ADITYA ENGINEERING COLLEGE (A)

Microwave Solid State Devices (UNIT-IV)

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Course Objectives

COB 1: To make the student understand the Structure of Microwave transmission lines.

COB 2: To enable the student understand different Microwave components and its applications.

COB 3: To impart the working principle of various Microwave Tubes.

COB 4: To impart the knowledge on Solid State Microwave devices.

COB 5: To study the principles of various parameters measurement using Microwave test bench.

Course Outcomes

At the end of the Course, Student will be able to:

CO1: Explain the characteristics of different wave guide structures.

CO2: Evaluate the performance of the Microwave components using S-matrix.

CO3: Explain the characteristics of Microwave tubes.

CO4: Dictum on working principles of Microwave Solid State Devices.

CO5: Measure different parameters by using a bench set-up.

Course Contents

Unit I: Microwave transmission lines & Micro-strip lines

Unit II: Waveguide components and applications

Unit III: Microwave Tubes

Unit IV: Microwave Solid state Devices

Unit V: Microwave measurements

Unit-4 Outcomes

At the end of the module, Student will be able to:

CO 1 : Make a comment on working principle of Transfer Electron Devices.

CO 2 : Explore the significance of negative resistance devices at microwave frequencies.

Unit-IV : Microwave Solid State Devices

Introduction, Classification, Applications.

TEDs – Introduction,

Gunn Diode

- Principle, RWH Theory, Characteristics,
- Basic Modes of Operation,
- Oscillation Modes.

Avalanche Transit Time Devices – Introduction,

- IMPATT Diodes – Principle of Operation and Characteristics
- TRAPATT Diodes – Principle of Operation and Characteristics
- Schottky Diodes – Principle of Operation and Characteristics
- Detectors –Principle of operation and Characteristics,
- PIN Diodes – Principle of Operation and Characteristics

Varactor Diodes –Principle of operation and Characteristics.

Introduction:

Introduction:

- Two problems with conventional transistors at higher frequencies are:

  1. Stray capacitance and inductance.

     - remedy is interdigital design.

  2. Transit time.

     - free electrons move quicker than holes therefore change from silicon to Gallium Arsenide

- Conventional bipolar transistors are not suitable for microwave frequencies.

  - Electrons move faster than holes.

- Component leads introduce elevated reactance.

  - XL increases and XC decreases therefore collector feedback becomes worse as frequency increases.
  - Transit time and mobility of carriers.
  - As transit time approaches signal period, phase shifts occur.

Introduction:

Classification: The classification of solid state Microwave devices can be done

- Depending upon their electrical behavior
  - Non-linear resistance type.
    - Example – Varistors (variable resistances)
  - Non-Linear reactance type.
    - Example – Varactors (variable reactors)
  - Negative resistance type.
    - Example – Tunnel diode, IMPATT diode, GUNN diode
  - Controllable impedance type.
    - Example – PIN diode(fixed or variable Capacitance and R)
- Depending upon their construction
  - Point contact diodes
  - Schottky barrier diodes
  - Metal Oxide Semiconductor devices MOS
  - Metal Insulation devices

Introduction:

Applications:

The types of diodes have many uses such as;

- amplification,
- detection,
- power generation,
- phase shifting,
- down conversion,
- Up-conversion,
- limiting
- modulation,
- switching, etc.

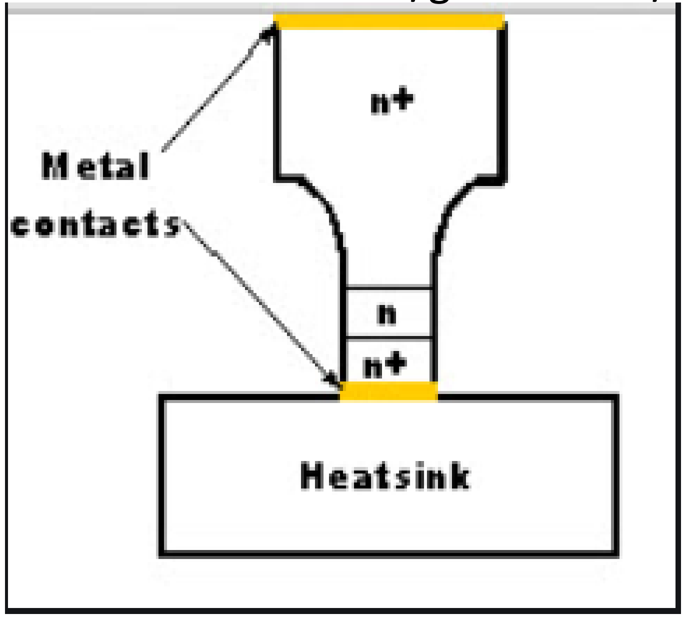
Transferred Electron Devices–TEDs

Introduction:

- TEDs are bulk devices having no junctions or gates.
- (Transistors operate with either junctions or gates)
- TEDs are fabricated from compound semiconductors, such as
    - gallium arsenide (GaAs),
    - indium phosphide (InP), or
    - cadmium telluride (CdTe).
    - (transistors are fabricated from elemental semiconductors, such as silicon or germanium)
- TEDs operate with "hot" electrons whose energy is very much greater than the thermal energy.
    - (Transistors operate with "warm" electrons whose energy is not much greater than the thermal energy (0.026 eV at room temperature) of electrons in the semiconductor)
- Because of these fundamental differences, the theory and technology of transistors cannot be applied to TEDs.

Gunn Diode

https://www.electrical4u.com/gunn-diode/



Principle:

- Gunn-effect diodes are named after J. B. Gunn, who, in 1963, discovered a **periodic fluctuations of current** passing through the n-type gallium arsenide (GaAs) specimen when the applied voltage exceeded a certain critical value.
- By that many devices developed
  - ❖ IMPact Ionization Avalanche Transit-Time (IMPATT)
  - ❖ Limited Space-charge-Accumulation diode (LSA diode) and
  - ❖ Indium Phosphide diode (InP diode) were also successfully developed.

RWH Theory: In 1964 Kroemer suggested that Gunn's observations were in complete agreement with the Ridley Watkins-Hilsum (RWH) theory.

Proposals:

Differential Negative Resistance

Two-Valley model Theory

Gunn Diode-RWH Theory

Differential Negative Resistance: The fundamental concept of RWH theory is differential negative resistance developed in a bulk solid state device either voltage or current is applied to the terminals of the sample.

