Q2 Detection of Microwaves:-

Two types of diodes are used for microwave detection:

(a.) Point Contact Diode
(b.) Schottky Barrier diode

(a.) Point contact Diode (silicon crystal diode):-

Point contact diodes consist of a thin tungsten 'whisker' touching a silicon chip. A typical construction is shown in fig. The fabrication starts with a thin wafer of polycrystalline p-type silicon. The wafer surface is cleaned chemically and polished flat. A thin oxide layer is grown by heating the wafer to about 1200°C in steam or oxygen. During oxidation some p-type impurities diffuse out (into oxide) and a high resistivity layer is formed. Oxide layer is then removed and the wafer divided into small chips.

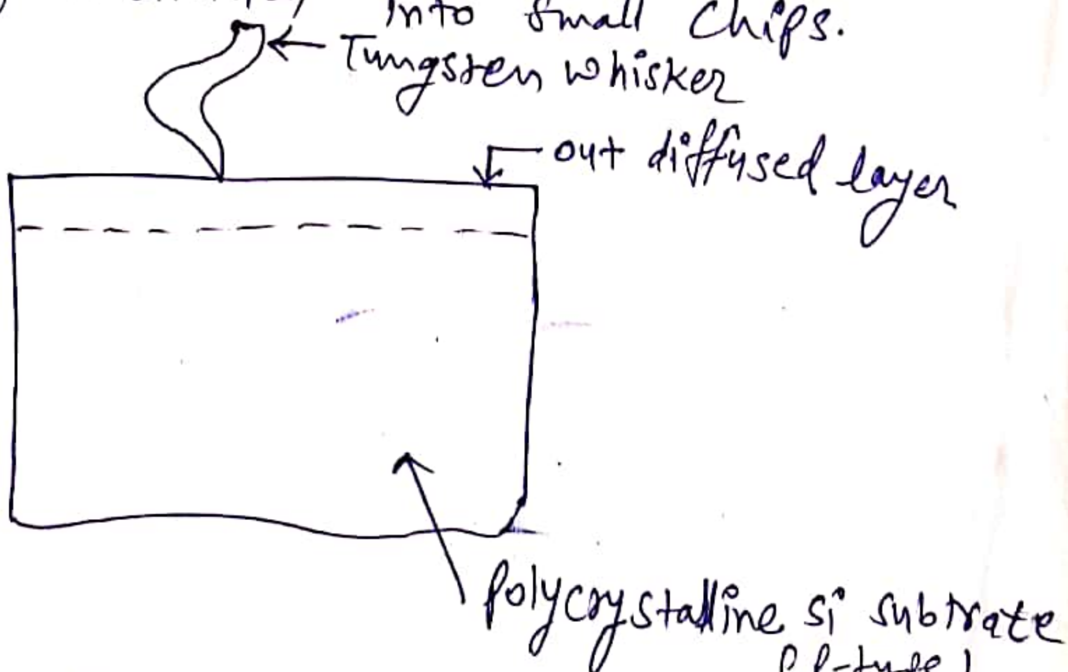


fig:- silicon crystal diode

tungsten whisker is etched electrolytically to obtain a tip diameter of the order of 12 μm. After assembly a process of 'adjusting' is necessary for obtaining the required diode characteristics. Adjusting is the process of increasing the tungsten whisker force by exciting mechanical resonances.

(b.) Schottky Barrier Diode:-

Alternative to point contact diode is a metal-semiconductor Schottky barrier diode. Typical construction of this type of diode is shown in fig.

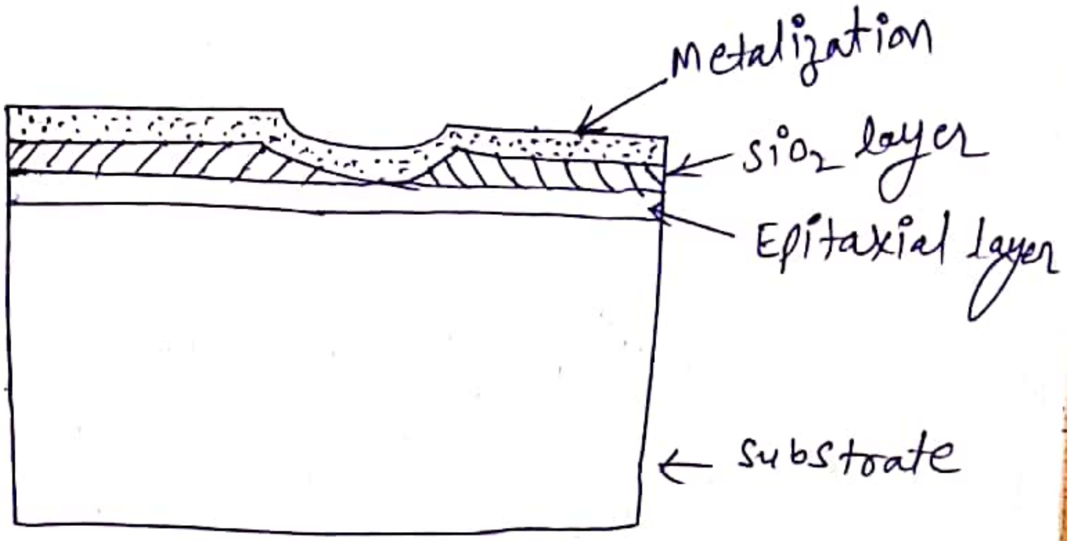


fig.:- Schottky Diode

In a schottky diode a junction is made between an n-type s/c and metal to form the diode. Like transistor or IC's, planner technology is utilized to fabricate it. Over the cleaned and polished surface of n^+ type silicon, a thin active layer of n-type silicon is grown epitaxially.

thin layer of SiO_2 is grown over this active layer and through which windows are created to make metal s/c junctions. The metal is deposited by vaccum evaporation. Excess metal over the surrounding areas is etched out by photo-etching process.

