Microwave Sources:-

Limitations of conventional tubes:
(1) lead inductance effect
(2) Interelectrode cap effect
(3) Transit time effect
(4) gain-b.w product limitation
(5) Skin effect
(6) power loss in tubes
(7) heat generated
(8) Incompatible dimension

* transit time $= t_t = \frac{d}{v_e}$ where $v_e = \sqrt{\frac{2eV_a}{m}} = .593\times10^6\sqrt{V_a}$ m/sec

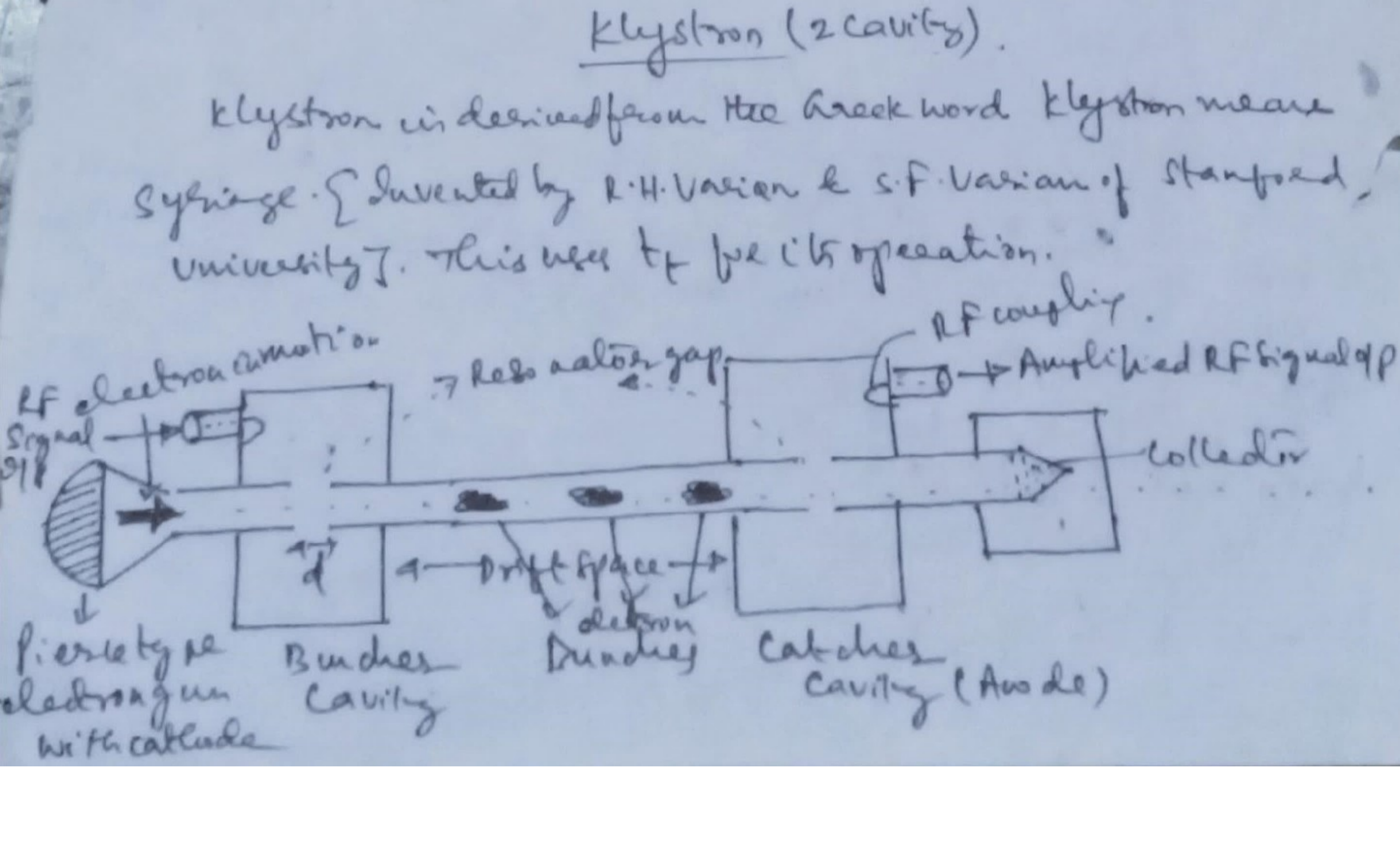
e = electron charge, V_a = Volt between anode & cathode
1.6×10^{-19} c
m = mass of electron - d = distance between electrodes

* gain-b.w = g_m/c where g_m = transconductance
c = capacitance

* klystron, Reflex klystron, magnetron, TWT & BWO (Backward wave oscl.) work on the principle of vel modulation.

Klystron (2 cavity).

klystron is derived from the Greek word klystron means syringe. [Invented by R.H. Varian & S.F. Varian of Stanford University]. This uses t_t for its operation.