There are two modes of Differential Negative Resistance devices

1. Voltage controlled mode
2. Current controlled mode

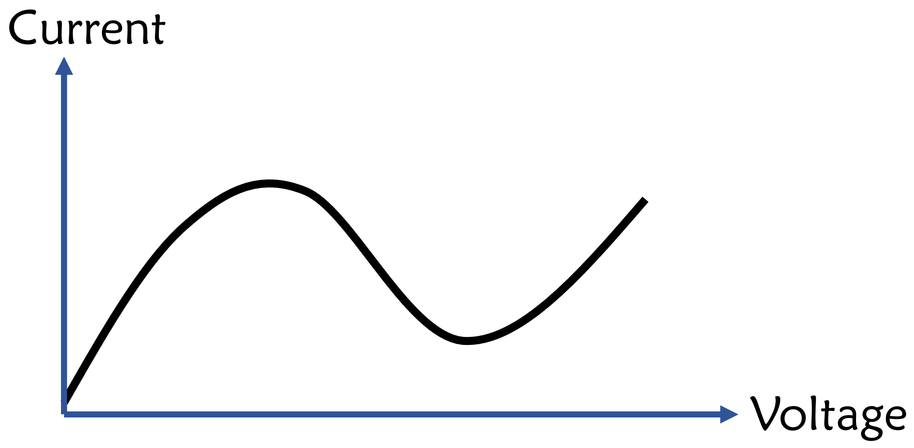


Fig. Voltage Controlled mode

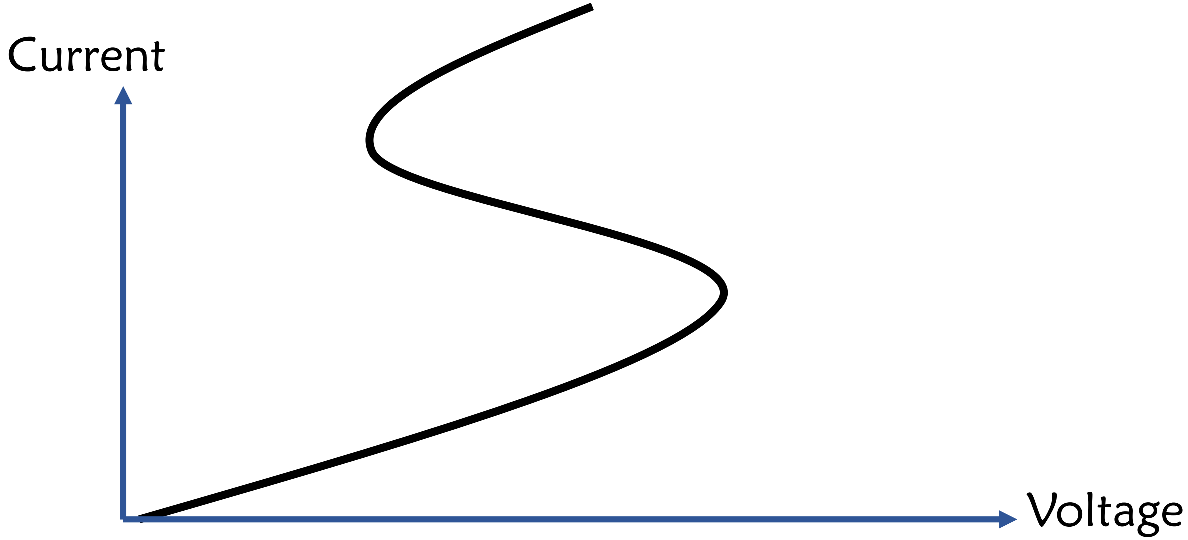
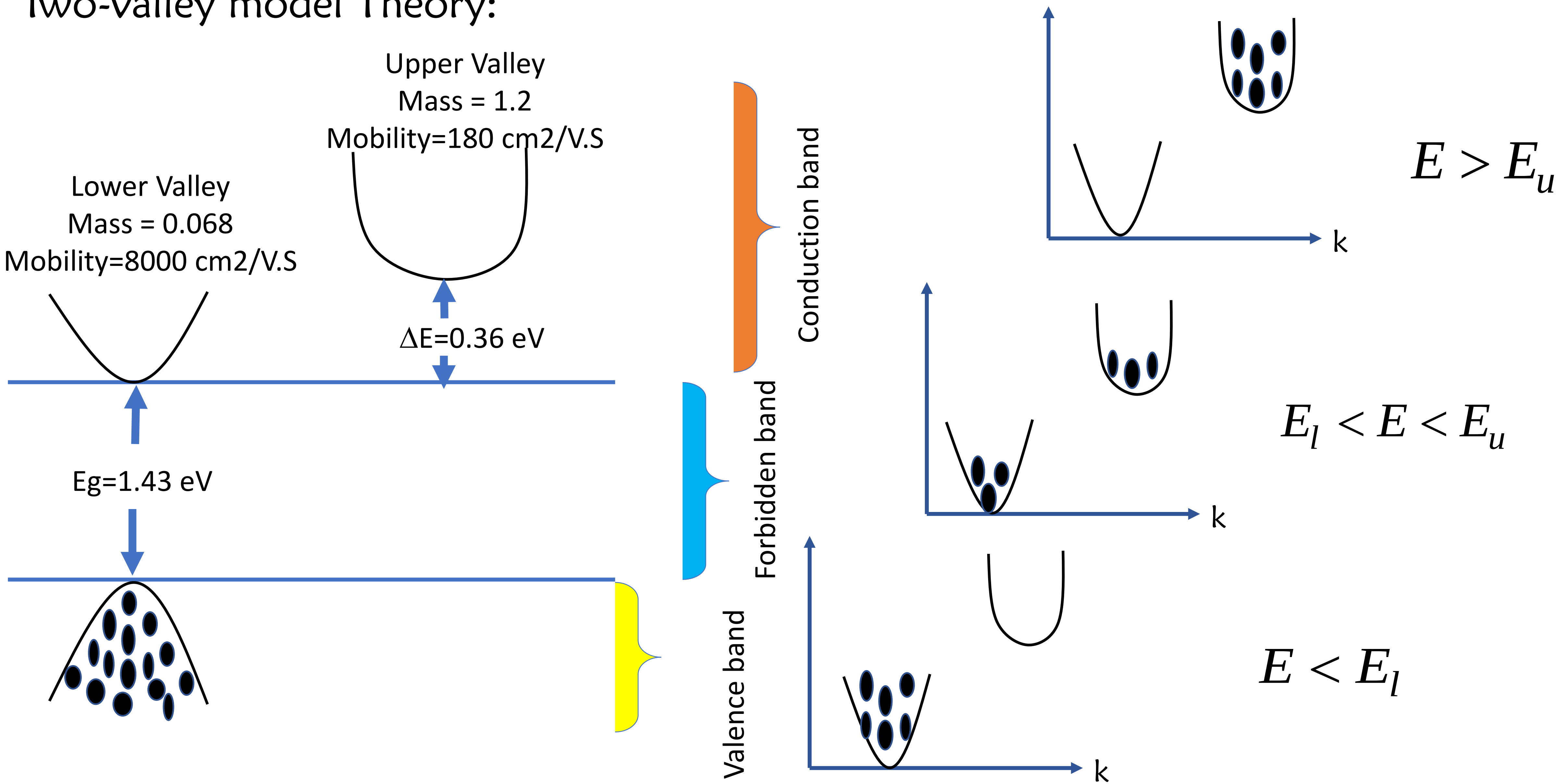


Fig. Current Controlled mode

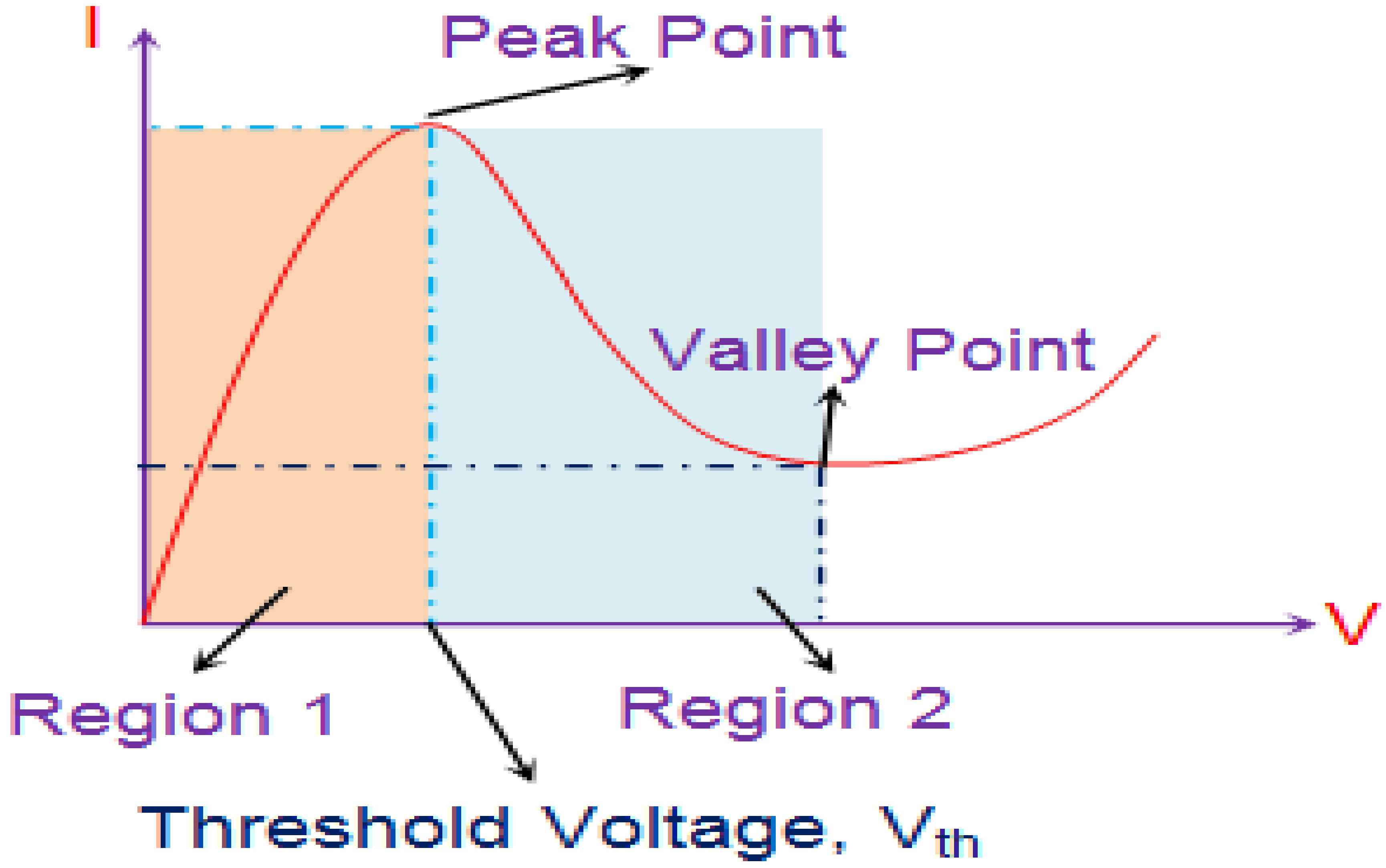
In the voltage controlled mode, the current density can be multi-valued, where as in the current control mode the voltage can be multi valued.

Gunn Diode-RWH Theory

Two-Valley model Theory:



Gunn Diode: V-I characteristics



Gunn Diode: V-I characteristics

On applying a DC voltage across the terminals of the Gunn diode, an electric field is developed across its layers, most of which appears across the central active region.

At initial stages, the conduction increases due to the movement of electrons from the valence band into the lower valley of the conduction band.

The associated V-I plot is shown by the curve in the Region 1 (colored in pink) of Figure. However, after reaching a certain threshold value (Vth), the conduction current decreases as shown by the curve in the Region 2 (colored in blue) of the figure.

This is because, at higher voltages the electrons in the lower valley of the conduction band move into its higher valley where their mobility decreases due to an increase in their effective mass.

The reduction in mobility decreases the conductivity which leads to a decrease in the current flowing through the diode.

As a result the diode is said to exhibit negative resistance region (region spanning from Peak point to Valley Point) in the V-I characteristic curve.

This effect is called transferred electron effect and thus the Gunn diodes are also called Transferred Electron Devices.

Gunn Diode-modes of operation

Gunn diode operation modes or Oscillating modes are;

Transit-Time (TT)mode and Limited-Space Charge Accumulation (LSA) mode.

Gunn diode TT mode:
When the voltage across n+ n n+ GaAs crystal exceeds the threshold voltage, electrons are transferred from (low energy, high mobility band) to (high energy, low mobility band).

Here heavier electrons bunch together to form electric field near the cathode.
The TT mode of oscillation has low efficiency of power generation.

In this mode, the frequency cannot be controlled by an external circuit.

Gunn diode LSA mode:
LSA mode in Gunn diode produces several watts of power at a minimum efficiency of about 20%.

The output power decreases with increase in frequency. For example, it generates 1Watt @ 10GHz and several mW@ 100GHz.

In LSA mode of operation, Gunn diode works as part of a resonant circuit.