→ Detector mounts:-

In order to work as a detector these diodes should be mounted across the waveguides and the other end of the guide be shorted. The distance b/w the diode and shorted end can be varied by moving the adjustable plunger and which tunes the detector at a desired frequency. The microwave detector diode are usually available in the type of the package as shown in fig. The package mounting the circuit is designed carefully so that the parasitic reactances introduced are minimum..

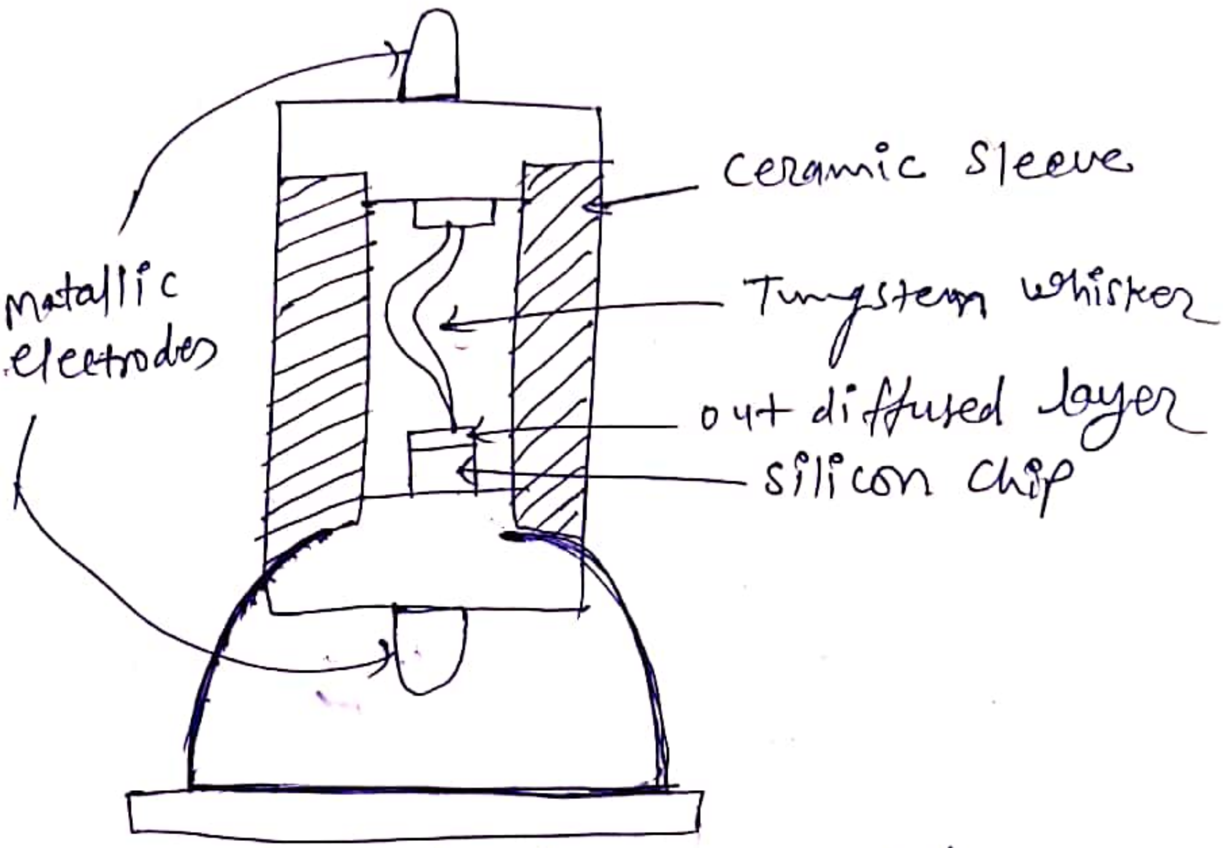
→

The detector diode may be mounted in coaxial line (a) or a waveguide (b) depending upon the type of the measurment system that is being used. The detected o/p is normally available at a coaxial (BNC) connector.

Performance of microwave detector is expressed in terms of the current sensitivity which is defined as follows:

$$\beta = \frac{\Delta i}{P}$$

where Δi = change in short circuit current resulting from an available input power P.



packaged point contact diode.