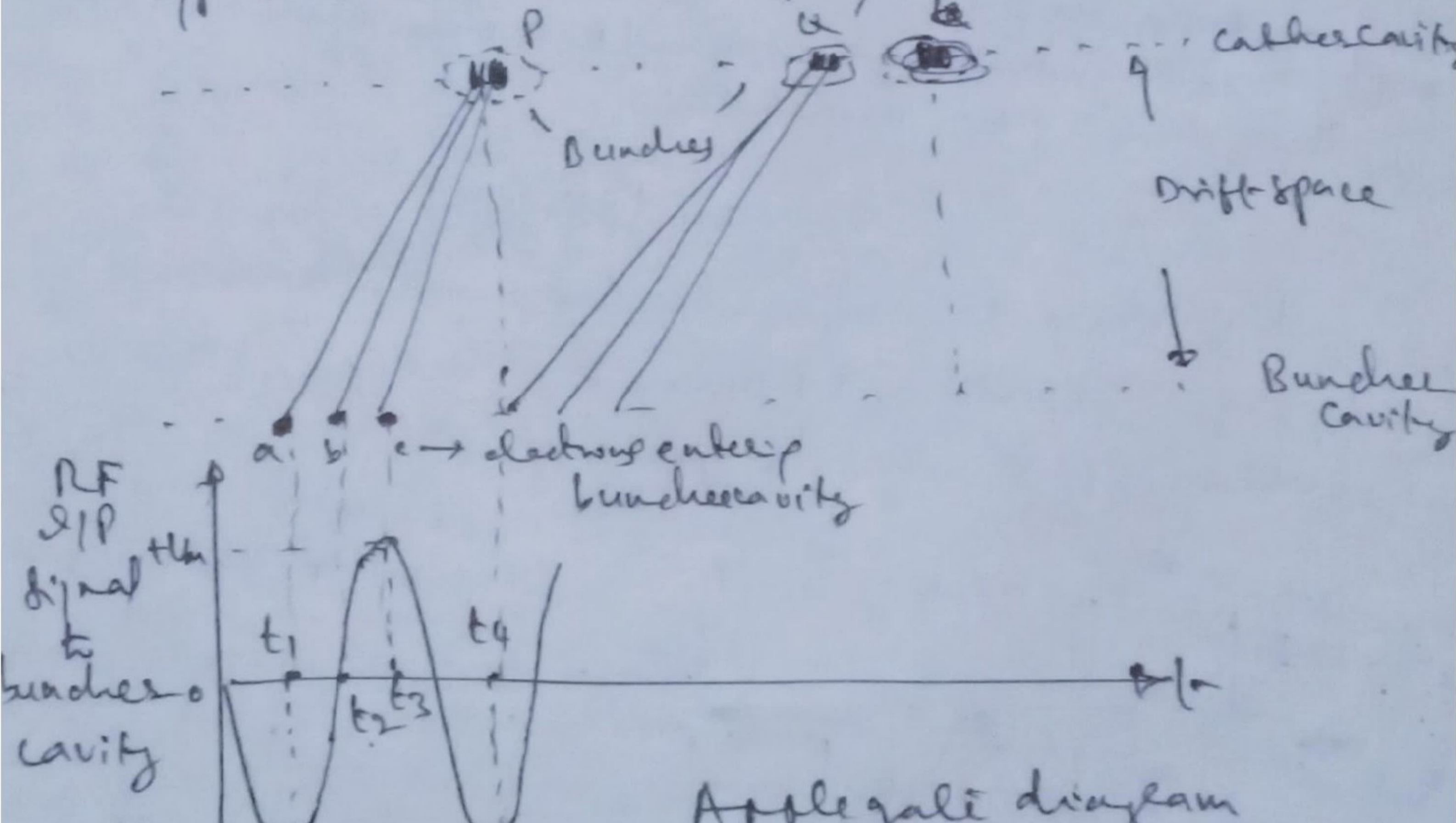
MN1-38

Bunching of electrons :-

DC bias of 250V is applied between anode & cathode. Electrons emitted from cathode travels at uniform vel V_0 initially when no volt is applied to buncher cavity.

If we apply a sinusoidal RF signal to buncher cavity, as volt ↑ during +ve half cycle vel of electrons also ↑ & during -ve half cycle when volt ↓, vel also ↓. ∴ Vel of electrons varies according to RF i/p volt.

Thus vel variation or vel modln produces bunching i.e one electron catching with other electron in the drift space. When bunches pass thru catcher cavity, they excite the catcher cavity & by cavity resonance amplified RF o/p is obtained thru RF coupling.



Applegate diagram

* At $t = t_1$, effective volt acc the buncher taken is

$$V_{eff} = V_{DC} - V_m (\text{RF signal } I/P)$$

Hence electron 'a' moves with a vel < V_0 (uniform vel)

* at $t = t_2$, $V_{eff} = V_{DC}$ & hence electron 'b' moves with vel V_0

* at $t = t_3$ $V_{eff} = V_{DC} + V_m$ — " — 'c' — " — $> V_0$

Hence there is possibility that electrons a, b & c can catch with one other in drift space & form a bunch. Like this there will be no. of bunches. These bunches travel with certain average vel & delivers RF energy to catcher cavity by cavity resonance.

Important parameters of klystron

(1) β_b - Beam coupling co-efft:- Defines amount of RF signal coupled to the buncher cavity their RF coupling.

$$= \frac{\sin\left(\frac{\omega t_t}{2}\right)}{\left(\frac{\omega t_t}{2}\right)} = Sa\left(\frac{\omega t_t}{2}\right) \qquad \omega = 2\pi f$$

$$t_t = d/V_e$$

If $\omega = 0$, $\beta_b = 1$. As $f \uparrow$, $\beta_b \downarrow$.

(2) m_v - Vel. modulation index (defines depth of modn.) as in AM, FM, PM etc.

$$= \frac{\beta_b V_i}{V_A}$$

(3) N - No of cycles of I/P signal freq (f) required for complete electron bunching

$$N = \omega t_t / 2\pi = f t_t.$$

20 (4) X – Bunching parameter:-

This determines the amount of electrons in a bunch

$$X = \pi N M V = \pi N \frac{\beta_b V_i}{V_a}$$

(5) Power o/p of klystron (P_o):-

$$= K \beta_c V_a I_a \left(1 - \frac{X}{\pi N \beta_b}\right) . J_1(X)$$

K = Beam Txn factor

$J_1(X)$ = Bessel fun. of electrode corresponding to electron bunching.

β_i & β_b = Beam coupling coefft. of catcher cavity, buncher cavity

V_a & I_a = Anode volt & current

$\therefore P_i = V_a I_a$ = i/p power to klystron

$$\text{klystron } \eta = P_o/P_i = K \beta_c \left(1 - \frac{X}{\pi N \beta_b}\right) J_1(X)$$

Max. η occurs for $X = 1.8$, root of Bessel fun. $\rightarrow J_1(X) = .582$

(6) Voltage gain of klystron

$$A_v = \frac{\beta_b^2 \theta_o J_1(X)}{R_o X} R_{sh}$$

θ_o = DC transit 1/s between buncher & catcher cavity

$$= \frac{\omega L}{v_e} = \frac{2\pi f L}{v_e} \quad \text{where } v_e = \sqrt{\frac{2eV_A}{m}}$$

R_{sh} = Eqvt. shunt resistance offered by the tube to the electron beam

R_o = o/p resist. or char. resist. of tube.