Gunn Diode

Principle, RWH Theory, Characteristics

Like conventional ordinary vacuum tubes cannot be used at high frequency, because some parameters generate complicated situations and these parameters are

1. The interelectrode capacitance effect
2. The Lead inductance effect
3. Transit time

To overcome the above problems one should use either a high frequency transistor or some other special type of semiconductor devices. Like negative resistance and non-linearity in the operation make these special devices (Varactor diode, PIN diode, IMPATT diode, TRAPATT diode, Tunnel diode and Gunn diode along with the high frequency transistors)

Some observations we conclude that Bulk semiconductor device- Gunn diode Ordinary p-n junction diodes- Varactor and Tunnel diodes Modified p-n junction diodes- IMPATT, TRAPATT, PIN diodes such as p+ -n or p-i-n type Microwave semiconductor devices have been developed for various applications like, detection, mixing, frequency multiplications, attenuation, switching, limiting, amplification or oscillation etc

Gunn Diode

Principle, RWH Theory, Characteristics

Classification:-

Microwave Semiconductor Devices

Transferred Electron Devices (TEDs)	FET	Microwave Transistors	Avalanche Transit time devices
Gunn diode, LSA diode BARRITT	JFET, MOSFET NMOS, CMOS	BJT, HBT, Tunnel devices	READ, IMPATT TRAPATT,
C,X and Ku bands	Frequency of operation up to 5 GHz		multimeter wave frequency

LSA- Limited Space Charge Accumulation

IMPATT- Impact Ionization Avalanche Transit Time Device

TRAPATT- Trapped Plasma Avalanche Triggered Transit Device

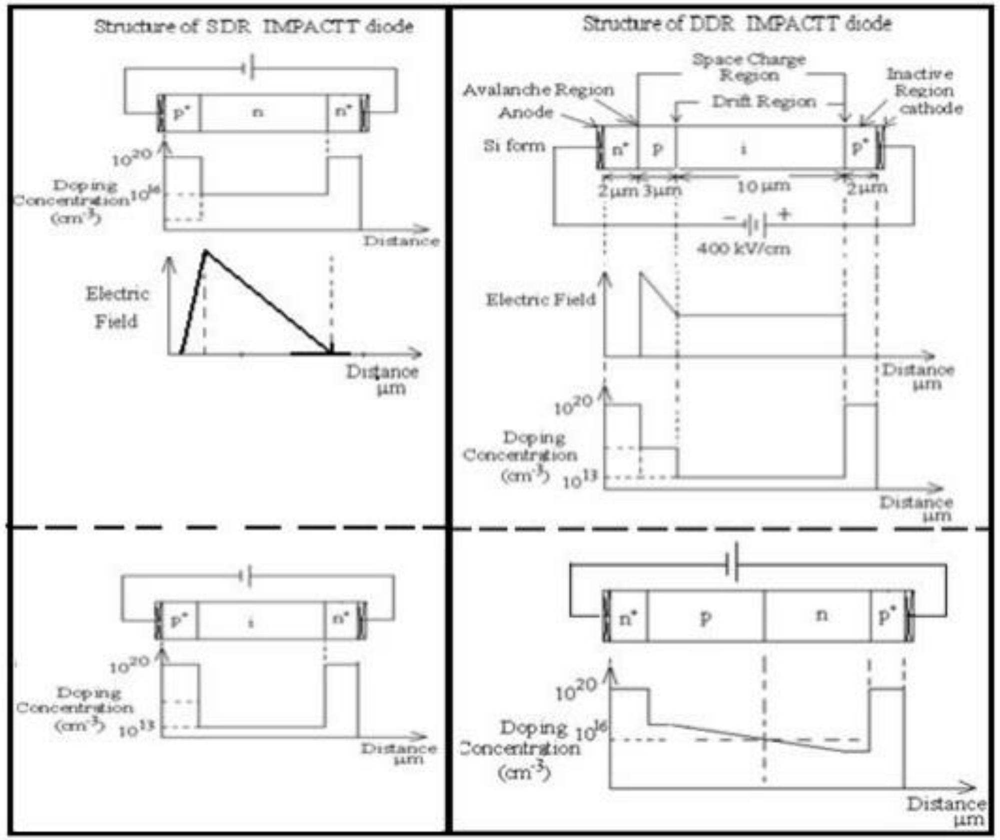
Types of Avalanche Transit Time Devices:-

1. IMPATT (Impact Ionization Avalanche Transit Time) device
2. TRAPATT (Trapped Plasma Avalanche Triggered Transit Time) device
3. BARITT (Barrier Injected Transit time) device

IMPATT (Impact Ionization Avalanche Transit Time) device

An IMPATT diode (Impact ionization Avalanche Transit-Time) is a form of high-power diode used in high-frequency electronics and microwave devices. They operate at frequencies between about 3 and 100 GHz or more. It has many forms like n + pip+ , p+ nin+ read device, p+ nn+ abrupt junction and p+ in+ diode. Here positive (+) sign indicates a high level of doping and i stands for intrinsic or pure silicon.

Types IMPATT diodes and Doping Profile

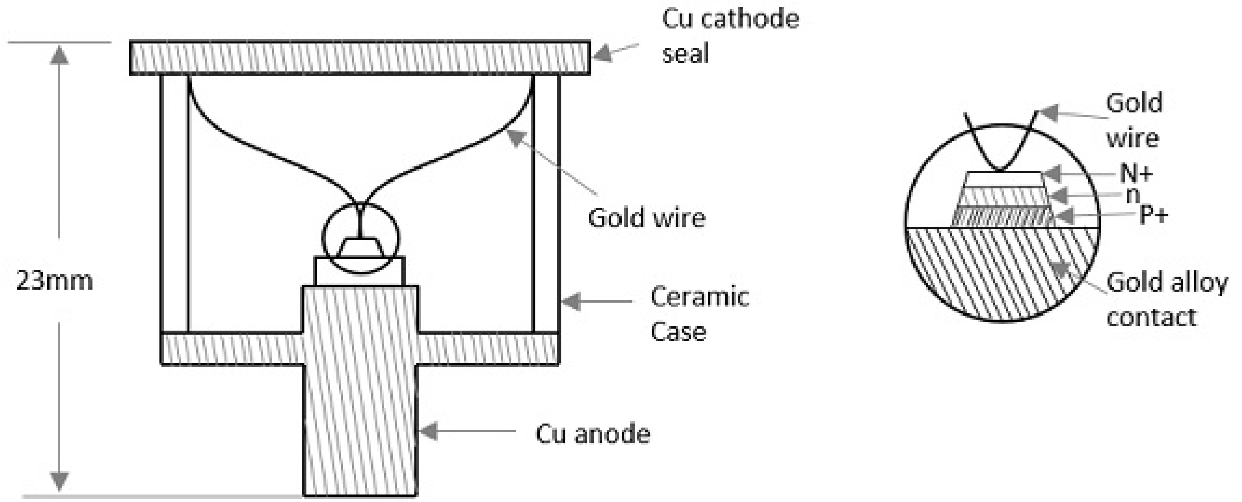


The two common types of IMPATT structures are SDR (Single Drift Region) and DDR (Double Drift Region). The doping and field profile of both SDR and DDR are shown in above figure.

The two common types of IMPATT structures are SDR (Single Drift Region) and DDR (Double Drift Region). The doping and field profile of both SDR and

- IMPATT diodes can be manufactured from Ga, Si, GaAs or InP. However GaAs provides the highest priority, because of its high efficiency, the highest operating frequency and least noise figure. But the fabrication process is more difficult and costly than Si.
- A main advantage is high-power capability. These diodes are used in a variety of applications from low-power radar systems to alarms.
- A major drawback of using IMPATT diodes is the generation of phase noise which result from the statistical nature of the avalanche process. Nevertheless these diodes make excellent microwave generators for many applications.

constructional details of an IMPATT diode.



Constructional details of IMPATT

The efficiency of IMPATT diode is represented as

$$\eta = \left[\frac{P_{ac}}{P_{dc}}\right] = \frac{V_a}{V_d}\left[\frac{I_a}{I_d}\right]$$

Where,

- P_{ac} = AC power
- P_{dc} = DC power
- V_a & I_a = AC voltage & current
- V_d & I_d = DC voltage & current

Disadvantages

Following are the disadvantages of IMPATT diode.

It is noisy as avalanche is a noisy process

Tuning range is not as good as in Gunn diodes

Applications

Following are the applications of IMPATT diode.