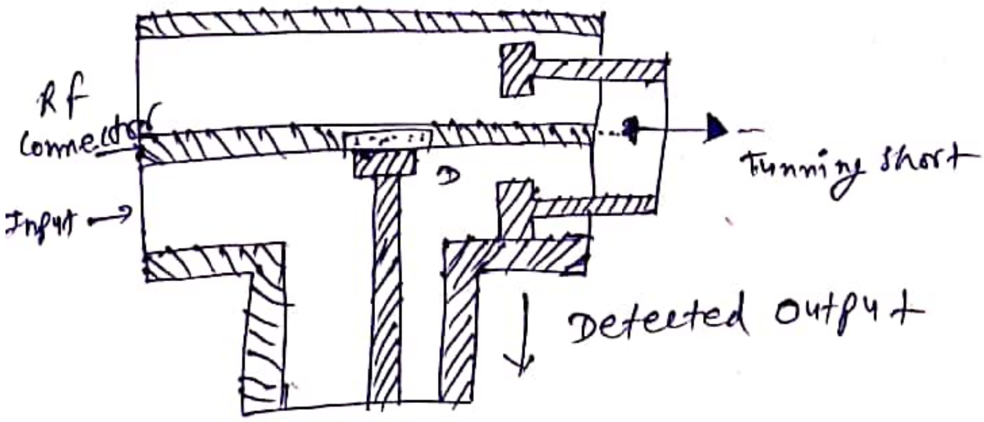
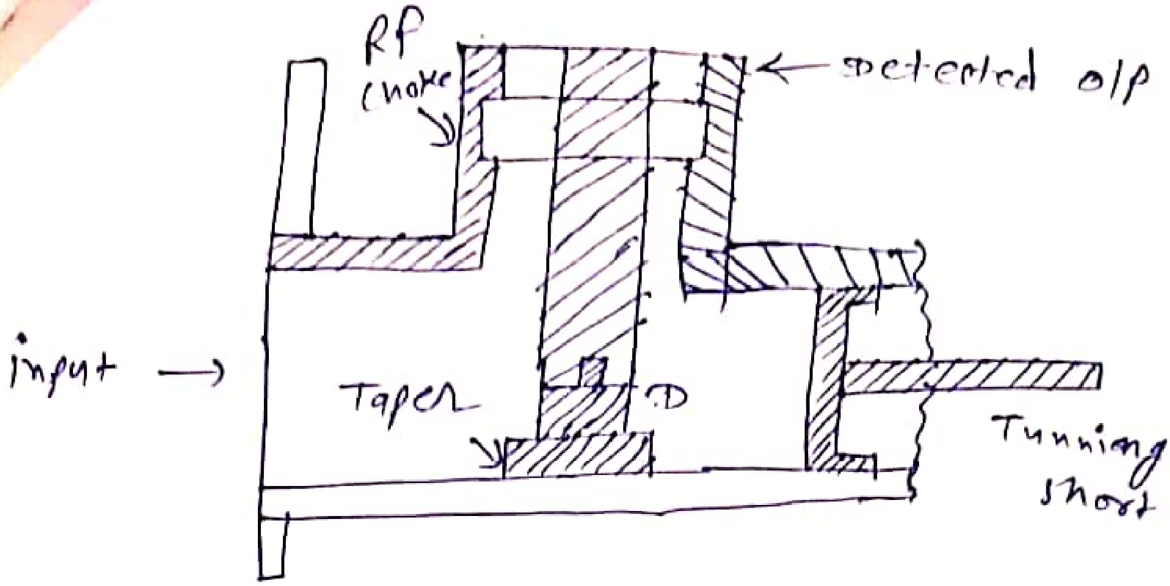


fig: (a) Detector diode mounted in a coaxial line



fig(b) Detector diode mounted in a waveguide.

Gunn diode:-

(a) Gunn diodes are also known as transferred electron devices, TED, are widely used in microwave RF applications for frequencies between 1 and 100 GHz.

- The Gunn diode is most commonly used for generating microwave RF - signals - these circuits may also be called a transferred electron oscillator or TEO. The Gunn diode may also be used for an amplifier in what may be known as a transferred electron amplifier or TEA.

→ Gunn diode basics:-

The Gunn diode is a unique component - even though it is called a diode, it does not contain a PN diode junction. The Gunn diode or transferred electron device can be termed a diode because it does have two electrodes. It depends upon the bulk material properties rather than that of a PN junction.

- The mechanism behind the transferred electron effect was first published by Ridley and Watkins in a paper in 1961. Further work was published by Hilsum in 1962, and then in 1963 John Battiscombe (J.B.) Gunn independently observed the first transferred electron oscillation using Gallium Arsenide, GaAs semiconductor.

Gunn diode symbol for circuit diagrams :- ②

The Gunn diode symbol used in circuit diagrams varies. Often a standard diode is seen in the diagram, however this form of Gunn diode symbol does not indicate the fact that the Gunn diode is not a PN junction. Instead another symbol showing two filled triangles with points touching is used as shown below.

Gunn diode Symbol.

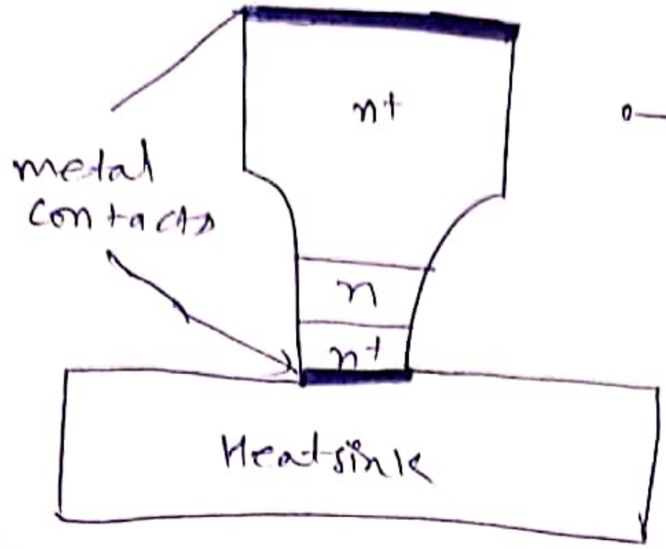
→ ## Gunn diode Construction :-

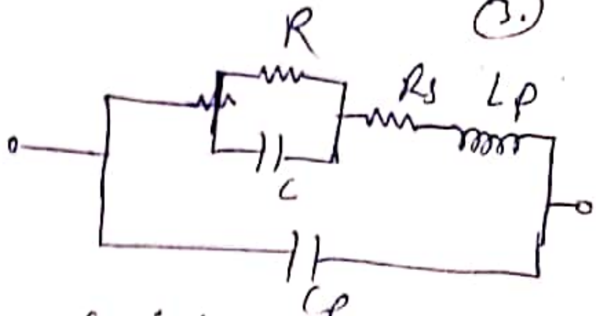
Gunn diodes are fabricated from a single piece of n-type semiconductor. The most common materials are ~~GaAs~~, (GaAs) and Indium phosphide, (InP).
gallium Arsenide,

The device is simply an n-type bar with n^+ contacts.

It is necessary to use n-type material because the transferred electron effect is only applicable to electrons and not holes found in a p-type material.

Within the device there are three main areas, which can be roughly termed the top, middle and bottom areas.





Equivalent circuit of Packaged Gunn diode

A discrete Gunn diode with the active layer mounted onto a heat sink for efficient heat transfer.

→ The most common method of manufacturing a Gunn diode is to grow and epitaxial layer on a degenerate n+ substrate. The active region is between a few microns and a few hundred micron thick. This active layer has a doping level b/w 10^{14} cm^{-3} and 10^{16} cm^{-3} - this is considerably less than that used for the top and bottom areas of the device. The thickness will vary according to the frequency required.