MW 1-41

Multicavity klystron:- By introducing more no of intermediate catcher cavities we get multicavity klystron. Important characteristics are

* Larger power o/p
* Requires smaller dc i/p power for operation.
* Higher gain-bw product
* Stagger tuning is possible to get BP chars.

Specifications:- 1) $\underset{GHz}{.5} < f < \underset{GHz}{10}$ 2) High $\eta = 40\%$.

3) They are linear amplrs. - Continuous o/p power 15 to 500kW; Pulsed power $\leq$ 30MW

4) Power gain 50-55dB

5) Typically $V_A = 250kV$ & $I_A \simeq 250$ Amps

6) Poor NF of 25dB ((SNR)i/p to (SNR)o/p)

Applications:- 1) used as final power amplr in TV Tx

2) used as harmonic generators for μwave mixers.

3) using reee f-b it can be converted as a source or oscltr

4) It can be used as a BPF in telecoling ckts

klystron amplr.

Appln.	f range GHz	Required power	Available power
1) UHF TV TX (CW)	0.5 - .9	55 kW	100kW
2) Long range Radar (pulsed)	1-12	10MW	20MW
3) Troposphere links (CW)	1.5-12	250kW	1000kW
4) Earth station TX (CW)	5.9-14	8kW	25kW.

Microwave Semiconductor Devices:-

[MW1-42]

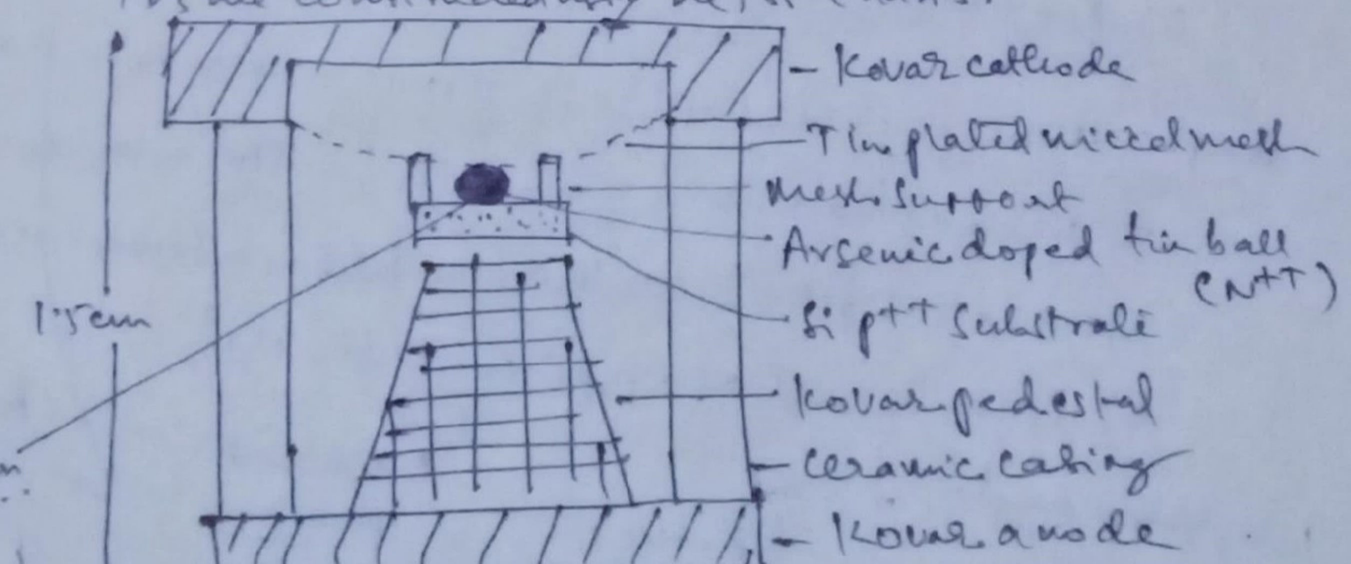
Adv:- Dimension compatible at µwave range, No heating elements required, low cost, light weight, Can be used in MICS (µwave ICs).

Disadv:- low power devices, higher noise level, difficult to be coupled to planar strip/µstrip lines (i.e coupling losses are higher)

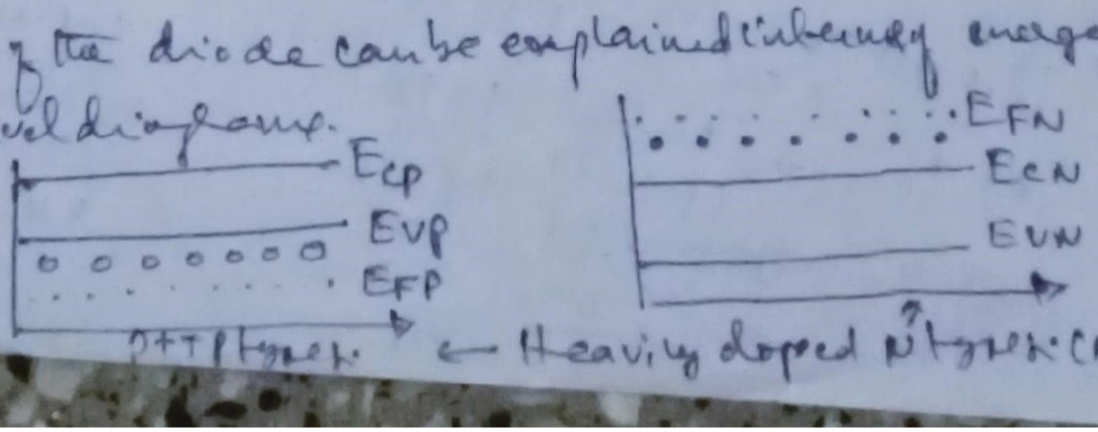
Tunnel diode (TD):- Invented by Japanese scientist L. Esaki in 1958. Works on the principle of QMT (Quantum Mechanical Tunneling)

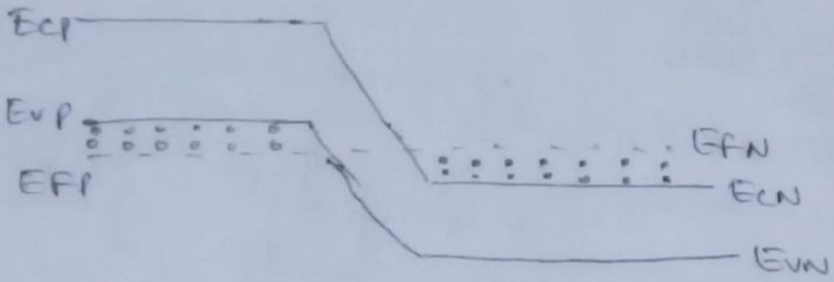
QMT:- Electron has dual nature i.e it behaves as a particle & as a wave. waves can penetrate thin walls instead of going around the walls. with barrier pot^{ll} electron behaves as a wave & it penetrates this thin jun. This is called tunneling effect.

