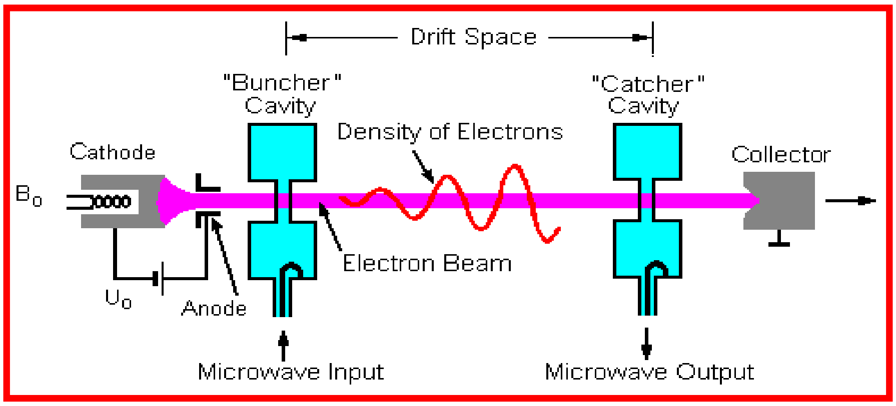
Microwave Active Devices

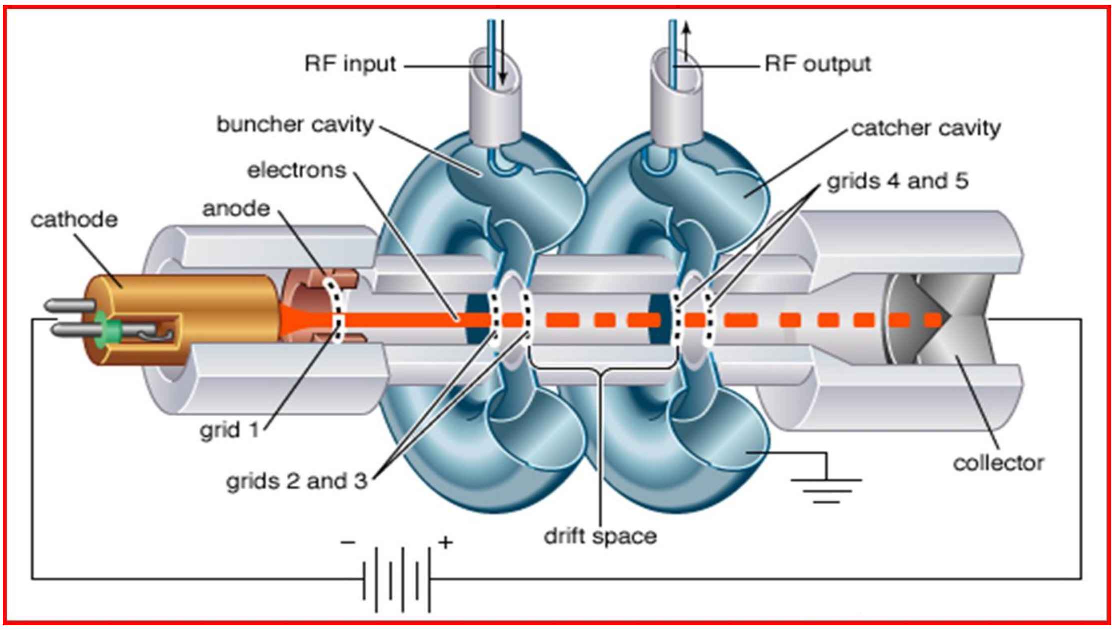
Klystron: A klystron is a vacuum tube that can be used either as a generator or as an amplifier of power, at microwave frequencies. Low-power klystrons are used as oscillators in terrestrial microwave relay communications links, while high-power klystrons are used as output tubes in UHF television transmitters, satellite communication, and radar transmitters, and to generate the drive power for modern particle accelerators.