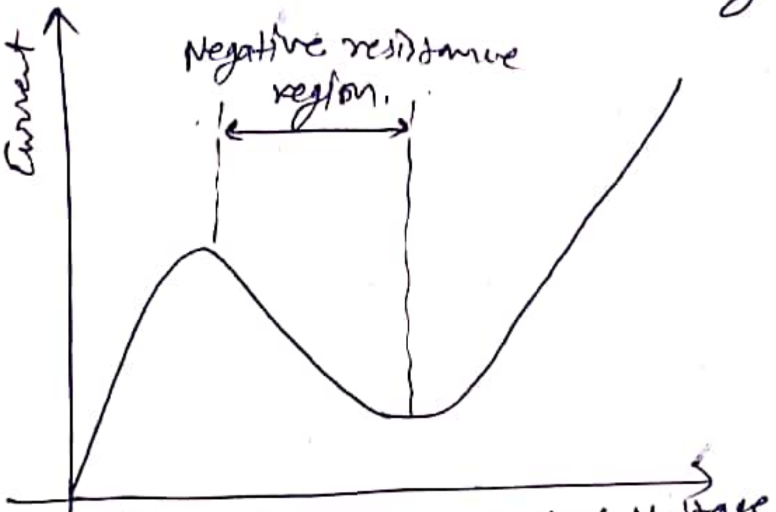
→ The top n+ layer can be deposited epitaxially or doped using ion implantation. Both top and bottom areas of the device are heavily doped to give n+ material. This provides the required high conductivity areas that are needed for the connections to the devices.

...ices are normally mounted on a conducting base to which a wire connection is made. The base also acts as a heat sink which is critical for the removal of heat. The connection to the other terminal of the diode is made via a gold connection deposited onto the top surface. Gold is required because of its relative stability and high conductivity. (4)

→ Gunn diode operation :-

The operation of the Gunn diode can be explaind in basic terms. When a voltage is placed across the device, most of the voltage appears across the inner active region. As this is particularly thin this means that the voltage gradient that exists in this region is exceedingly high.

The device exhibits a negative resistance region on its V/I curve as seen below. This negative resistance area enables the Gunn diode to amplify signals. This can be used both in amplifiers and oscillators. However Gunn diode oscillators are the most commonly found.



Gunn diode characteristic

This negative resistance region means that the current flow in diode increases in the negative resistance region when the voltage falls - the inverse of the normal effect in any other positive resistance element.

→ Typical Characteristics:-

It typically uses a 10-12V supply with typical bias current of 250 mA giving a continuous wave power of 25mW in the X-band.

1. CW power : 25mW to 250mW X-band (5-15 GHz)
   100mW at 18-26.5 GHz
   40mW at 26.5-40 GHz
2. Pulsed power : 5W (5-12 GHz)
3. Efficiency : 2% to 12% (at 1.5W CW to 50 mW CW)