TDs are constructed using Ge, Si & GaAs.

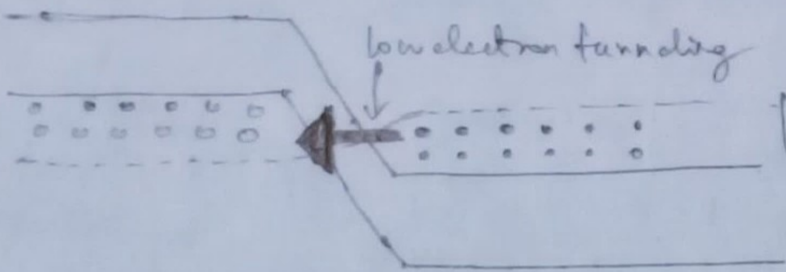


operation of the diode can be explained in terms of energy level diagrams.

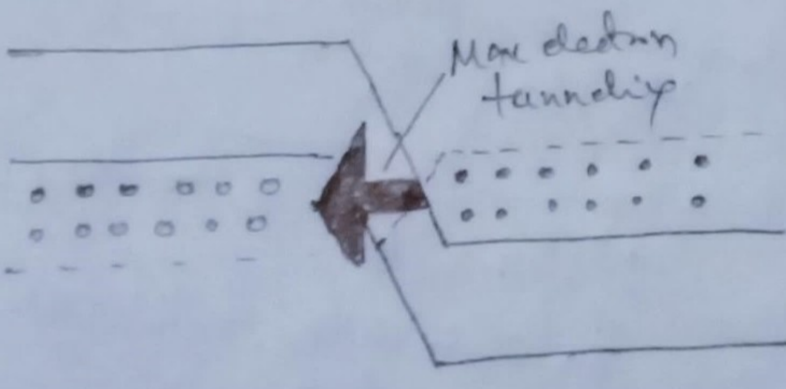




(a) Un-biased pn junction
No current flows since e that are not able to cross the jun. due to barrier pot. (point O)

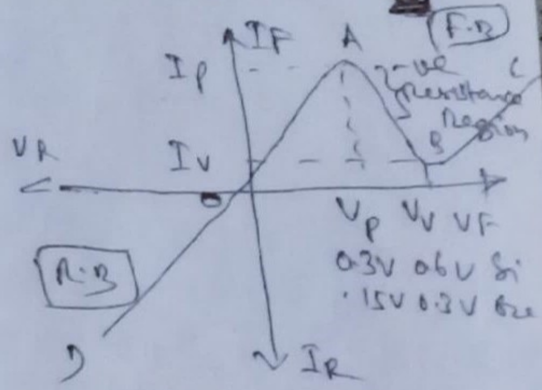


(b) F.B voltage $0 < V_F < 0.3V$
Due to external bias, barrier is lowered so that there will be low tunneling & small current flow. As bias ↑, I_F also increases (portion OA).

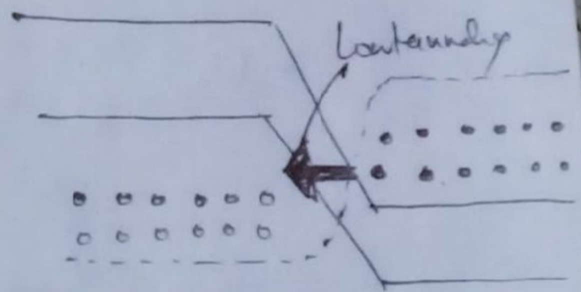


(c) If $V_F = 0.3V$ or $.15V$ for Si or Ge
Max tunneling. I_F current reaches a max or peak value, point 'A'
i.e region OA diode act as a bulk device where I_F ↑ with V_F linearly.

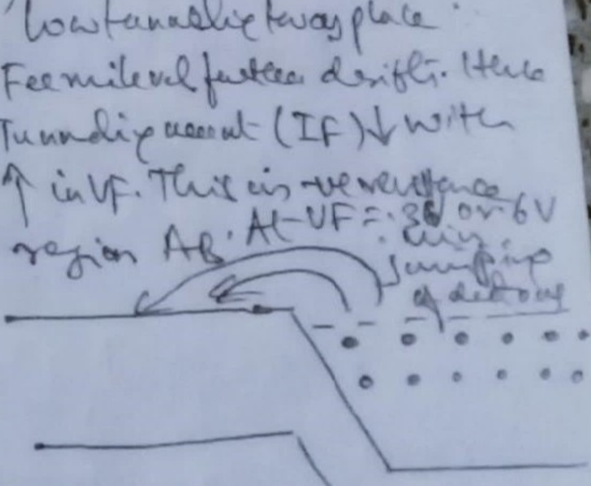
MW1-43



Characteristics

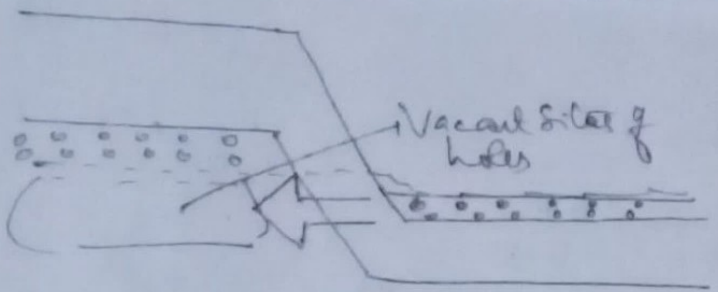


(d) $.3V < V_F < .6V$
Low tunneling takes place. Fermi level further deviates. Hence Tunneling current (I_F) ↓ with ↑ in V_F. This is -ve resistance region AB. At $V_F = .3V$ or $.6V$