Types of Klystron

1. Two cavity Klystron
   a. Two cavity Klystron Amplifier
   b. Two cavity Klystron oscillator
2. Reflex Klystrons
3. Multicavity klystron
4. Tuning a klystron
5. Optical klystron

Two cavity Klystron Amplifier





Construction and work of Two cavity Klystron Amplifier

1. At one end of the tube is the hot cathode heated by a filament which produces electrons. The electrons are attracted and pass through an anode cylinder at a high positive potential; these act as an electron gun to produce a high velocity stream of electrons. An external electromagnet winding creates a longitudinal magnetic field along the beam axis which prevents the beam from spreading.
2. There are two microwave cavity resonators, the "catcher" and the "buncher". When used as an amplifier, the weak microwave signal to be amplified is applied to the buncher cavity through a coaxial cable or waveguide, and the amplified signal is extracted from the catcher cavity. The beam first passes through the "buncher" cavity resonator, through grids attached to each side. The buncher grids have an oscillating AC potential across them, produced by standing wave oscillations within the cavity, excited by the input signal at the cavity's resonant frequency applied by a coaxial cable or waveguide.

Beyond the buncher grids is a space called the *drift space*. This space is long enough so that the accelerated electrons catch up to the retarded electrons, forming "bunches" longitudinally along the beam axis. The electrons then pass through a second cavity, called the "catcher", through a similar pair of grids on each side of the cavity. The function of the *catcher grids* is **to absorb energy from the electron beam.**

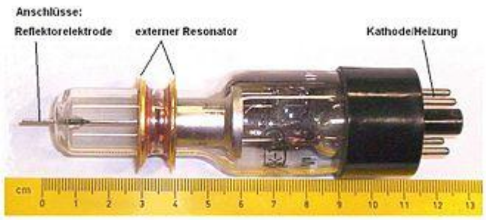
3. **Collector:** After the RF energy has been extracted from the electron beam, the electrons are absorbed by a collector (anode) electrode which has a positive voltage. Some klystrons include depressed collectors, which recover energy from the beam before collecting the electrons, increasing efficiency.

Applications of Two cavity Klystron

- **As power output tubes**
    1. in UHF TV transmitters
    2. in troposphere scatter transmitters
    3. satellite communication ground station
    4. radar transmitters
- **As power oscillator** (5 – 50 GHz), if used as a klystron oscillator

1. Reflex Klystrons

A *reflex klystron* is an obsolete type in which the electron beam was reflected back along its path by a high potential electrode, used as an oscillator**.** The reflex klystron has been the most used source of microwave power in laboratory applications.



Construction of Reflex Klystrons

- A reflex klystron consists of an electron gun, a cavity with a pair of grids and a repeller plate as shown in the above diagram.
- In this klystron, a single pair of grids does the functions of both the buncher and the catcher grids.
- The main difference between two cavity reflex klystron amplifier and reflex klystron is that the output cavity is omitted in reflex klystron and the reflector electrode, placed a very short distance from the single cavity, replaces the collector electrode.

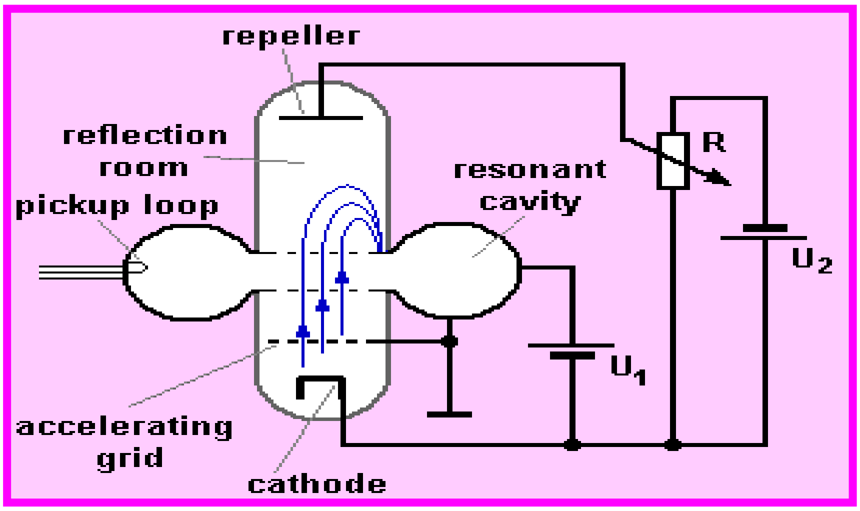
Working of Reflex Klystron

The cathode emits electrons which are accelerated forward by an accelerating grid with a positive voltage on it and focused into a narrow beam.