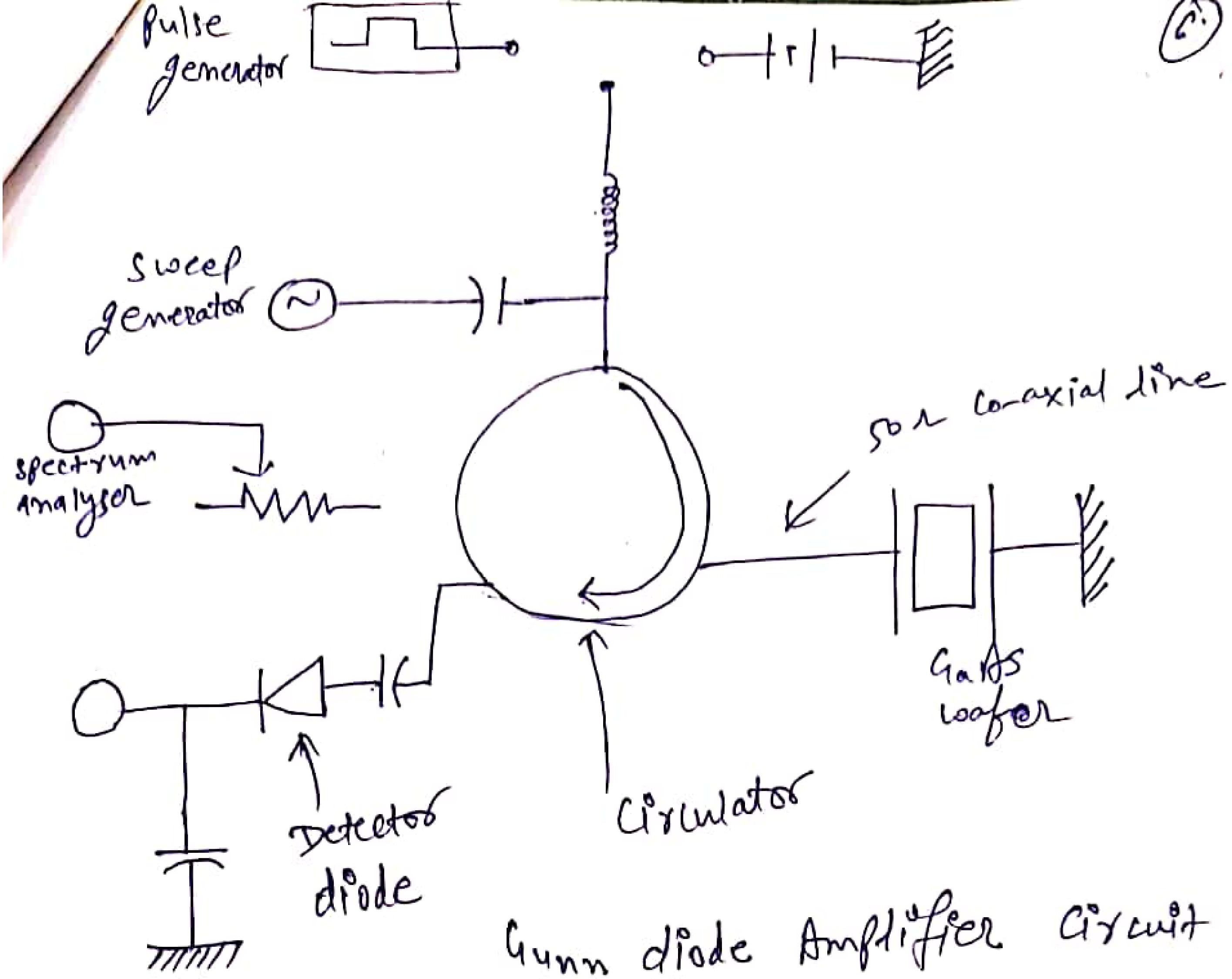
→ Gunn Diode Amplifier:-

Gunn diode with negative resistance characteristics can be used as an amplifier but are not very popular. Gunn diode amplifiers available have been able to give the following performance characteristics.

1. Power : 1W at frequencies between 4 and 16 GHz
2. Gain Bandwidth Product : >10 db
3. Average Gain : 1-12 dB
4. Noise Figure : 15 dB.

The basic circuit of Gunn diode amplifier is as shown in fig.

→ The gain of this amplifier can be obtained by replacing G by -G in the definition of the reflection coefficient of one port circuit terminating port 3 of the circulator.



Gunn diode Amplifier Circuit

→ Applications of Gunn Diode :-

(1.) In Radar transmitters (Police Radar, CW Doppler Rad
(2.) Pulsed Gunn diode oscillators used in transponders f air traffic (ATC) Control and in industry teleme Systems.
(3.) Broadband linear amplifier (replacing TWT's)
(4.) fast Combinational and sequential logic circuits.
(5.) Low and Medium power oscillator in microwave receivers.
(6.) As Pump sources in par amp.

Advantages and Disadvantages:-

Gunn diode have an advantage over IMPATT diodes in that they have lesser noise. The disadvantage of Gunn diode is that it is very temperature dependent 0.5 - 3 MHz/°C change, well designed device have 50KHz/°C for a range of -40°C to +70°C

→ Avalanche Transit - Time Devices (ATTD):-

1. IMPATT: Impact Ionization Avalanche Transit Time Device
2. TRAPATT: Trapped plasma Avalanche Triggered Transit Device
3. BARITT: Barrier Injected Transit Time Device.

(3)(b)

(1) IMPATT Diodes:-

IMPATT diodes have many forms viz., n^+pip^+ or p^+nin^+ read device, p^+nn^+ abrupt junction, and p^+in^+ diode some of which are shown in fig. together with their doping profiles.

Such diodes can be manufactured from Ge, Si, GaAs or InP. However, GaAs provides the highest efficiency, the highest operating frequency and least noise figure, but the fabrication process is more difficult and is more expensive than Si. A typical construction and package are shown in fig. An n-type epitaxial layer is formed over the n^+ substrate. On top of this is the diffused p^+ layer. A metallized cathode and plated heat sink as anode are also included.