Microwave oscillator

Microwave generators

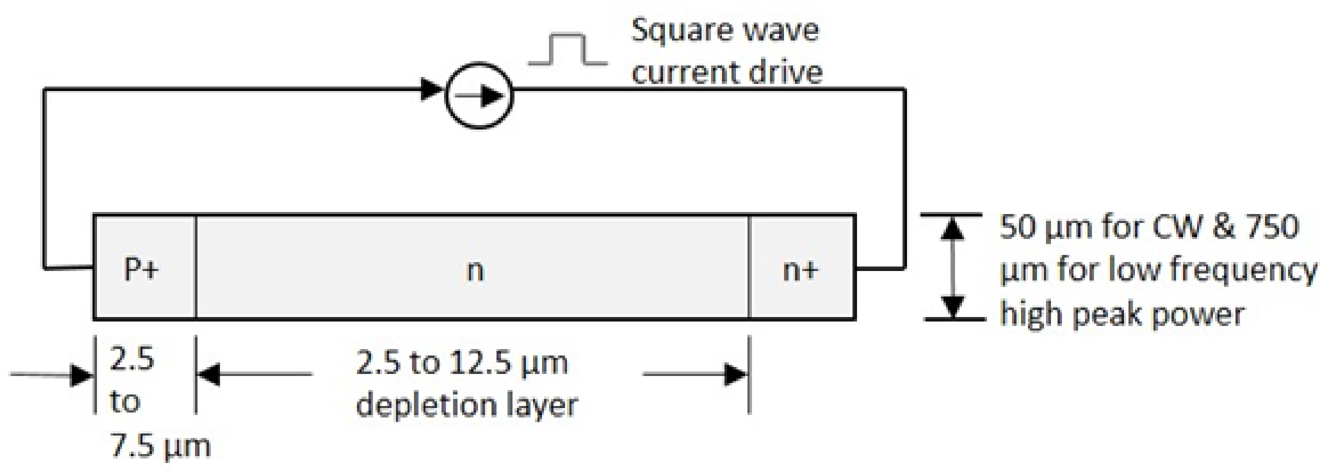
Modulated output oscillator

Receiver local oscillator

Negative resistance amplifications

TRAPATT Diode

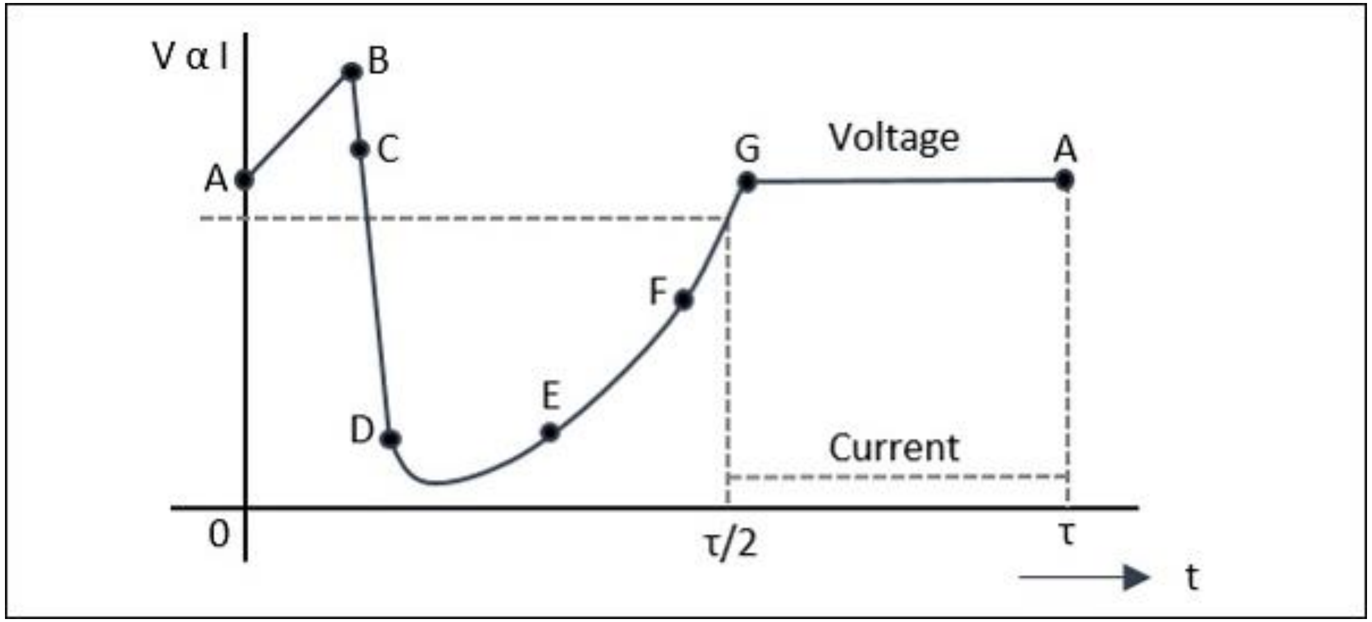
The full form of TRAPATT diode is TRApped Plasma Avalanche Triggered Transit diode. A microwave generator which operates between hundreds of MHz to GHz. These are high peak power diodes usually n+- p-p+ or p+-n-n+ structures with n-type depletion region, width varying from 2.5 to 1.25 Âµm. The following figure depicts this.



Arrangement in TRAPATT diode

The electrons and holes trapped in low field region behind the zone, are made to fill the depletion region in the diode. This is done by a high field avalanche region which propagates through the diode.

The following figure shows a graph in which AB shows charging, BC shows plasma formation, DE shows plasma extraction, EF shows residual extraction, and FG shows charging.



Let us see what happens at each of the points.

A: The voltage at point A is not sufficient for the avalanche breakdown to occur. At A, charge carriers due to thermal generation results in charging of the diode like a linear capacitance.

A-B: At this point, the magnitude of the electric field increases. When a sufficient number of carriers are generated, the electric field is depressed throughout the depletion region causing the voltage to decrease from B to C.

C: This charge helps the avalanche to continue and a dense plasma of electrons and holes is created. The field is further depressed so as not to let the electrons or holes out of the depletion layer, and traps the remaining plasma.

D: The voltage decreases at point D. A long time is required to clear the plasma as the total plasma charge is large compared to the charge per unit time in the external current.

E: At point E, the plasma is removed. Residual charges of holes and electrons remain each at one end of the deflection layer.

E to F: The voltage increases as the residual charge is removed.

F: At point F, all the charge generated internally is removed.

F to G: The diode charges like a capacitor.

G: At point G, the diode current comes to zero for half a period. The voltage remains constant as shown in the graph above. This state continues until the current comes back on and the cycle repeats.

The avalanche zone velocity V_s is represented as

$$V_s = \frac{dx}{dt} = \frac{J}{qN_A}$$

Where

- J = Current density
- q = Electron charge 1.6 x 10^{-19}
- N_A = Doping concentration

The avalanche zone will quickly sweep across most of the diode and the transit time of the carriers is represented as

$$\tau_s = \frac{L}{V_s}$$

Where

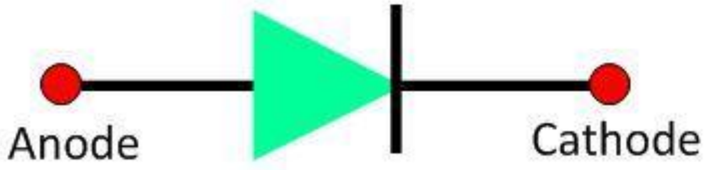
- V_s = Saturated carrier drift velocity
- L = Length of the specimen

Applications

There are many applications of this diode.

- Low power Doppler radars
- Local oscillator for radars
- Microwave beacon landing system
- Radio altimeter
- Phased array radar, etc.

PIN Diode



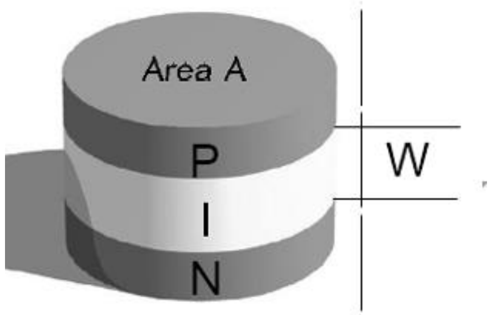
What is a PIN Diode?

- The PIN diode is a one type of photo detector, used to convert optical signal into an electrical signal.
- The PIN diode comprises of three regions, namely P-region, I-region and N-region.
- Typically, both the P and N regions are heavily doped due to they are utilized for Ohmic contacts.
- The intrinsic region in the diode is in contrast to a PN junction diode.
- This region makes the PIN diode an lower rectifier, but it makes it appropriate for fast switches, attenuators, photo detectors and applications of high voltage power electronics.

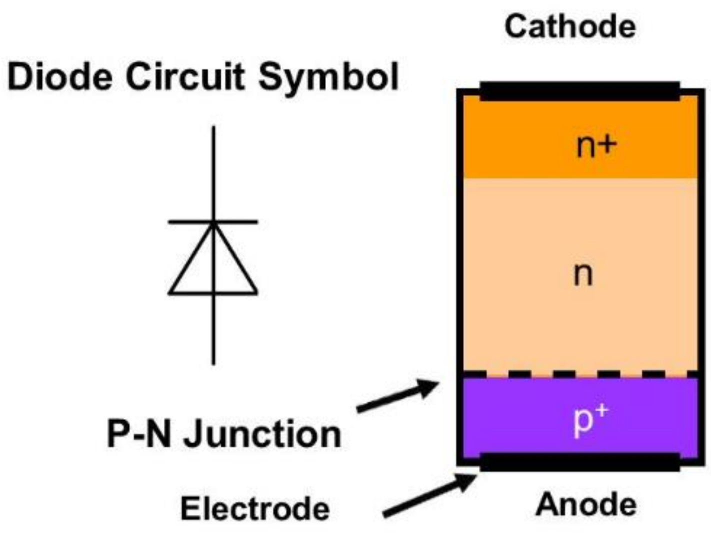
Structure and Working of PIN Diode

The term PIN diode gets its name from the fact that includes three main layers. Rather than just having a P-type and an N-type layer, it has three layers such as

- **P-type layer**
- **Intrinsic layer**
- **N-type layer**



The working principle of the PIN diode exactly same as a normal diode. The main difference is that the depletion region, because that normally exists between both the P & N regions in a reverse biased or unbiased diode is larger. In any PN junction diode, the P region contains holes as it has been doped to make sure that it has a majority of holes. Likewise the N-region has been doped to hold excess electrons.



The layer between the P & N regions includes no charge carriers as any electrons or holes merge As the depletion region of the diode has no charge carriers it works as an insulator. The depletion region exists within a PIN diode, but if the PIN diode is forward biased, then the carriers come into the depletion region and as the two carrier types get together, the flow of current will starts.

When the PIN diode is connected in forward biased, the charge carriers are very much higher than the level of intrinsic carrier's attention. Due to this reason the electric field and the high level injection level extends deeply into the region. This electric field assists in speeding up of the moving of charge carriers from P to N region, which consequences in quicker operation of the PIN diode, making it an appropriate device for high frequency operations.

Reversed Biased PIN Diode

When the reverse voltage is applied across the diode, the width of the depletion region increases. The thickness of the region increases until the entire mobile charge carrier of the I-region swept away from it. The reverse voltage requires for removing the complete charge carrier from the I-region is known as the swept voltage.

In reverse bias, the diode behaves like a capacitor. The P and N region acts as the positive and negative plates of the capacitor, and the intrinsic region is the insulator between the plates.

$$C = \frac{\in A}{w}$$

Where, A – junction diode
w – intrinsic region thickness

The lowest frequency at which the effect starts to begins is expressed as

$$f_\tau = \frac{1}{2\pi\rho\varepsilon}$$

Where, ε – silicon dielectric constant

Characteristics of PIN Diode

At a lower level of reverse bias, the depletion layer becomes fully depleted. The capacitance of the pin diode becomes independent of the level of bias once the depletion layer is fully depleted. This is because there is very little net charge in the intrinsic layer. The leakage of RF signal is lower than other diodes because the level of capacitance is typically lower.

In forward bias, the diode behaves as a resistor than a non-linear device and produces no rectification or distortion. The value of the resistance depends on the bias voltage. Pin diode is used as RF switch or variable resistor as they produce fewer distortions than a normal diode.