(e) $V_F > .6V$ or $.3V$. Tunneling stops (i.e wave behaviour of electron stops) & now electron act as particle, which jumps across the jun resulting in current flow ↑ with bias volt: i.e. normal diode

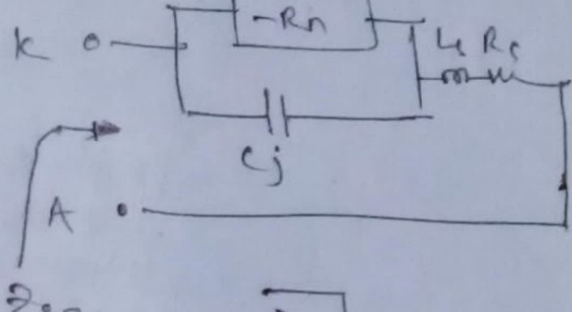
Arsenic doped tin ball

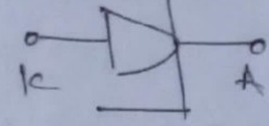


(e) In R.B region, at low V_R zener breakdown results in smaller I_R. As $V_R \uparrow$, I_R also $\uparrow$ as electrons drift towards vacant sites of holes in p region (region OD).

MW1-44

TD equivalent ckt :





symbol

$-R_n \rightarrow$ −ve resistance, $C_j \rightarrow$ jn cap.

typically:- $R_n \simeq 100\Omega$, $C_j \simeq 5pF$, $R_s \simeq 0.5\Omega$ & $L_s \simeq 0.1nH$

R_s, L_s − lead resist, inductance

$$Z_{eq} = \left[-(R_n) \,||\, (-jX_{C_j})\right] + R_s + jX_{L_s}$$

Simplifying $= R_{eq} \pm jX_{eq}$. As there are two resonant ckts ∴ there are two resonant frequencies

(i) If $X_{eq} = 0$, $f = f_r = \dfrac{1}{2\pi C_j R_n}\sqrt{\dfrac{C_j R_n^2}{L_s} - 1}$ — (1)

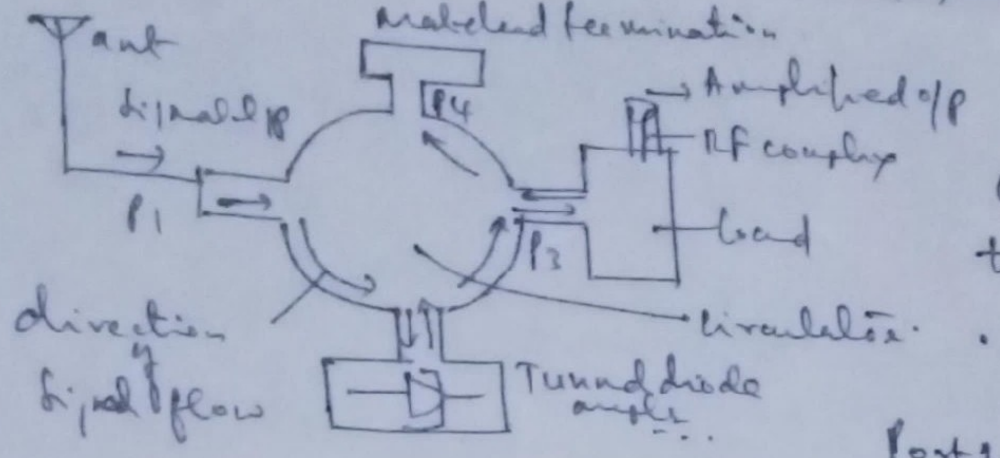
(ii) If $R_{eq} = 0$ $f = f_c = \dfrac{1}{2\pi C_j R_n}\sqrt{\dfrac{R_n}{R_s} - 1}$ — (2)

↓ resistive cutoff freq

∴ $f_r \simeq 22.3\,GHz$, $f_c \simeq 45\,GHz$ i.e $f_c > f_r$

Applications : General : • Because of low C_j, used in high speed RF switches, flip-flops, logic gates

• Microwave amplifier : As TD is 2 terminal, to be used as an ampli we require 3 terminal. Use TD with circulator.