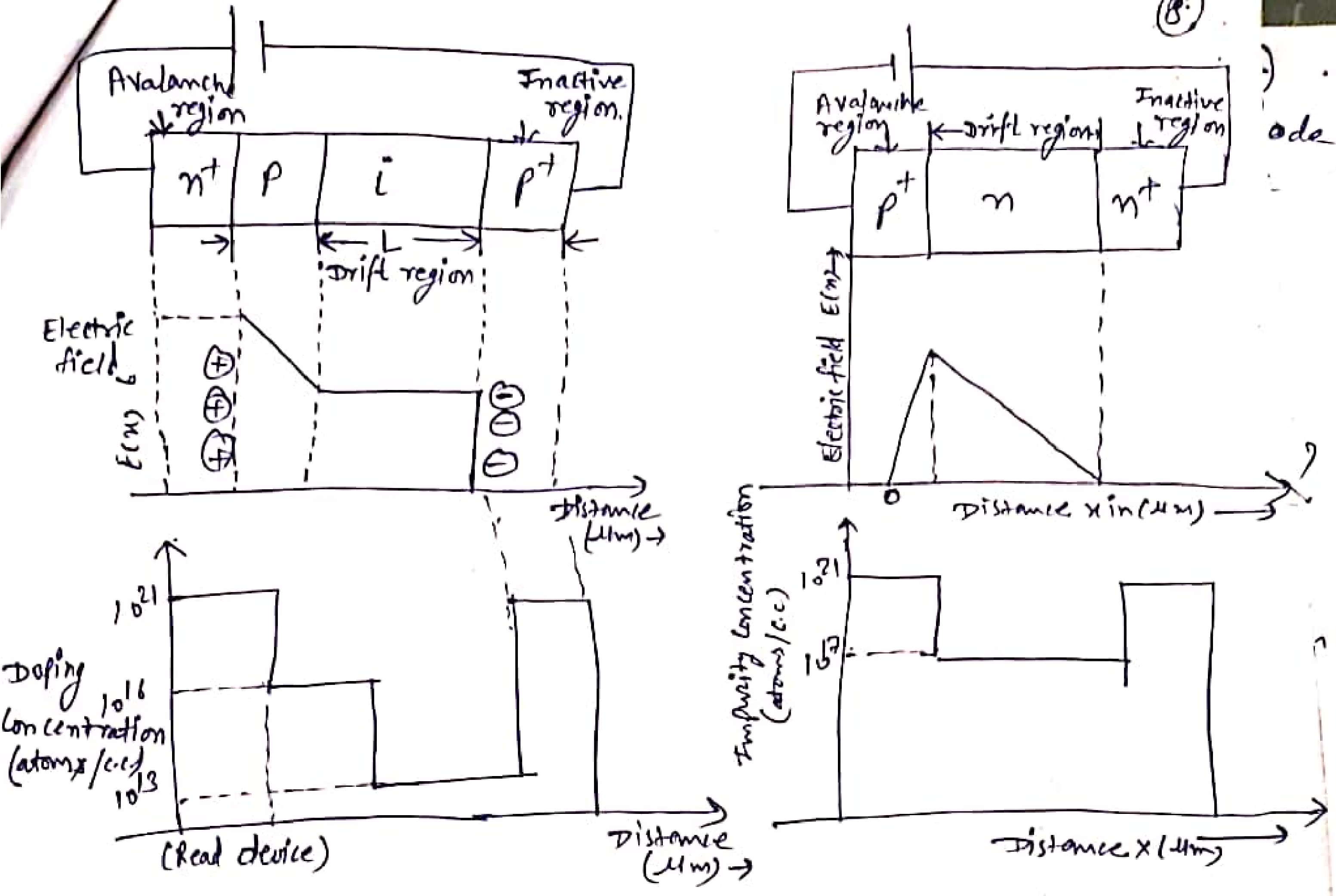


Fig: Structure electric field distribution and doping profile of IMPATT diodes.

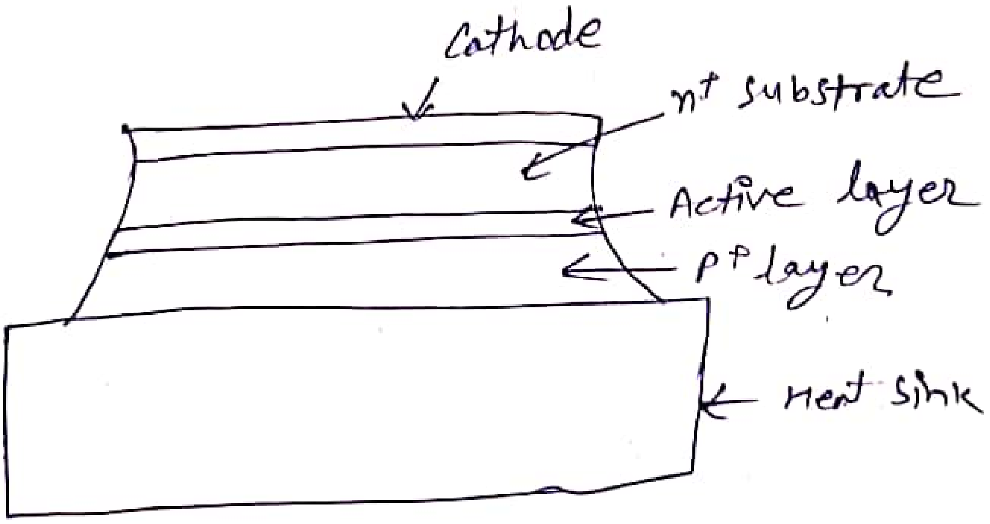


Fig: Construction and package of p^+nn^+ IMPATT diode.

...g Principles:-

Any device which exhibits negative resistance for dc will also exhibit it for ac i.e. if an ac voltage is applied current will rise when voltage falls at an ac rate. Hence negative resistance can also be deffined as that property of a device which causes the current through it to be 180° out of phase with the voltage across it. this is the kind of negative resistance exhibited by IMPATT diode i.e., so if we show voltage and current have a 180° phase difference, then negative resistance in IMPATT diode is proved.

A combination of delay involved in generating avalanche current multiplication together with delay due to transit time through a different space provides the necessary 180° phase difference b/w applied voltage and the resulting current in an IMPATT diode.

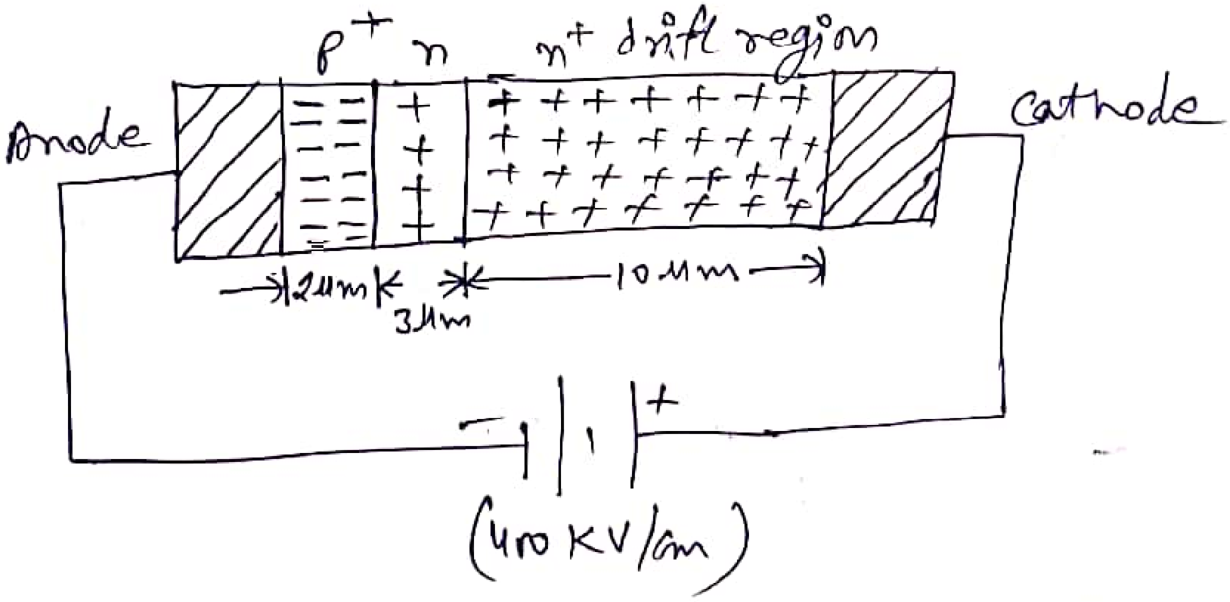


fig:- IMPATT diode schematic

As shown in fig., IMPATT is a diode, the junct[ion] being b/w the p^+ and n layers.

on extremely high voltage gradient (400kV/cm) applied to the IMPATT diode eventually resulting in a very high current. A normal diode would very quickly breakdown under these conditions but IMPATT is constructed such that it will withstand these conditions repeatedly. Such a high potential gradient back biasing the diode causes a flow of minority carriers across the junction. Let us consider application of a RF ac voltage superimposed on top of the high dc voltage. Increased velocity of ēs and holes results in additional e's and holes by knocking them out of the crystal structure by so called 'Impact Ionization'. These additional carriers continue the process at the junction and it now snowballs into an avalanche. If the original dc field was just at the threshold of allowing this situation to develop, this voltage will be exceeded during the whole of the RF positive cycle and the avalanche current multiplication will be taking place during this ~~current~~ entire time.