- The electrons pass through the cavity and undergo velocity modulation, which produces electron bunching and the beam is repelled back by a repeller plate kept at a negative potential with respect to the cathode.

- On return, the electron beam once again enters the same grids which act as a buncher, therby the same pair of grids acts simultaneously as a buncher for the forward moving electron and as a catcher for the returning beam.

Reflex Klystron oscillator



Working Reflex Klystron oscillator

- The feedback necessary for electrical oscillations is developed by reflecting the electron beam, the velocity modulated electron beam does not actually reach the repeller plate, but is repelled back by the negative voltage.
- The point at which the electron beam is turned back can be varied by adjusting the repeller voltage.
- Thus the repeller voltage is so adjusted that complete bunching of the electrons takes place at the catcher grids, the distance between the repeller and the cavity is chosen such that the repeller electron bunches will reach the cavity at proper time to be in synchronization.

- Due to this, they deliver energy to the cavity, the result is the oscillation at the cavity producing RF frequency.

Applications Reflex Klystron

The reflex klystrons are used in

1. Radar receivers
2. Local oscillator in microwave receivers
3. Signal source in microwave generator of variable frequency
4. Portable microwave links
5. Pump oscillator in parametric amplifier

Magnetron

The magnetron is a high-powered vacuum tube that generates microwaves using the interaction of a stream of electrons with a magnetic field. Magnetrons provide microwave oscillations of very high frequency.

Types of magnetrons

1. Negative resistance type
2. Cyclotron frequency type
3. Cavity type

Description of types of magnetron

1. Negative resistance Magnetrons

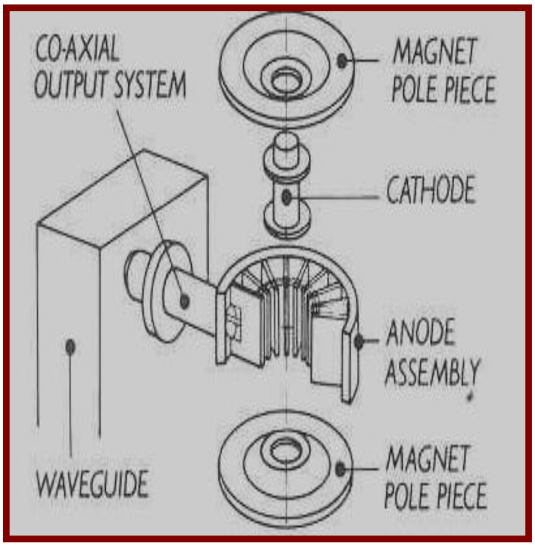
- Make use of negative resistance between two anode segments but have low efficiency and are useful only at low frequencies (< 500 MHz).

2. Cyclotron frequency Magnetrons

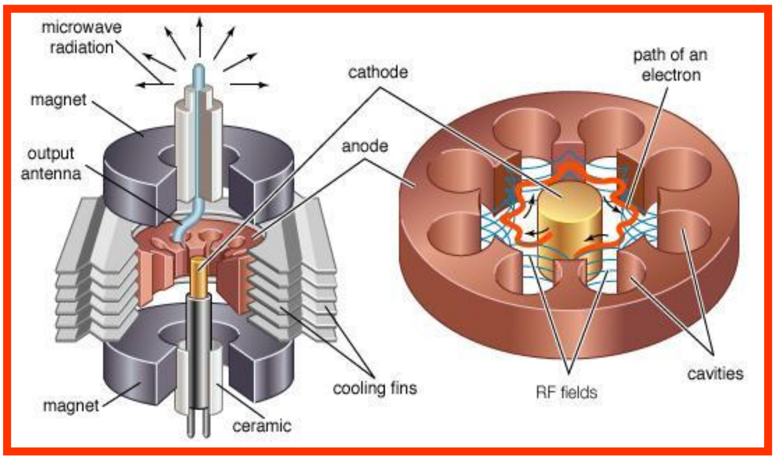
- Depend upon synchronization between an alternating component of electric and periodic oscillation of electrons in a direction parallel to this field.
- Useful only for frequencies greater than 100 MHz.