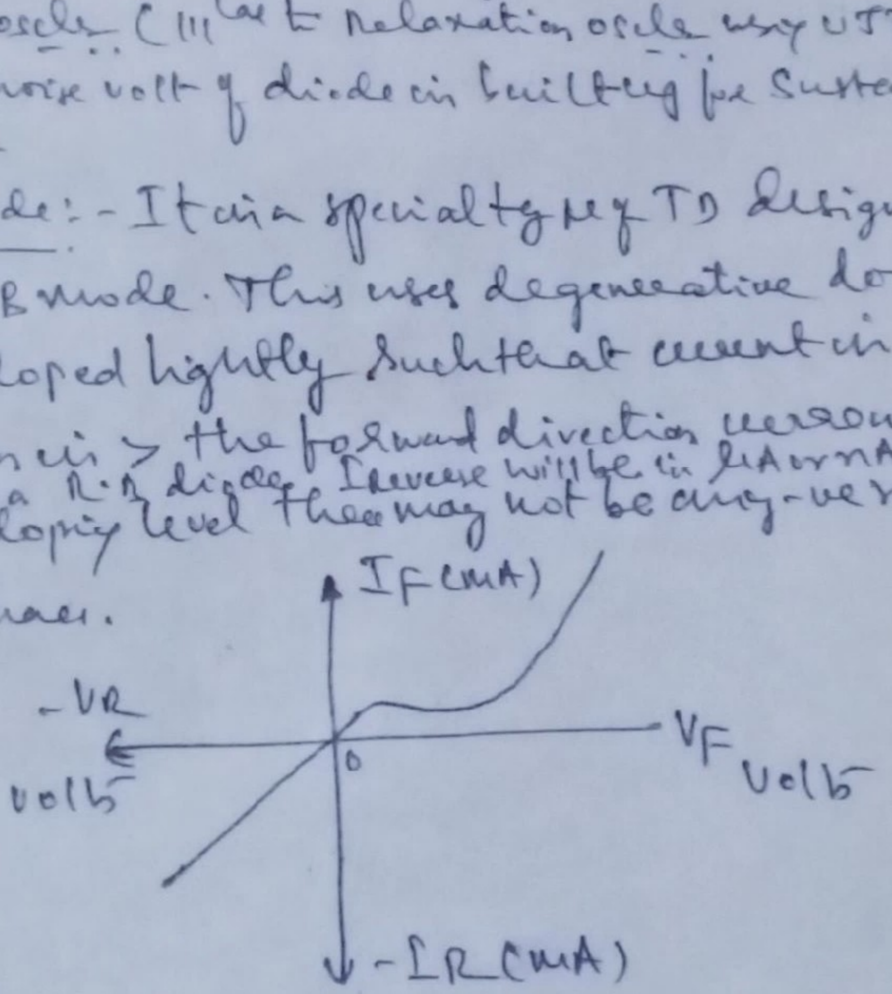


MW1-45

Circulator is used to i/p & o/p of TD ampli. ∵ it is a two terminal device.
Port 1 & port 4 are isolated.

(b) Microwave oscln:- In the -ve resist. region it can be used as a source or an oscln. (similar to relaxation oscln using UJT) Here internal noise volt of diode is building for sustained oscln.

(c) Backward diode:- It is a special type of TD designed to operate in R.B mode. This uses degenerative doping. P-N regions are doped highly such that current in reverse direction is > the forward direction current. Generally in a R.B diode I reverse will be in μA or nA. Also based on the doping level there may not be any -ve resist region in the F.B char.



(d) used as a rectifier to rectify small signal ampli-tudes (mV range) at μwave fre.

e) can be used as a detector in demodulators

(f) can be used as a mixer in RX ckts -

MW1-47

Gunn diode:- They belong to a class of microwave semiconductor devices called TED (Transferred electron devices).

- Gunn effect was noticed by J.B. Gunn in 1963 working in IBM corporation.

Gunn effect:- (Negative differential mobility):

In direct band gap materials like GaAs, InP, a sufficiently high E-field can cause electron to scatter into regions where band gap is larger. (Satellite conduction band or valley band)

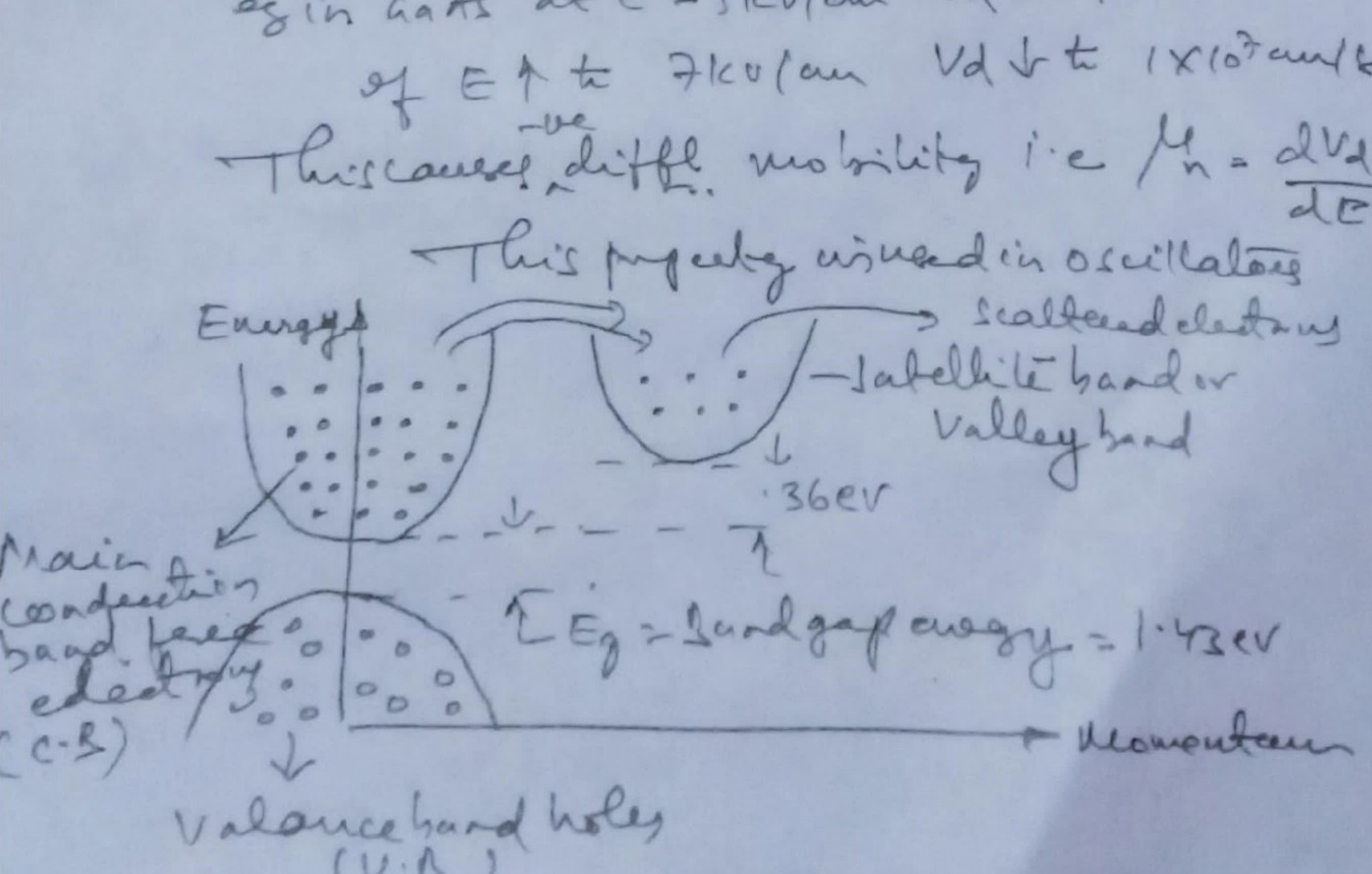
As a result band gap energy also increases, due to this electron suffers loss in its mobility (μ/m) which determines drift velocity. $V_d = nq\mu/m$

eg in GaAs at $E = 5kV/cm$ $V_d = 2\times10^7 cm/sec$.