Since it is a multiplication process avalanche is not instaneous. This process in facts takes a time such that the current pulse maximum at the junction occurs at the instant when RF voltage across the diode is zero and going negative. A 90° phase shift or phase difference b/w voltage and current has then been achieved.

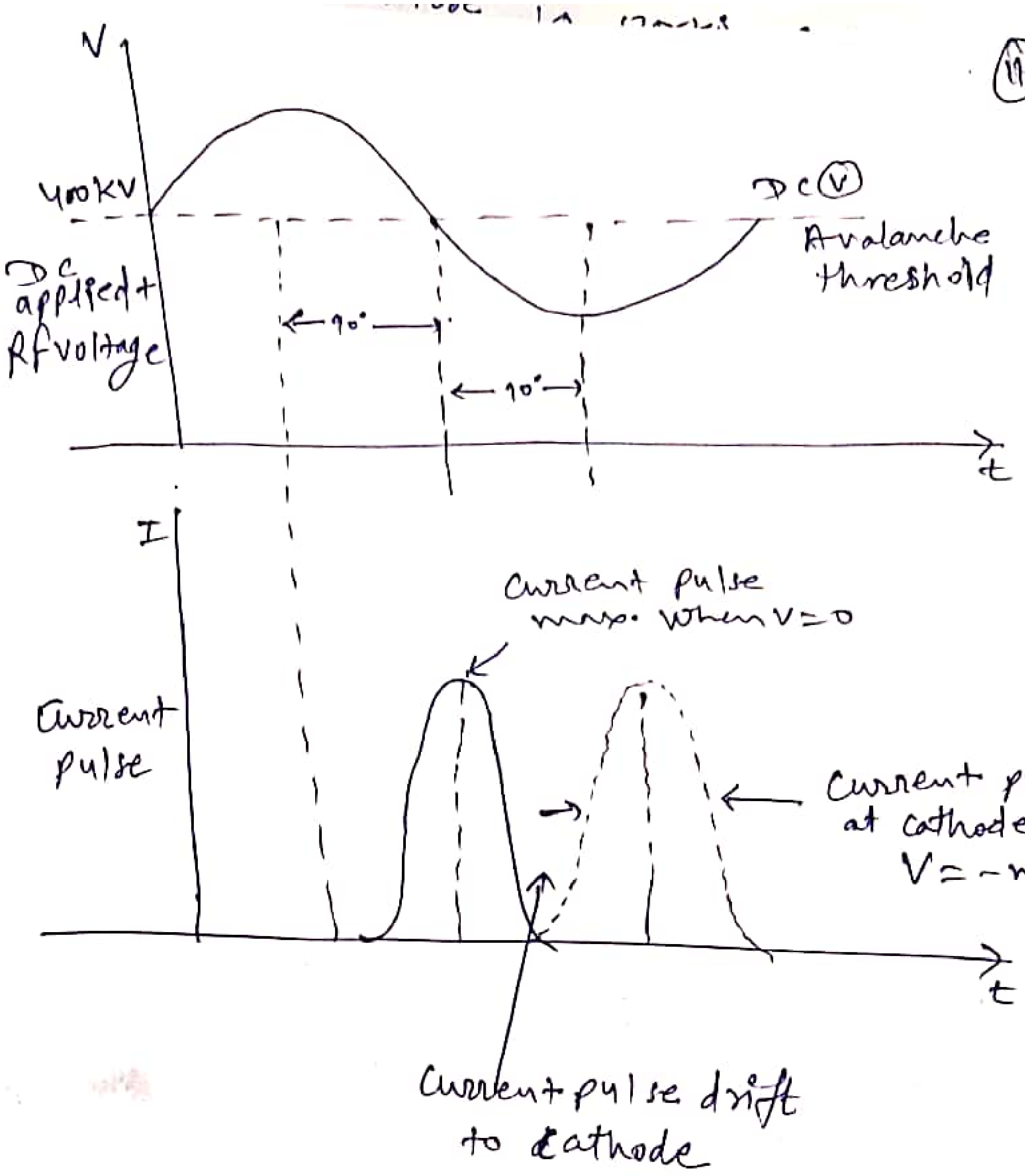


fig V and I versus t characteristics

The current ~~phase~~ pulse as shown in fig. is situated at the junction. It does not stay there but moves towards the cathode due to applied reverse bias at a drift velocity dependent on the presence of high dc field. The time taken by the pulse to reach the cathode depends on this velocity and on the thickness of the highly doped 'n+' (charges) layer thickness is adjusted such that time (2) taken for current pulse to move from $V=0$ position to $V=$ negative maximum of RF cycle is exactly 90°. Hence IMPATT diode is useful both as an oscillator and as an amplifier. The resonant frequency of IMPATT diode is given by –

$$f = \frac{1}{2t_d} \Rightarrow f = \frac{V_d}{2L}$$

Where, V_d = Carrier drift velocity
L = Length of the drift space charge region.

and the drift time is given by $t_d = \frac{L}{V_d}$

The efficiency η of IMPATT diode is given by –

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

Where, P_{ac} = ac Power
P_{dc} = dc Power
V_a and I_a = ac voltage and current
V_d and I_d = dc voltage and current