2. Cavity Magnetrons

- Depend upon the interaction of electrons with a rotating electromagnetic field of constant angular velocity.
- Provide oscillations of very high peak power and hence are useful in radar applications.



Major elements in the Magnetron oscillator

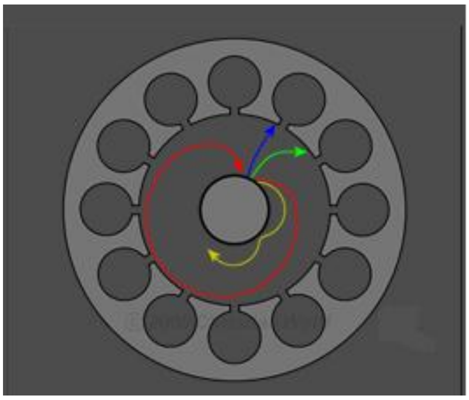


Cavity Magnetrons

Operation of Magnetrons

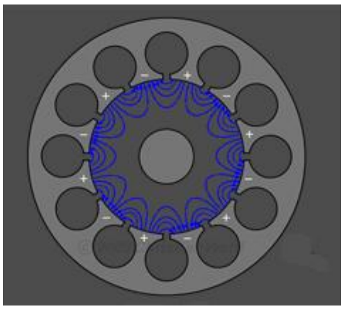
- In a magnetron, the source of electrons is a heated cathode located on the axis of an anode structure containing a number of microwave resonators.
- Electrons leave the cathode and are accelerated toward the anode, due to the dc field established by the voltage source E.
- The presence of a strong magnetic field B in the region between cathode and anode produces a force on each electron which is mutually perpendicular to the dc field and the electron velocity vectors, thereby causing the electrons to spiral away from the cathode in paths of varying curvature, depending upon the initial electron velocity at the time it leaves the cathode.

The electron path under the influence of different strength of the magnetic field



- As this cloud of electrons approaches the anode, it falls under the influence of the RF fields at the vane tips, and electrons will either be retarded in velocity, if they happen to face an opposing RF field, or accelerated if they are in the vicinity of an aiding RF field.

- Since the force on an electron due to the magnetic field B is proportional to the electron velocity through the field, the retarded velocity electrons will experience less "curling force" and will therefore drift toward the anode, while the accelerated velocity electrons will curl back away from the anode.
- The result is an automatic collection of electron "spokes" as the cloud nears the anode with each spoke located at a resonator having an opposing RF field.
- On the next half cycle of RF oscillation, the RF field pattern will have reversed polarity and the spoke pattern will rotate to maintain its presence in an opposing field.



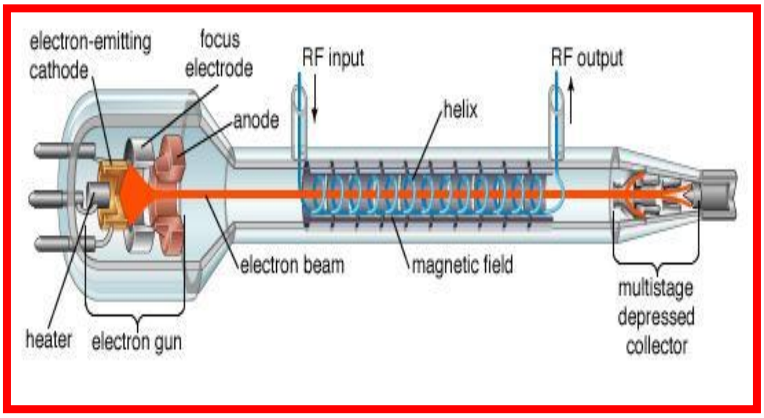
Applications of Magnetron

1. Pulsed radar is the single most important application with large pulse powers.
2. Voltage tunable magnetrons are used in sweep oscillators in telemetry and in missile applications.
3. Fixed frequency, CW magnetrons are used for industrial heating and microwave ovens.