if $E\uparrow$ to $7kV/cm$ $V_d\downarrow$ to $1\times10^7 cm/sec$

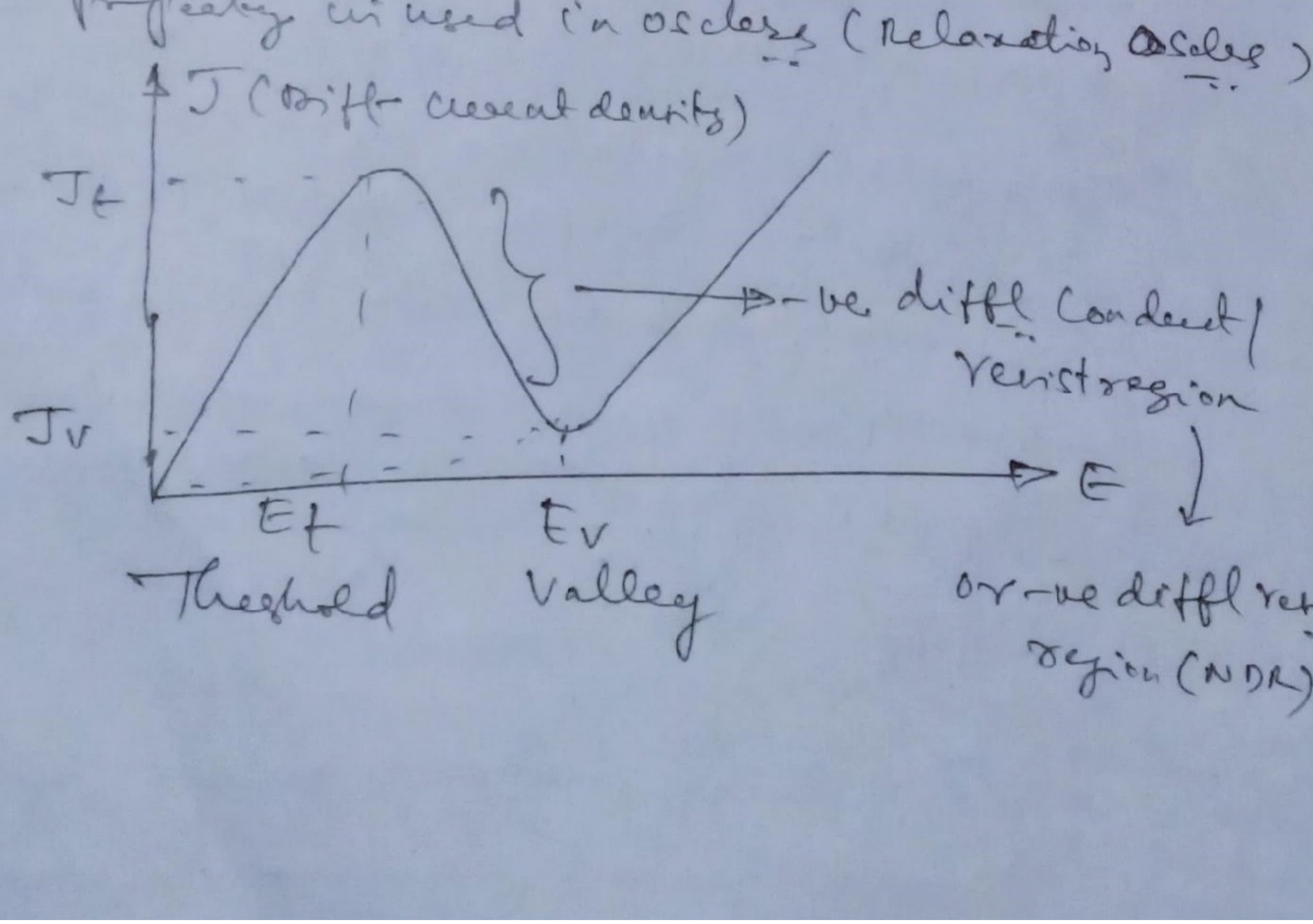
This causes -ve diffl. mobility i.e $\mu_n = \frac{dV_d}{dE} < 0$

This property is used in oscillators

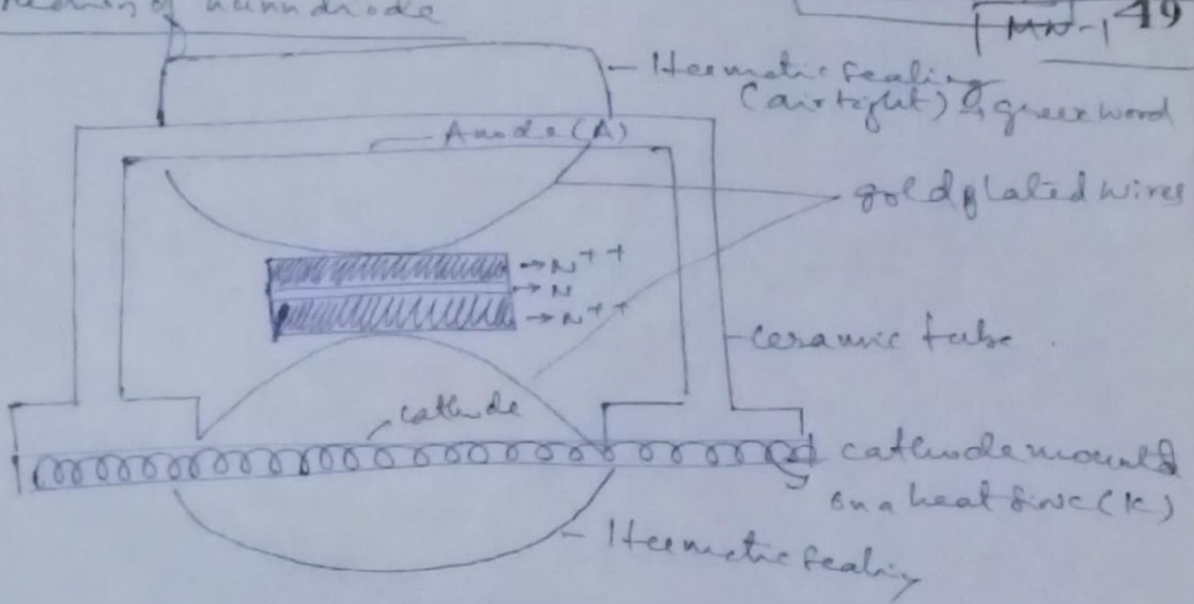


For this to happen special doping is needed for the SC material. MW1-48

- GaAs is a direct band gap material with $E_g = 1.43eV$ & we must apply an external energy = or > than " — to lift electrons from V.B to C.B.
- If we apply an energy > 1.43eV, V.B electrons losses its mobility
- Since mobility is directly associated with flow of currents, we can infer that reduction in mobility with increased E_g gives rise to the condition of "−ve Conductance". This property is used in osclrs (Relaxation osclrs)



