changing the external applied voltage, junction barriers can be changed. In forward bias (n-side is connected to negative terminal of the battery and p-side is connected to the positive), the barrier is decreased while the barrier increases in reverse bias. Hence, forward bias current is more (mA) while it is very small (μA) in a p-n junction diode.
10. Zener diode is one such special purpose diode. In reverse bias, after a certain voltage, the current suddenly increases (breakdown voltage) in a Zener diode. This property has been used to obtain *voltage regulation*.
11. p-n junctions have also been used to obtain many photonic or optoelectronic devices where one of the participating entity is „photon‟:(a) Photodiodes in which photon excitation results in a change of reverse saturation current which helps us to measure light intensity; (b) Solar cells which convert photon energy into electricity; (c) Light Emitting Diode and Diode Laser in which electron excitation by a bias voltage results in the generation of light.

Some important key points

Solid are **classified** in three categories metals, semiconductors and non-metals depending upon their conductivity.

Semiconductors have their conductivity in between those of metals and non-metals. Unlike metals they have a negative temperature coefficient of resistivity. This mean with the rise of temperature there is a decrease in their resistance and their conductivity increases.

Intrinsic Semiconductors: Semiconductors in their purest form possible are known as intrinsic semiconductors. Even intrinsic semiconductors have free electrons and vacancy (i.e. hole) because some of the electrons break their covalent bonds. This is because of the thermal energy acquired by these electrons. For intrinsic semiconductor density of holes is equal to the density of the electrons.

Holes: When an electron gets free from a covalent bond it creates a vacancy in the bond. This vacancy (center of electron deficiency) acts as a positive center know as hole.

Intrinsic semiconductors have very **low conductivity** as the number density of electrons and holes in pure semiconductors is very low.

Extrinsic semiconductors: Semiconductors in their pure form are not very useful because of their low conductivity. In order to increase their conductivity, impurities are added to them.

Doping: The deliberate addition of a desirable impurity is called *doping* and the impurity atoms are called *dopants*. Such a material is also called a *doped semiconductor/extrinsic semiconductor.*

n – type semiconductor: An *n* -type material is created by introducing impurity elements that have *five* valence electrons (*pentavalent*), such as *antimony*, *arsenic*, and *phosphorus*. The pentavalent dopant is donating one extra electron for conduction and hence is known as *donor* impurity. For n-type semiconductors, density of electrons is much higher than the density of holes i.e. **.**

p – type semiconductor: The *p* -type material is formed by doping a pure germanium or silicon crystal with impurity atoms having *three* valence electrons. The elements most frequently used for this purpose are *boron*, *gallium*, and *indium*. The trivalent dopant is deficient of one electron and thus creates a vacancy. The resulting vacancy will readily *accept* a free electron: thus diffused trivalent impurities are called acceptor atoms. For p-type semiconductors, density of holes is much higher than the density of electrons i.e. **.**

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Extrinsic semiconductor like intrinsic semiconductors as a whole are neutral in nature. This is because the total number of protons and the electrons are equal.

In an n-type material the electron is called the majority carrier and the hole the minority carrier. On the other-hand in a p-type material the hole is the majority carrier and the electron is the minority carrier.

p-n junction: When a p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called p-n junction. Most semiconductor devices contain one or more *p-n* junctions. The *p-n* junction is of great importance because it is in effect, the *control element* for semiconductor devices.

Depletion Layer: When a p-n junction is formed this cause electron hole recombination near the junction. As a result of this around the junction both p and n side are left with only immobile ions and all the charge carriers are gone. These two layers of positive and negative charges form the *depletion region* (or *depletion layer*). The term depletion is due to the fact that near the junction, the region is depleted (*i.e.* emptied) of *charge carries* (free electrons and holes) due to diffusion across the junction.

Barrier Potential: There exists a potential difference across the depletion layer and is called barrier potential ( ). The barrier potential of a *p-n* junction depends upon several factors including the type of semiconductor material, the amount of doping and temperature. The typical barrier potential is approximately: For silicon, = 0.7 V ; For germanium, = 0.3 V.

p-n junction diode: A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for the application of an external voltage. It is a two terminal device.

Forward Biasing: When external d.c. voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing**.**

Reverse Biasing: When the external d.c. voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing.

Junction Breakdown: The process by which a depletion region at the p-n junction is destroyec and allows a large reverse current is called depletion region breakdown. There are two main mechanisms of junction breakdown, depending on the dopant concentration levels.

1. Avalanche breakdown 2. Zener breakdown

Avalanche breakdown: Avalanche breakdown occurs in moderately and lightly doped p-n junctions with a wide depletion region. Electron hole pairs thermally generated in the depletion region are accelerated by the external reverse bias. Electrons are accelerated towards then side and holes towards the p side. These electrons can interact with other Si atoms and if they have sufficient energy can knock off electrons from these Si atoms. This process is called impact ionization and leads to production of a large number of electrons. This causes the rapid rise in current.

Zener Breakdown: With increase in doping concentration the breakdown mechanism, changes from Avalanche to a tunneling mechanism. This is called a Zener breakdown. This is because th depletion width decreases with dopant concentration. Also, the reverse bias causes an offset in the bands such that it is possible for carriers to tunnel across the narrow depletion region.

Zener Diode: It is a special purpose semiconductor diode, named after its inventor C. Zener. It designed to operate under reverse bias in the breakdown region and used as a voltage regulator.

Tunnel Diode: The tunnel diode was first introduced by Leo Esaki in 1958. Its characteristics, are different from any other diode as it has a negative-resistance region. In this region, an increase in terminal voltage results in a reduction in diode current. It has a greatly reduced depletion region, of the order of magnitude of cm, or typically about 1/100 the width of this region for a typical semiconductor diode. It is this thin depletion region, through which many carriers can "tunnel" rather than attempt to surmount, at low forward-bias potentials.

Varactor Diode: A junction diode which acts as a variable capacitor under changing reverse bias is known as a varactor diode**.** The capacitance of varactor diode is found as

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where = Total capacitance of the junction, Ɛ = permittivity of the semiconducting material A = Area of cross section of the junction, = Width of the depletion layer

Photo diode: It is a reverse-biased silicon or germanium p-n junction in which reverse current increases when the junction is exposed to light. The reverse current in a photo-diode is directly proportional to the intensity of light falling on its p-n junction. This means that greater the intensity of light falling on the p-n junction of photo-diode, the greater will be the reverse current.

LED: The light-emitting diode is a diode that gives off visible or invisible (infrared) light when energized. In any forward-biased $p - n$ junction there is, within the structure and primarily close to the junction, a recombination of holes and electrons. This recombination requires that the energy possessed by the unbound free electrons be transferred to another state. In all semiconductor $p - n$ junctions some of this energy is given off in the form of heat and some in the form of photons.

Some useful links

Some useful links

FOR TYPES OF DIODES:

https://www.electrical4u.com/diode-working-principle-and-types-of-diode/

https://www.allaboutcircuits.com/video-lectures/diode-characteristics-circuits/

https://www.khanacademy.org/science/electrical-engineering/ee-semiconductor-devices/ee-diode/v/ee-diode

FOR BREAKDOWN:

https://www.youtube.com/watch?v=EzISafjMltc