Traveling Wave Tube (TWT)

A **traveling-wave tube (TWT)** is a specialized vacuum tube that is used in electronics to amplify radio frequency (RF) signals in the microwave range. The TWT belongs to a category of "linear beam" tubes, such as the klystron, in which the radio wave is amplified by absorbing power from a beam of electrons as it passes down the tube. Although there are various types of TWT, two major categories are:

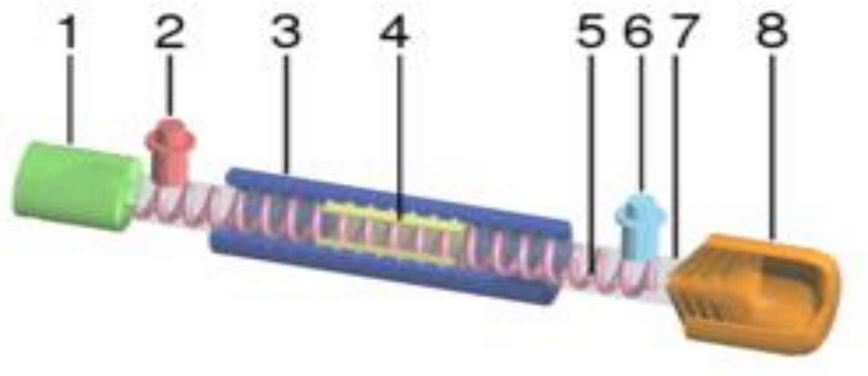
1. Helix TWT - in which the radio waves interact with the electron beam while traveling down a wire helix which surrounds the beam. These have wide bandwidth, but output power is limited to a few hundred watts.
2. Coupled cavity TWT - in which the radio wave interacts with the beam in a series of cavity resonators through which the beam passes. These function as narrowband power amplifiers.



Basic structure of a Traveling Wave Tube (TWT)

Basic structure of a Helix Traveling Wave Tube (TWT)

- The basic structure of a TWT consists of a cathode and filament heater plus an anode that is biased positively to accelerate the electron beam forward and to focus it into a narrow beam.
- The electrons are attracted by a positive plate called the collector, which has given a high dc voltage.
- The length of the tube is usually many wavelengths at the operating frequency.
- Surrounding the tube are either permanent magnets or electromagnets that keep the electrons tightly focused into a narrow beam. The structure of TWT is illustrated in figure below



(1) Electron gun (2) RF input

(3) Magnets (4) Attenuator

(5) Helix coil (6) RF output

(7) Vacuum tube (8) Collector.

Features of a Traveling Wave Tube (TWT)

- The unique feature of the TWT is a helix or coil that surrounds the length of the tube and the electron beam passes through the center or axis of the helix.
- The microwave signal to be amplified is applied to the end of the helix near the cathode and the output is taken from the end of the helix near the collector.
- The purpose of the helix is to provide path for RF signal.
- The propagation of the RF signal along the helix is made approximately equal to the velocity of the electron beam from the cathode to the collector

Functioning of a Traveling Wave Tube (TWT)

- The passage of the microwave signal down the helix produces electric and magnetic fields that will interact with the electron beam.
- The electromagnetic field produced by the helix causes the electrons to be speeded up and slowed down, this produces velocity modulation of the beam which produces density modulation.
- Density modulation causes bunches of electrons to group together one wavelength apart and. these bunch of electrons travel down the length of the tube toward the collector.
- The electron bunches induce voltages into the helix which reinforce the voltage already present there. Due to that the strength of the electromagnetic field on the helix increases as the wave travels down the tube towards the collector.

- At the end of the helix, the signal is considerably amplified. Coaxial cable or waveguide structures are used to extract the energy from the helix.