Applications of PIN Diode

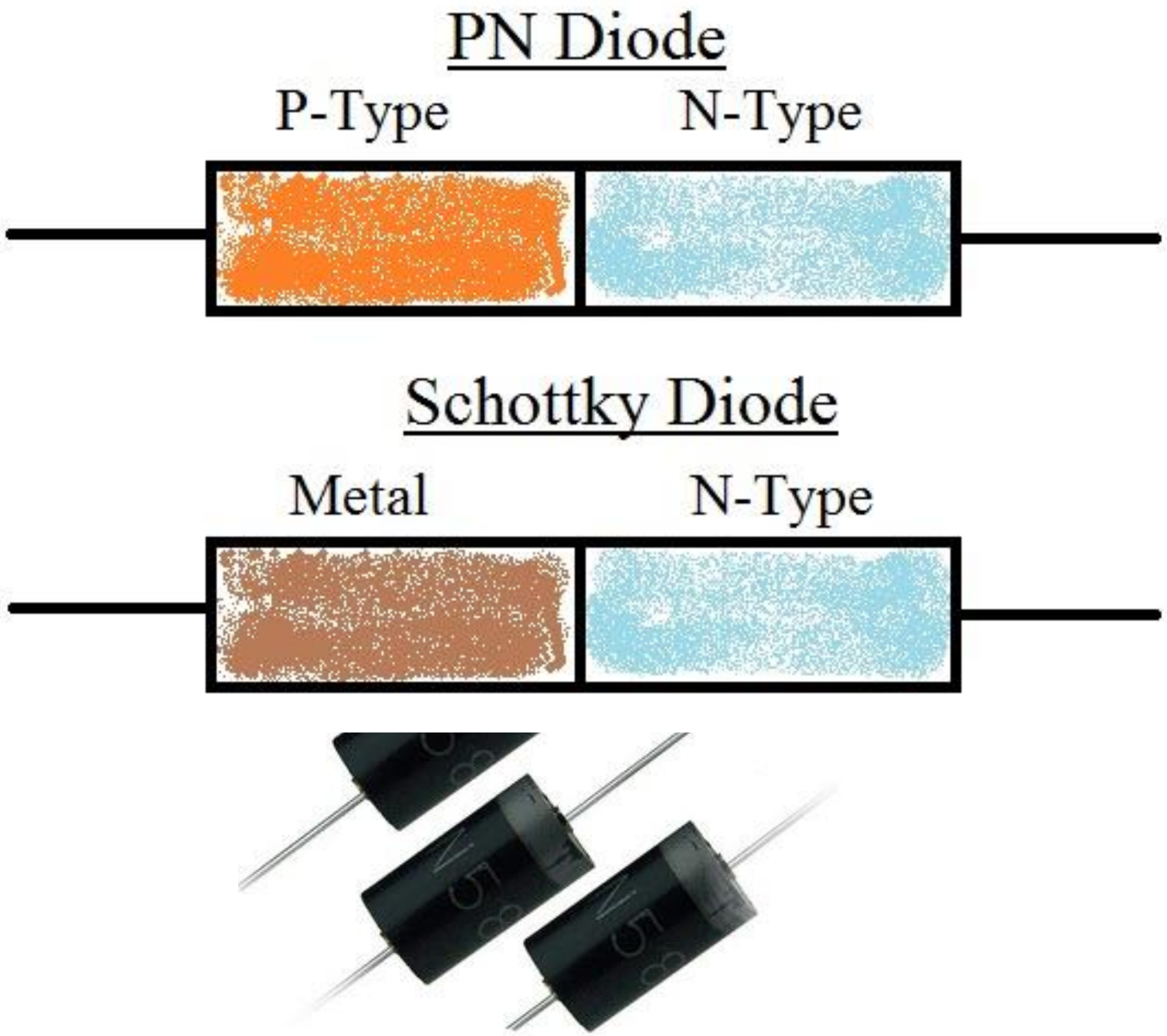
High Voltage Rectifier – It is used as a high voltage rectifier. The diode has a large intrinsic region between the N and P-region which can tolerate the high reverse voltage.

Photo-detector – The PIN diode is used for converting the light energy into the electrical energy. The diode has large depletion region which improves their performance by increasing the volume of light conversion.

The PIN diode is most suitable for low voltage applications.

Schottky Diode

Schottky diode is a dev ... al – semiconductor
junction diode. Barrier ... names for Schottky
diode. When compare ... lower in Schottky
diode. A scientist na ... Schottky diode.
Generally, in a PN junc ... negative type (n-
type) are joined toget ... a Schottky diode,
materials like aluminum ... conductors.



Symbol of Schottky Diode

The following image shows the symbol of a Schottky Diode.

Working of Schottky Diode

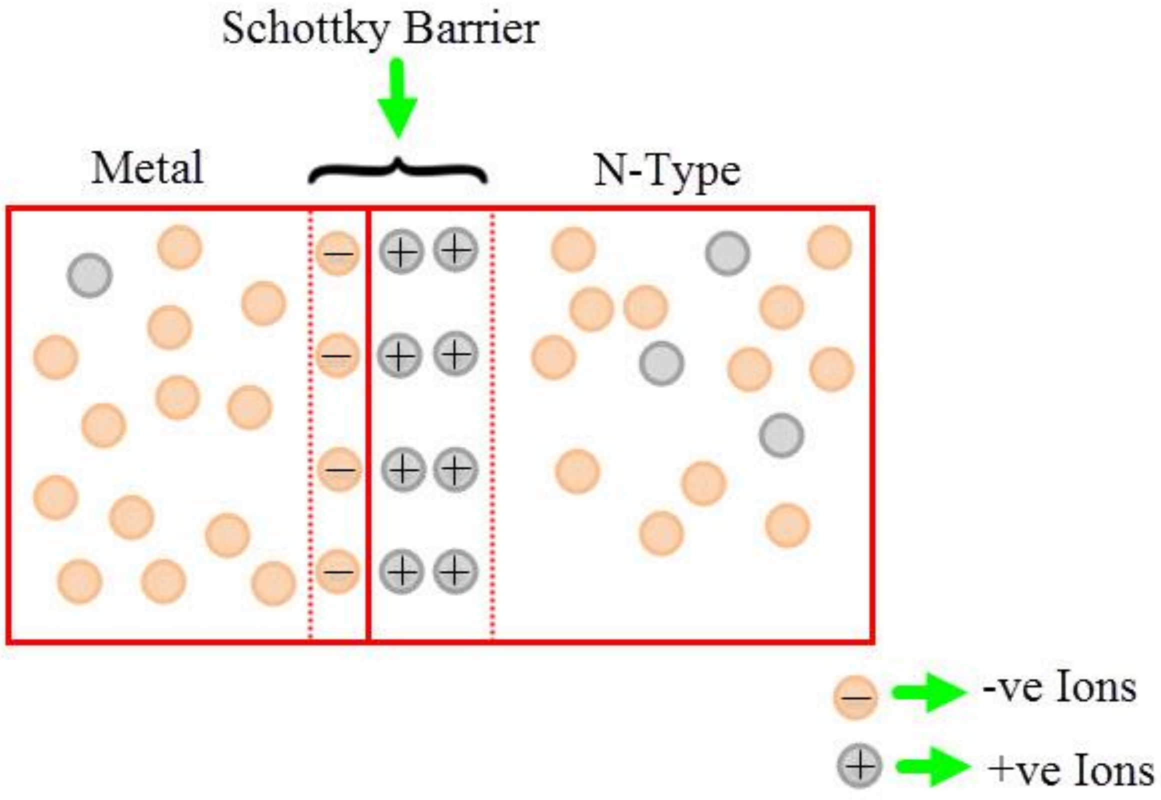
The most important physical parameter of this Schottky diode is their fast switching rate and less forward voltage drop. It is a metal – semiconductor junction that does not have the capacity to store charges at their junction. The reason behind this is due to absence of depletion layer.

Usually, a voltage drop happens across the diode terminals, when current flows through a diode. Schottky diode voltage drop is usually between 0.15 and 0.45 volts when compared to a normal diode. A normal PN junction diode has a voltage drop ranging between 0.6 to 1.7 volts. For a better efficiency and output, voltage drop should be low. When manufacturing the diode, N-type semiconductor acts as a cathode and the metal side acts an anode of the diode.

When voltage is given to the diode, the current flows in the forward direction. When this current flows through the diode, there will be a minimum voltage loss across the terminals of the diode. This loss of voltage is called as Voltage drop.

Construction of Schottky Diode

It is made of a metal and semiconductor forming unilateral junction. Few metals like
gold, silver, molybde . Usually an N type
semiconductor, which ed for low frequency
operation.

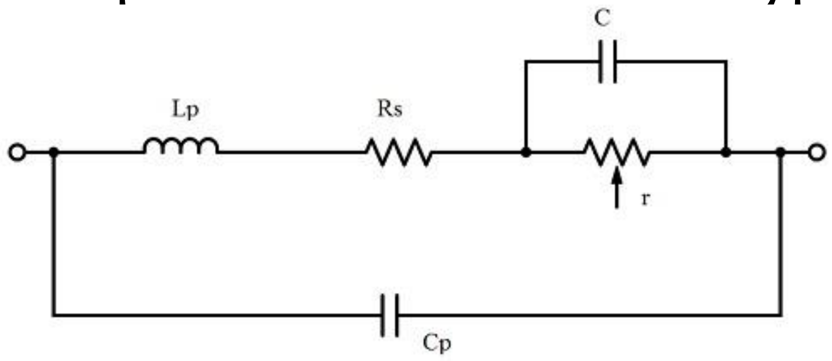


Schottky diode is relat N type semiconductor,
decrease and increase appens. Between the
semiconductors–metal n as Schottky barrier.
This barrier is called Schottky barriers are
Rectifying and Non-re doped semiconductor
meets each other, the en a metal encounters
the heavily doped se barrier. The width of
depletion layer rises w t the same time, when
width decreases charge carriers travels through tunnel and reaches the depletion layer. When doping level increases, the junction does not act as rectifier and it becomes ohmic contact.

Under unbiased condition, electrons accumulated on the semiconductor side will have a lower energy level than electrons present on the metal region. Due to this reason, electrons cannot flow across the Schottky Barrier.

Under forward biased condition, an electron present in the N-side receives more energy to cross the junction barrier and enters into the metal. Due to this, the electrons are also called as hot carrier. Hence, diode is called as hot carrier Diode.