→ Equivalent circuit IMPATT diode :–

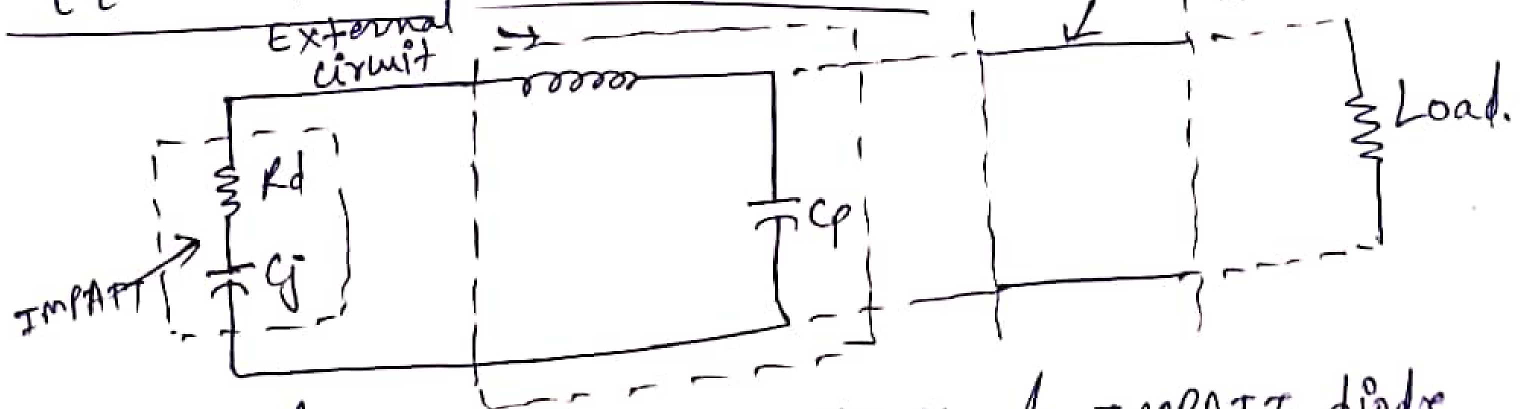


fig :- Equivalent circuit of IMPATT diode

Q(3) A Gunn diode ... (B) ... ma (15)

Disadvantages of IMPATT Diode:-

The disadvantage of IMPATT diode is that it is very noisy because avalanche is a noisy process. Noise figures for IMPATT being 30dB are not as good as Klystron / Gunn diode / TWT amplifier. Also, tunning range is not as good as Gunn diodes. Amplifiers are comparable to Gunn diode amplifier with higher power and frequency.

Applications of IMPATT Diode:-

(1.) IMPATT diodes are used as microwave oscillators, such as (i.) Microwave generators (ii.) modulated output oscillators (iii.) Receiver local oscillators and (iv.) par amp pumps.

(2.) In the final power stage of solid state microwave transmitters (RADAR) for communication purpose.

(3.) In the transmitter of television system.

(4.) Used in FDM / TDM systems.

(5.) As a microwave source in the laboratory.

(6.) As a missile seeker head.

(7.) High Q IMPATT's are used in intrusion alarm networks, police radar and low power microwave transmitter whereas low Q IMPATT's are useful in FM telecommunication transmitters and CW (Continuous wave) doppler radar transmitter.

", 44nm diode is working :

(15)

An IMPATT diode has a drift length of 2μm. (14.)
Determine the operating frequency of the IMPATT diode if the drift velocity for si is 10^7 cm/sec.

Soln:- $f = \frac{V_d}{2L}$ $= \frac{10^7 \times 10^{-2}}{2 \times 2 \times 10^{-6}} = 25 GHz$ Ans

(5)

Q(2) An IMPATT diode has a drift length of 2μm, $V_d = 10^{05}$ cm/sec., Determine
(a.) The drift time of the carrier.
(b.) The operating frequency of the diode.

Soln:- $f = \frac{1}{2t_d} = \frac{V_d}{2L}$

where V_d = Carrier drift velocity
L = drift length

(a.) Drift time $t_d = \frac{L}{V_d} = \frac{2 \times 10^{-6}}{10^{5}} = 2 \times 10^{-11}$ sec.

(b.) operating frequency, $f = \frac{1}{2t_d} = \frac{1}{2 \times 2 \times 10^{-11}}$

$= 25 GHz$ Ans

$2 \times 10^{-6} / 10^5 \times 10^{-2}$

$2 \times 10^{-1} \times 10^{-3}$

Q(5.) A Gunn diode is working in transit time mode at 12 GHz. The domain of charges move at 10^7 cm/sec. speed. Calculate -

(i.) the length of the device

(ii.) Can the device work at 10 GHz and 14 GHz. Which is the mode of operation in each case?

Soln:- (i.) If L be the length of the device and τ_t be the transit time of the carrier, then saturated drift velocity.

$$V_d = \frac{L}{\tau_t} \quad (\because V_d = fL) \text{ here } f = \frac{1}{\tau_t}$$

$$\Rightarrow L = V_d \times \tau_t = 10^7 \times \frac{1}{12 \times 10^9}$$

$$\simeq 8.33 \times 10^{-4} \text{ cm}$$

$$\simeq 8.33 \ \mu m.$$

(ii.) (a.) for 10 GHz the corresponding time period

$$\tau_0 = \frac{1}{10 \times 10^9} = 10^{-10} \text{ sec.}$$

whereas the transit time of the device

$$\tau_t = \frac{1}{12 \times 10^9} = 0.08 \times 10^{-9} \text{ sec.}$$

As, $\tau_0 > \tau_t$ hence can operate in delayed mode.

(b) for 14 GHz, the corresponding time period is

$$\tau_0 = \frac{1}{14 \times 10^9} = 0.07 \times 10^{-9} \text{ sec.}$$

As, $\tau_0 < \tau_t$, hence can operate in quenched mode.