Advantages of a Traveling Wave Tube (TWT)

1. TWT has extremely wide bandwidth. Hence, it can be made to amplify signals from UHF to hundreds of gigahertz.
2. Most of the TWT's have a frequency range of approximately 2:1 in the desired segment of the microwave region to be amplified.
3. The TWT's can be used in both continuous and pulsed modes of operation with power levels up to several thousands watts.

Applications of TWT

1. Low noise RF amplifier in broad band microwave receivers.
2. Repeater amplifier in wide band communication links and long distance telephony.
3. Due to long tube life (50,000 hours against ¼th for other types), TWT is power output tube in communication satellite.
4. Continuous wave high power TWT's are used in troposcatter links (due to larger power and larger bandwidths).
5. Used in Air borne and ship borne pulsed high power radars.

Coupled-cavity TWT

- **Helix TWTs** are limited in peak RF power by the current handling (and therefore thickness) of the helix wire. As power level increases, the wire can overheat and cause the helix geometry to warp. Wire thickness can be increased to improve matters, but if the wire is too thick it becomes impossible to obtain the required helix pitch for proper operation. Typically helix TWTs achieve less than 2.5 kW output power.

- The **coupled-cavity TWT** overcomes this limit by replacing the helix with a series of coupled cavities arranged axially along the beam. This structure provides a helical waveguide, and hence amplification can occur via velocity modulation. Helical waveguides have very nonlinear dispersion and thus are only narrowband (but wider than klystron). A coupled-cavity TWT can achieve 60 kW output power.

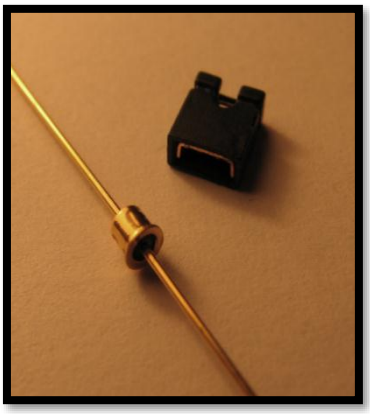
MICROWAVE SOLID-STATE DEVICES (SEMICONDUCTOR DIODE)

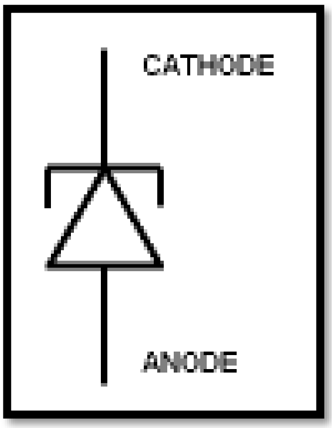
1. Tunnel Diode (Esaki Diode)
2. Gunn Diode
3. PIN Diodes
4. Varactor Diodes
5. Schottky Barrier Diode

Tunnel Diode (Esaki Diode)

- Invented by Dr. Leo Esaki in 1958.
- Also called Esaki diode.
- Basically, it is heavily doped PN- junction.
- These diodes are fabricated from germanium, gallium arsenide (GaAs), and Gallium Antimonite.

Symbol of Tunnel Diode:





Description of Tunnel Diode

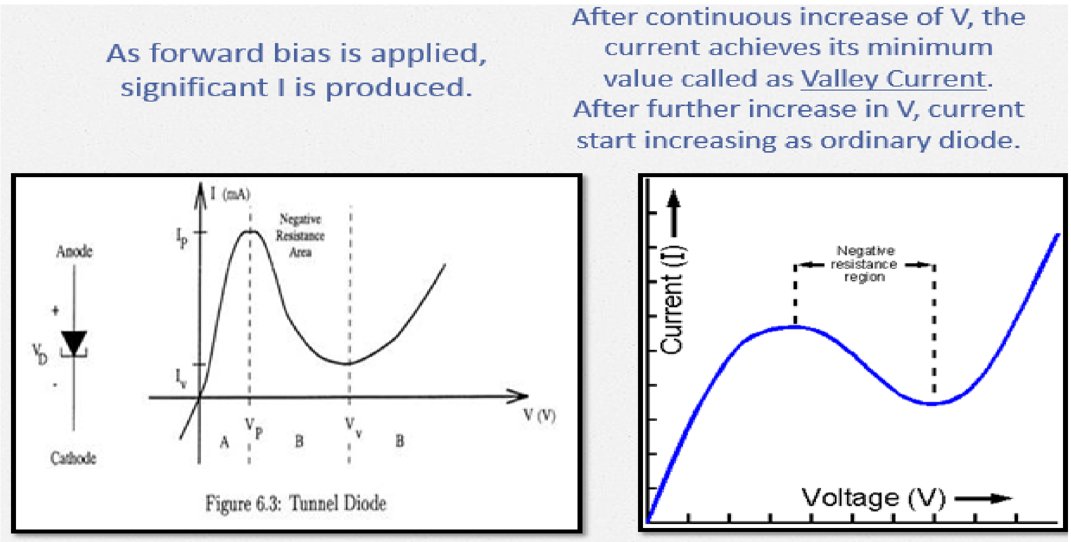
- Highly doped PN- junction. Doping density of about 1000 times greater than ordinary junction diode.

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

Working of Tunnel Diode:

- 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 or easily pass because the voltage barrier is reduced due to high doping.

I/V Characteristics of Tunnel Diode:



Applications of Tunnel Diode:

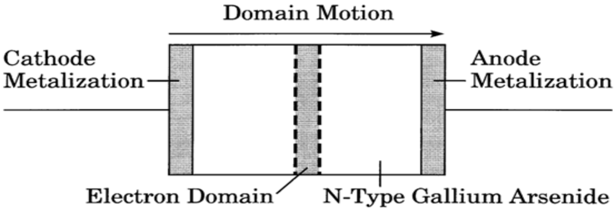
- It is used as an ultra- high speed switch due to tunneling (which essentially takes place at speed of light). It has switching time of nanoseconds or picoseconds.
- Used as logic memory storage device.
- In satellite communication equipment, they are widely used.

Gunn Diodes

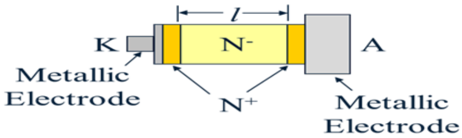
Gunn diodes are semiconductor diodes that form a cheap and easy method of producing relatively low power radio signals at microwave frequencies. Gunn diodes are a form of semiconductor component able to operate at frequencies from a few Gigahertz up to frequencies in the THz region. As such they are used in a wide variety of units requiring low power RF signals.

Properties of Gunn diodes

- Slab of N-type GaAs (gallium arsenide)
- Sometimes called Gunn diode but has no junctions
- Has a negative-resistance region where drift velocity decreases with increased voltage
- This causes a concentration of free electrons called a domain



GUNN DIODE (CROSS SECTION)



Application of Gunn diode

1. The Gunn diode is used as local oscillator covering the microwave frequency range of 1 to 100GHz
2. Local Oscillator and Avoid Collision Radar instead of Klystron etc..

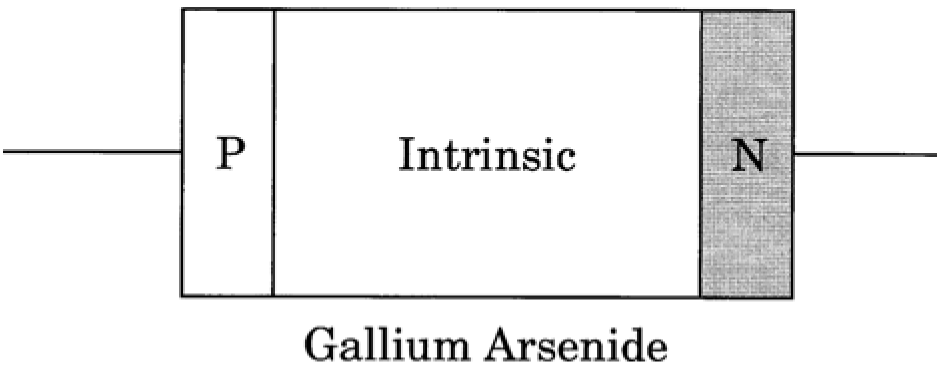
Advantages of Gunn diode

- Low noise
- High frequency operation and Medium RF Power

PIN DIODE

A **PIN diode** is a diode with a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region. The p-type and n-type regions are typically heavily doped because they are used for ohmic contacts.