The Schottky diode can be represented as an electrical equivalent circuit with typical values of the components is shown below.



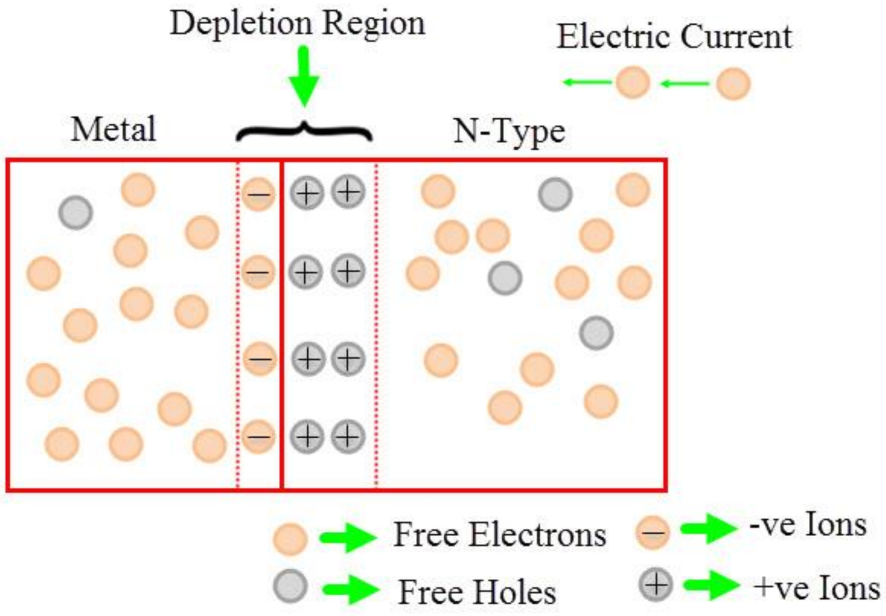
Lp = 3nH, Rs = 7Ω, Cp = 15pF, C = 1pF, r = 26Ω

Specialties of Schottky Diode

- Due to the absence of the current flow from metal to N-type semiconductor, it acts as a unipolar device. Whereas, a PN junction diode is a bipolar device.
- The metal does not have any holes, it does not store any charge. Due to this reason, Schottky diode has the advantage to quickly switch with relatively low noise.
- It has a low barrier potential compared to PN diode.

Operation of Schottky Diode
Unbiased Schottky Diode

The free electrons present inside the n – type semiconductor will move from n – type semiconductor to a metal during the combination between metal and n – type semiconductor. This results in production of equilibrium state. When free electrons moves across the junction, it provides an extra electron to the atoms present in the atom.

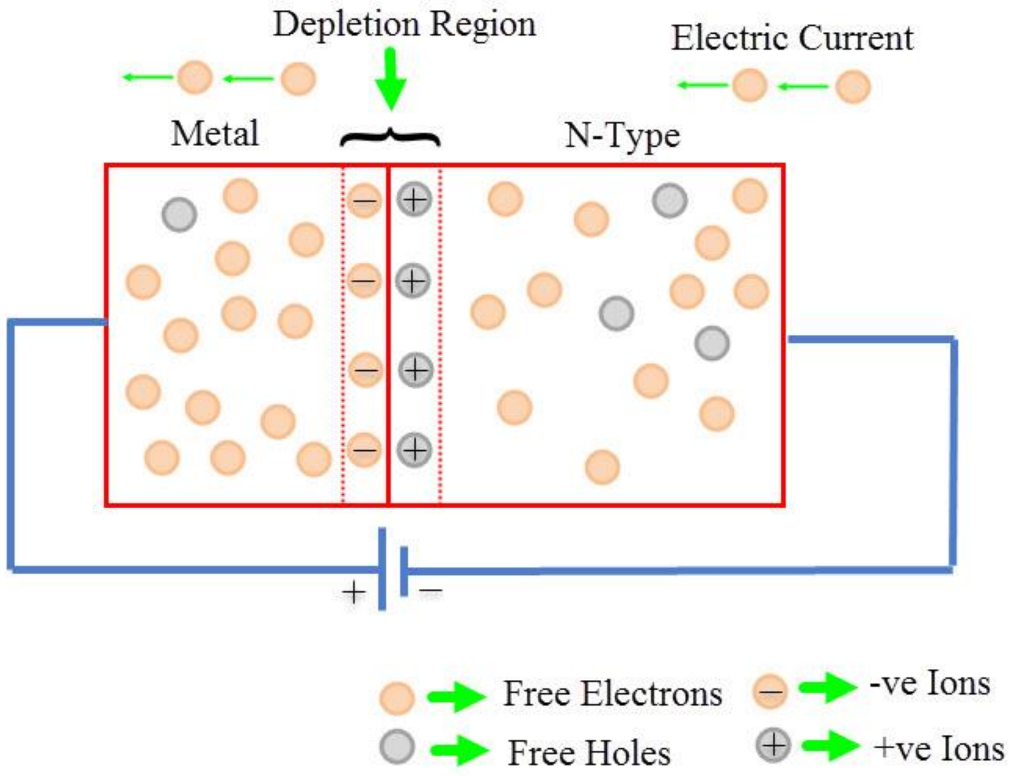


Due to this, atoms present in the metal junction receive an extra electron. The atoms at the negative side junction lose electrons and become positive ions. On the metal junction, atoms will gain extra electrons and tries to become negative ions.

Hence, this will result in production of positive ions at negative side and negative ions on the positive side at the metal junction. Depletion region will be formed when these positive and negative ions comes together. In unbiased Schottky diode, only less number of electrons will flow from semiconductor to metal. Other electron flow is stopped due to the built in voltage.

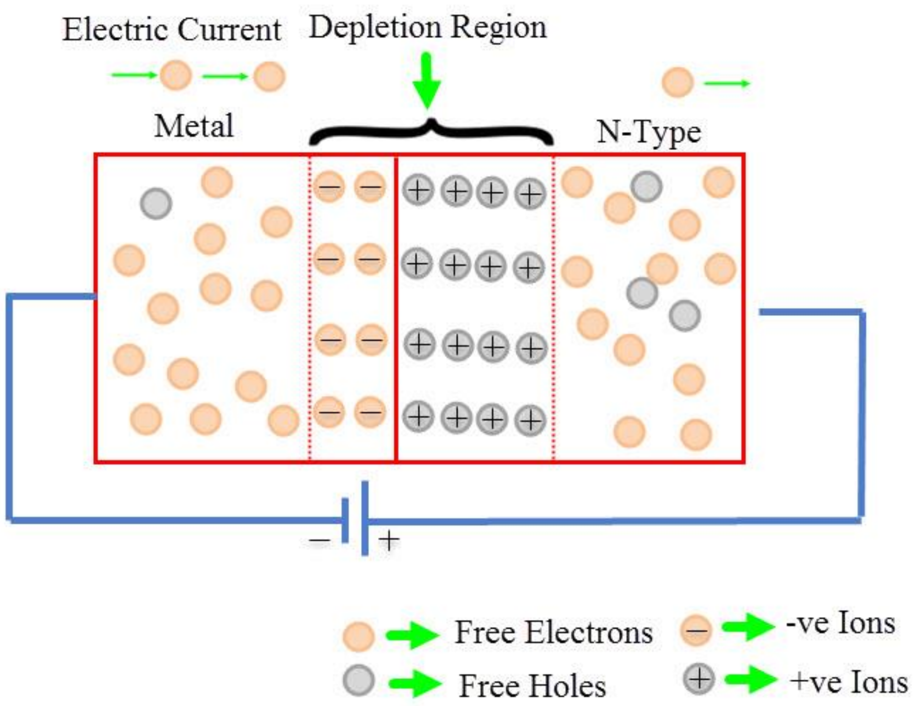
Forward Biased Schottky Diode

- In the n-type semiconductor when positive terminal of the battery is connected to metal and negative terminal is connected to n-type conductor,
- it is called as Forward biased Schottky diode. On the diode, when forward bias voltage is applied, more electrons are formed in the metal and conductor.
- When a voltage greater than 0.2 volts are applied, free electrons cannot move through the junction barrier. Due to this current will flow through diode.
- When voltage value increases, depletion region becomes thin and disappears.



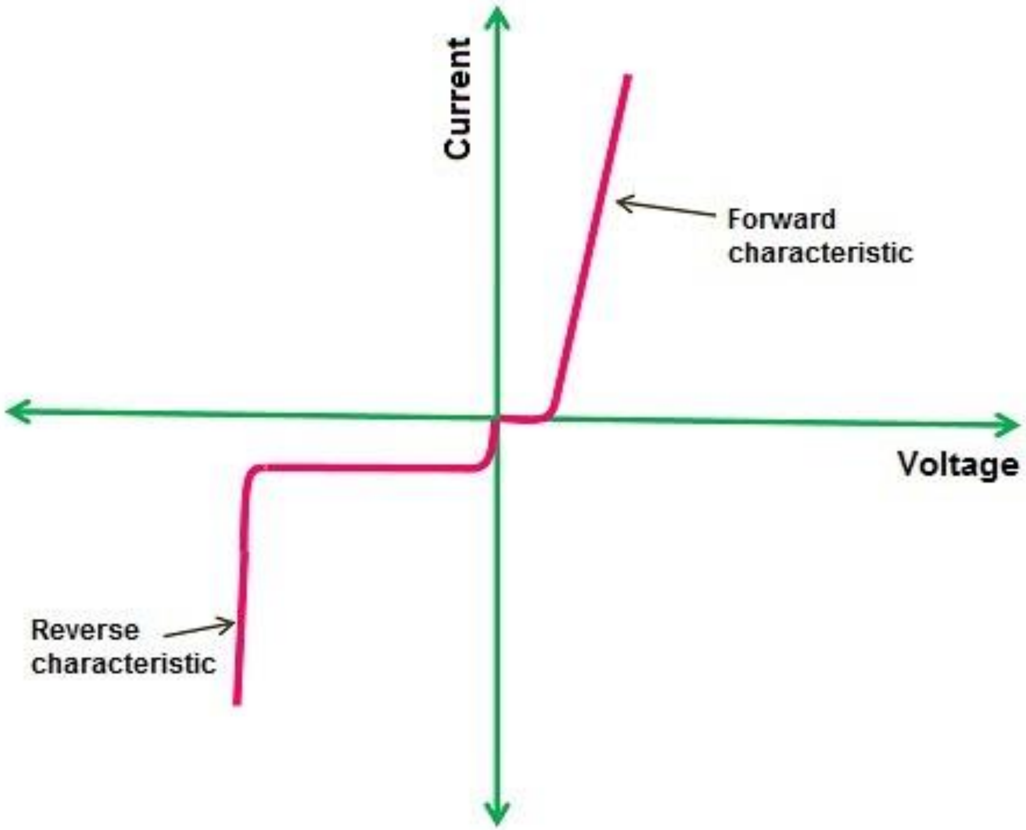
Reverse Biased Schottky Diode

- In the n-type semiconductor if the negative terminal of the battery is coupled to metal and positive terminal is connected to n-type conductor,
- it is called as Reverse biased Schottky diode. At the same time, if a reverse bias voltage is applied, the width of depletion region increases.
- Therefore, the current flow stops. In the metal plate, there will be more number of excited electrons. Due to this, there will be flow of a small amount of leakage current.
- When reverse biased voltage increases further, current also increases due to weak barrier. When abnormal increase in bias voltage takes place, electric current also increases suddenly.
- A device will be damaged, when the depletion region breaks down.