The wide intrinsic region is in contrast to an ordinary PN diode. The wide intrinsic region makes the PIN diode an inferior rectifier (one typical function of a diode), but it makes the PIN diode suitable for attenuators, fast switches, photodetectors, and high voltage power electronics applications.



PIN DIODE

The speed of the PIN diode is limited by variation in the time it takes electrons to pass through the device. This time spread can be spread in two ways:

- **By increasing the bias-voltage**
- **By reducing the thickness of intrinsic layer**

TYPES of PIN DIODE

- **Metal-Semiconductor PIN diode**
- **Heterojunction PIN diode**

Operation of PIN Diode

- A microwave PIN diode is a semiconductor device that operates as a variable resistor at RF and Microwave frequencies.
- A PIN diode is a current controlled device in contrast to a varactor diode which is a voltage controlled device.
- When the forward bias control current of the PIN diode is varied continuously, it can be used for attenuating, leveling, and amplitude modulating an RF signal.
- When the control current is switched on and off, or in discrete steps, the device can be used for switching, pulse modulating, and phase shifting an RF signal.
- When the diode is forward biased, holes and electrons are injected into the I-region. This charge does not recombine instantaneously, but has a finite lifetime (t) in the I-region.

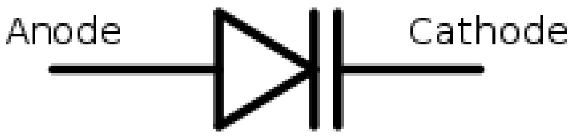
Applications of PIN Diode

- It is used as a Photo Detector for most fiber optic application.
- They are used in electronic pre-amplifier to boost sensitivity.
- They are used as a variable resistor in at RF and microwave frequency.
- Widely used in RF modulator circuit to control RF intermodulation distortion.
- In a phase shifter circuit considered as a lumped variable-impedance microwave circuit element.

- PIN diodes are utilized as series or shunt connected switches in phase shifter designs. The switched elements are either lengths of transmission line or reactive elements.

VARACTOR DIODE

A microwave solid-state device. Also called a parametric diode, tuning diodes or varicap diodes. Provides a voltage-dependent variable capacitance.



Types Of Varactor Diode

- Abrupt and hyper abrupt type : When the changeover p-n junction is abrupt then it is called abrupt type. When change is very abrupt, they are called hyper abrupt type. They are used in oscillators to sweep for different frequencies.
- Gallium-arsenide varactor diodes : The semiconductor material used is gallium arsenide. They are used for frequencies from 18 GHz up to and beyond 600 GHz.

Characteristics Of Varactor Diode

1. Low-noise characteristic : produce much less noise than most conventional amplifiers.
2. Low cost
3. High reliability

4. Light weight
5. Small size

Applications Of Varactor Diode

- **FREQUENCY MULTIPLIERS -** used in applications where it's difficult to generate microwave signals.
- Producing relatively high power outputs at frequencies up to 100GHz.
- Does not have gain ; in fact, it produces a signal power loss,
- Output can be as high as 80% of the input.
- **PARAMETRIC AMPLIFIERS**. **-** named for the time-varying parameter, or value of capacitance, associated with the operation.
- Since the underlying principle of operation is based on reactance, the parametric amplifier is sometimes called a REACTANCE AMPLIFIER.
- **TUNING -** Since the frequency can be made to vary they are used as electronic tuning devices in tuners for television, mobiles.
- **Other Applications:**

  They are used in PLL, voltage controlled oscillators, harmonic generation, electronic tuning devices in tuners for television, mobiles, parametric amplification, AM radios, voltage-variable tuning, frequency multipliers, etc.