V-I Characteristics of Schottky Barrier Diode

- The V-I (Voltage-Current) characteristics of Schottky diode is shown in the below figure. Along the graph, the vertical line signifies the current flow and the horizontal line denotes the voltage applied across the Schottky diode.
- The V-I characteristics of Schottky diode is almost similar to the P-N junction diode. Nevertheless, the forward voltage drop of Schottky diode is very low when compared to the P-N junction diode. The forward voltage drop ranges from 0.3 volts to 0.5 volts.
- The barrier of forward voltage drop is made of silicon. The forward voltage drop is proportional to the doping concentration of N type semiconductor. Due to high concentration of current carriers, the V-I characteristic of Schottky diode is steeper.



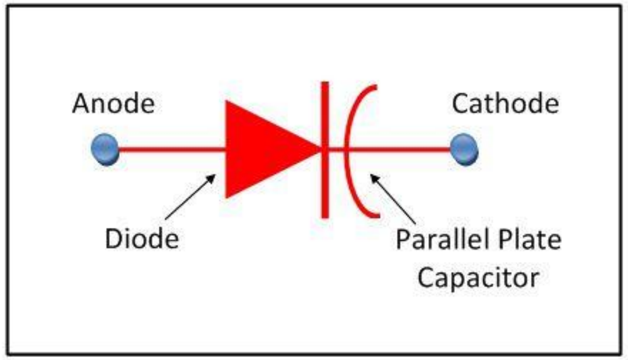
Applications Of Schottky Diode

- Schottky diodes are used for the voltage clamping applications and prevention of transistor saturation due to the high current density in the Schottky diode.
- It's also been a low forward voltage drop in Schottky diode, it is wasted in less heat, making them an efficient choice for applications that are sensitive and very efficient.
- Because of the Schottky diode used in stand-alone photovoltaic systems in order to prevent batteries from discharging purpose for the solar panels at night as well as in grid-connected systems, containing multiple strings are connected in parallel connection. Schottky diodes are also used as rectifiers in power supplies.

Varactor Diode

- The diode whose internal capacitance varies with the variation of the reverse voltage such type of diode is known as the Varactor diode. It is used for storing the charge. The varactor diode always works in reverse bias, and it is a voltage-dependent semiconductor device.
- The voltage-dependent device means the output of the diode depends on their input voltage. The varactor diode is used in a place where the variable capacitance is required, and that capacitance is controlled with the help of the voltage. The Varactor diode is also known as the Varicap, Voltcap, Voltage variable capacitance or Tunning diode.

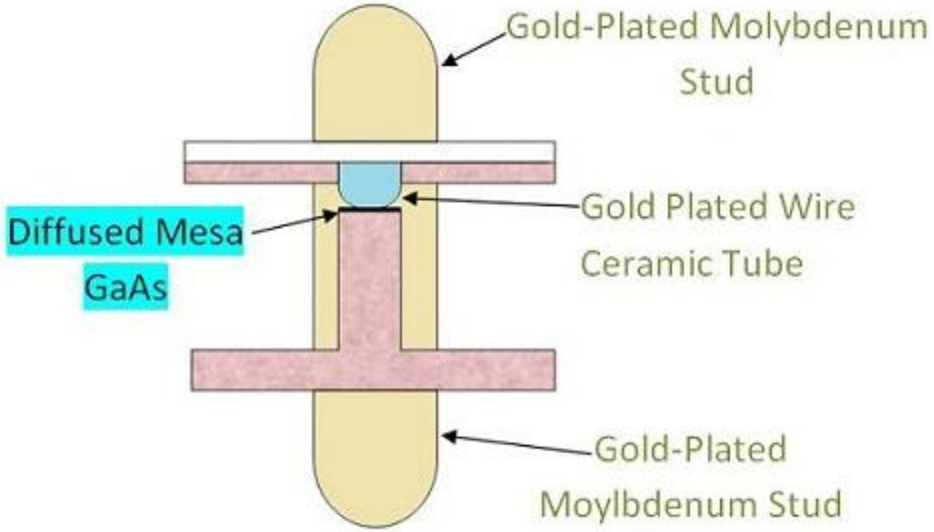
The symbol of the varactor diode is similar to that of the PN-junction diode. The diode has two terminals namely anode and cathode. The one end of a symbol consists the diode, and their other end has two parallel lines that represent the conductive plates of the capacitor. The gap between the plates shows their dielectric.



- Varactor diode is used in microwave frequency multiplier, parametric amplifier and as tuning element.
- In parametric amplifier, reactance varied in such a manner that amplification results.

Construction of Varactor Diode

It is formed of P-type and N-type semiconductor and reverse biasing is applied to it. The majority carriers in an N-type semiconductor are electrons and the majority carriers in a P-type semiconductor are holes. At the junction, the electrons and holes recombine. Due to which immobile ions accumulate at the junction. And no more current can flow due to majority carriers Thus, the depletion region is formed. The depletion region is called so because it is depleted of charge carriers i.e. the majority carriers are absent in depletion region. This works as a dielectric layer and P and N-type semiconductor works as plates of a capacitor.

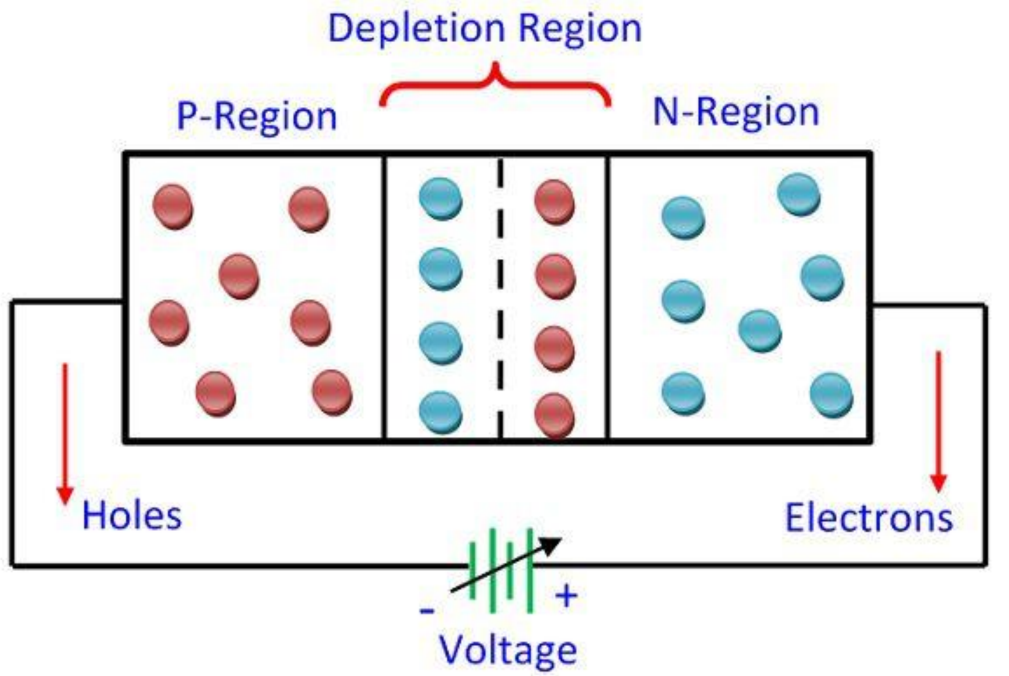


Construction of Varactor Diode

Working of Varactor Diode

The Varactor diode is made up of n-type and p-type semiconductor material. In an n-type semiconductor material, the electrons are the majority charge carrier and in the p-type material, the holes are the majority carriers. When the p-type and n-type semiconductor material are joined together, the p-n junction is formed, and the depletion region is created at the PN-junction. The positive and negative ions make the depletion region. This region blocks the current to enter from the PN-region.

The varactor diode operates only in reverse bias. Because of reverse bias, the current does not flow. If the diode is connected in forward biasing the current starts flowing through the diode and their depletion region become decreases. The depletion region does not allow the ions to move from one place to another.



Depletion Region in a Reverse Biased P-N junction

Summary

The Varactor diode is used for storing the charge not for flowing the charge. In the forward bias, the total charge stored in the diode becomes zero, which is undesirable. Thus, the Varactor diode always operates in the reverse bias.

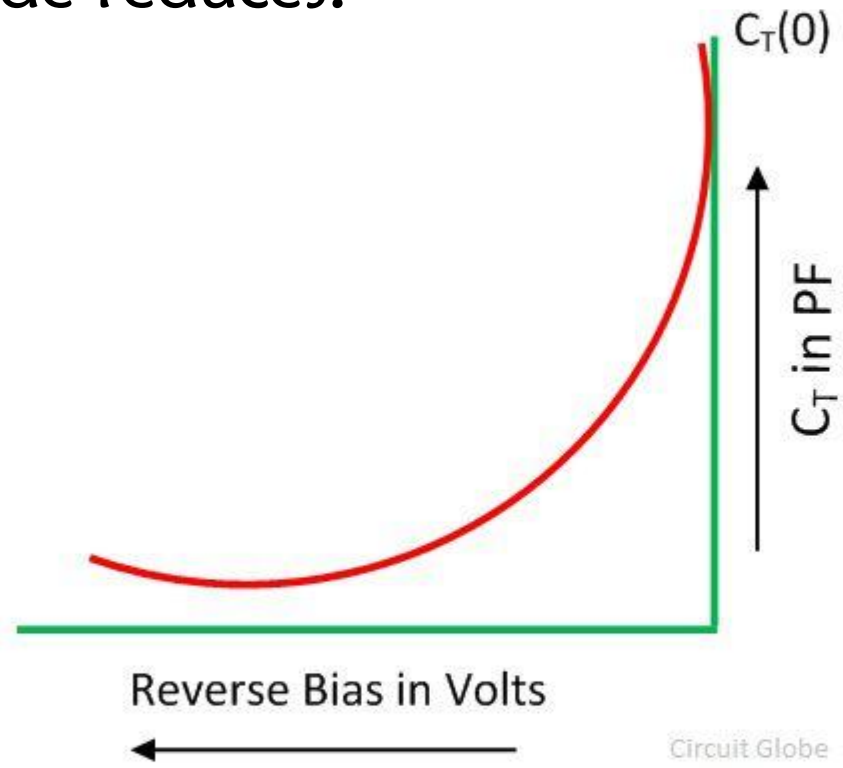
The formula gives the capacitance of varactor diode,

$$C_T = \frac{\in A}{W}$$

Where, ε – Permittivity of the semiconductor material.
A – area of PN-junction
W – width of depletion region

Characteristic of Varactor Diode

The characteristic curve of the varactor diode is shown in the figure below. The graph shows that when the reverse bias voltage increases the depletion region increases, and the capacitance of the diode reduces.



Advantages of Varactor Diode

The following are the advantages of the varactor diode.

1.The varactor diode produces less noise as less compared to the other diode.

2.It is less costly and more reliable.

3.The varactor diode is small in size and less in weight.

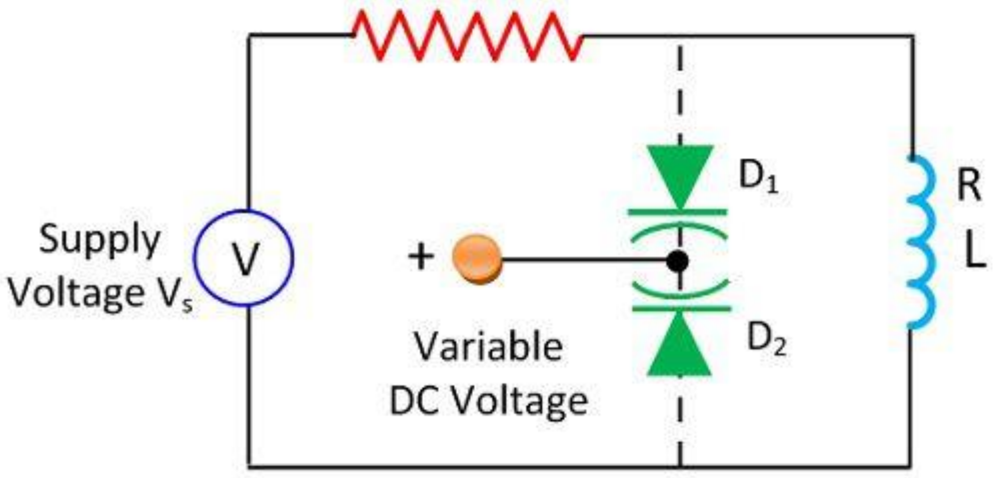
Varactor diode in tunning Circuit

The figure below shows that D1 and D2 are the two Varactor diode. These diodes provide the variable resistance in the parallel resonance circuit. The Vc is the DC voltage used for controlling the reverse voltage of the diode.

$$f_0 = \frac{1}{2\pi\sqrt{LC_T}}$$

Where,

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$



Varactor Diode in Tunning Circuit

Circuit Globe

The L is the inductance of the circuit, and it is measured in Henry. The resonant frequency of the circuit is expressed as C_1 and C_2 is the maximum voltage capacitance of the diode

Applications of Varactor Diode

Television receivers: Varactor diodes are used as tuned capacitors and have replaced mechanically tuned capacitors in various applications. It is used in television in the resonant tank circuit.

Radio receivers: Radio receivers also use this diode for tuning purposes.

Frequency Multiplier: It is also used as a frequency multiplier in various electronic circuits.

Phase Locked Loops: It is used in Phase locked loop for frequency modulation. Varactor diodes help in achieving frequency modulation. Thus, in communication devices varactor diodes are significant.

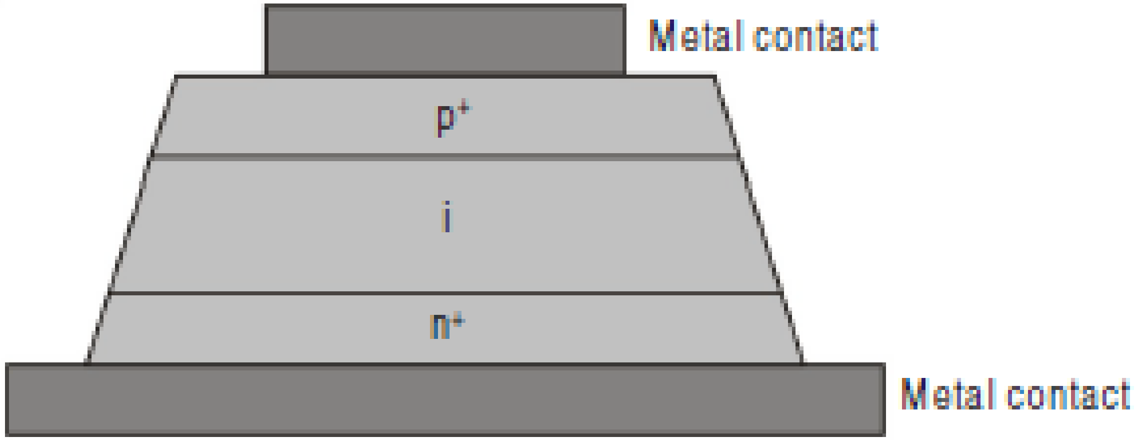
Voltage controlled oscillators: Voltage control oscillators are used extensively in transmission and receiving circuits in communication. And varactor diode plays a significant role in construction of voltage controlled oscillator.

Parametric Amplifiers: It is used in parametric amplifier as a significant component.

In most of the low power applications, solid-state devices have replaced electron beam devices because of the advantages of their small size, light weight, high reliability, low cost and capability of being incorporated into microwave integrated circuits. Some of the widely used microwave diodes like PIN diode, varactor diode, gunn diode IMPATT and TRAPATT

Microwave semiconductor devices has advantages like low cost, small size, less weight, high reliability and also employed in microwave integrated circuits.

A PIN diode consists of a heavily doped *p*-type semiconductor material (*p*+) and a heavily doped *n*-type semiconductor material (*n*+) separated by a layer of extremely high resistivity intrinsic semiconductor material (*i* layer).



- PIN diode has heavily doped *p* and *n* region separated by a layer of high resistivity intrinsic material.
- PIN diode is used as a microwave switch.

A more practical definition of a PIN diode is a semiconductor diode which consists of two heavily doped *p+* and *n+* regions separated by substantially higher resistivity p or n regions. This leads to the two types of PIN diode structures:

(i) π-type

(ii) ν-type.

In π-type PIN diode, heavily doped p and n regions separated by an unusually lightly doped p-type intrinsic layer and in ν-type, heavily doped p and n regions are separated by an lightly doped n-type intrinsic layer. The thickness of the high resistivity layer (i layer) is usually in the range of 10 to 200 µm.

Operation

Zero Bias

At zero bias, two space charge region are formed in the *p* and *n*-layers adjacent to the intrinsic layer because of the diffusion of holes and electrons across the junctions. The thickness of space charge regions is inversely proportional to the impurities, *i.e.*, it is totally depleted of mobile charge carriers.

Reverse Bias

When reverse bias is applied, the space charge region in the p and n-layers become wider.

A uniform electric field exists in the intrinsic region, dropping linearly to zero through the depletion regions in n and p-layers. The space charge regions offers a very high resistance in reverse bias.

Forward Bias

When a forward bias is applied to the diode, carrier injection into the i layer takes place. Electrons are injected into the i layer from the n layer, and holes are injected from p layer. The carriers diffuse into the i layer, the diffusion of carriers causes the carrier concentrations in the i layer to increase above their equilibrium levels, and the resistivity of layer drops as the forward bias is increased. Thus, low resistance is offered in the forward direction.

- Under zero and reverse bias, PIN diode has very high impedance.
- PIN diode has a very low impedance for small forward bias.
- PIN diode resistance changes from nearly 6 kΩ under negative bias to around 5Ω under positive bias.

- In the series configuration, switch is ON when the diode is forward bias and it is OFF when diode is reverse bias.
- In the shunt configuration, switch is ON when the diode is reverse bias and it is OFF when diode is forward bias.
- Limiters are used to protect the sensitive microwave components.
- A PIN diode limiter is a microwave switch that is controlled by self bias rather than external bias. PIN diodes in shunt are used to limit the power.

Characteristic	*Gunn*	*IMPATT*	*TRAPATT*
Operating frequency	1–100 GHz	0.5–100 GHz	1–10 GHz
Construction	n^+nn^+ GaAs single crystal	n^+pip^+	p^+nn^+ or n^+pp^+
Bandwidth	2% of centre frequency	One tenth of centre frequency	–
Application	Oscillator	Oscillator, amplifier	Oscillator
Power output	A few watts (CW) 100–200 W (pulsed)	1 W (CW) 400 W (pulsed)	100 W (pulsed)
Basic semiconductor	GaAs, InP	Si, Ge, GaAs or InP	Si
Harmonics	–	Less	Strong
Size	Small	Small	Small
Ruggedness	Yes	Yes	Yes