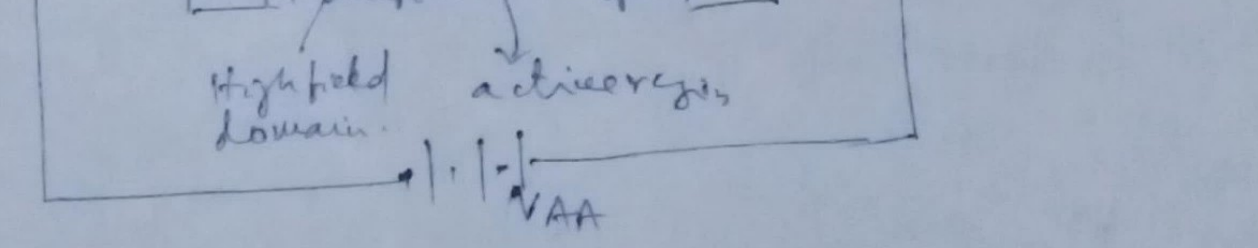
Construction of Gunn diode



* GD belongs to BSD category. (Bulk semiconductor devices).
BSD are made of a short length of N^{++} or p made of GaAs with 2 external leads called A & K.
* N layer is lightly doped & N++ layers are heavily doped.

Gold plated wire improves conductivity.

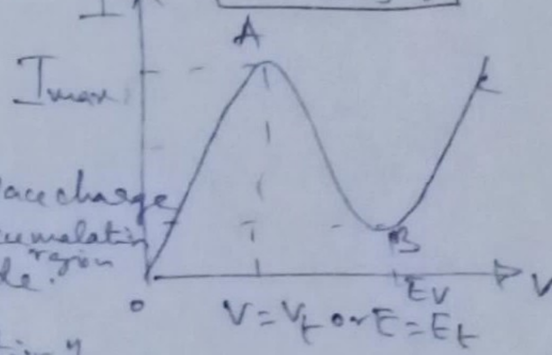
operation/working :-



If VAA applied produces a E < 3kv/cm then device just acts as a two terminal bulk diode with drift current flowing from anode to cathode (due to random motion of electrons from cathode to Anode thru N layer.

20 This bulk current of with ↑ in bias reaches max at point A.

MW 1-50



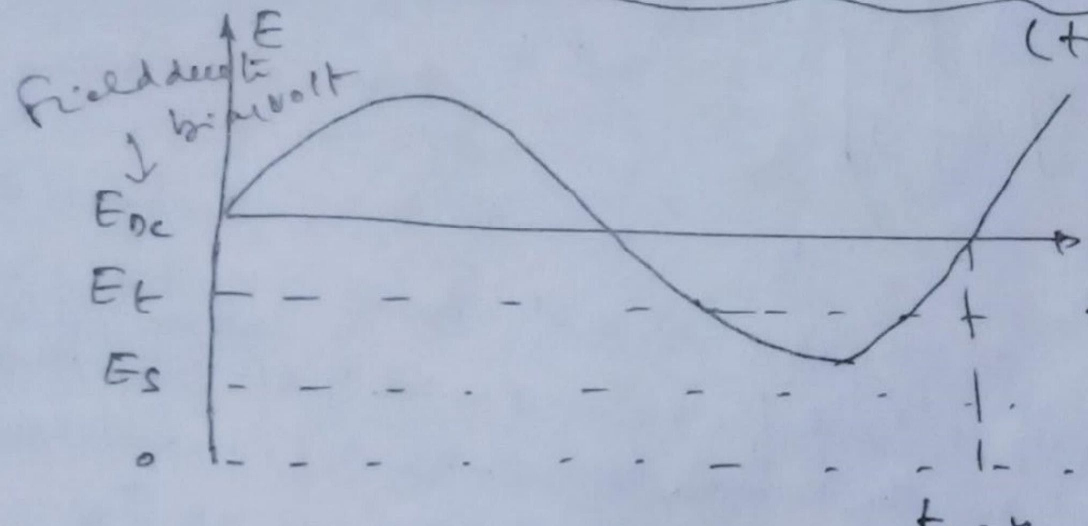
* If $V_{AA} = 30V$, $L = 100 \mu m$ then $E_t \simeq 3 kV/cm$. Due to non uniformity in doping a high field domain is produced as in fig near cathode. High field region is nothing but accumulation of electrons at a specific point in n-layer.
* If $E > E_t$, the vel of electrons leaving the high field domain is smaller than the electrons entering (-ve diff mobility)
* As time progresses accumulation of electrons to the left of domain will be more than at right [This is ||| lar to a Buffet where if serving is slow, people leaving the queue will be in small nos than the people entering due to rush].
* The domain slowly drifts towards anode under the influence of V_{AA}. Drift vel of domain << vel of individual electrons. Finally at anode the domain collapses (||| lar to water bubble on the surface of water which slowly moves outwards & bursts due to wind at the shore). In this process it releases the (i.e. it has acquired from its motion towards anode.
* Under suitable conditions a noise volt of appropriate freq existing in the diode gets self amplified. This results in sustained osclm. This continues until $E < E_V$ (portion AB)
* Then if $E > E_V$ normal diode action commences in the picture (portion BC). point B is called the valley point

Modes of operation: There are four important modes [MW1-51]

1) Resonant Gunn mode or Ac transit time mode

($t_0 = \tau$)

$\boxed{\eta_c = 10\%}$



E_t = Field for threshold operation

E_s = field for sustained operation

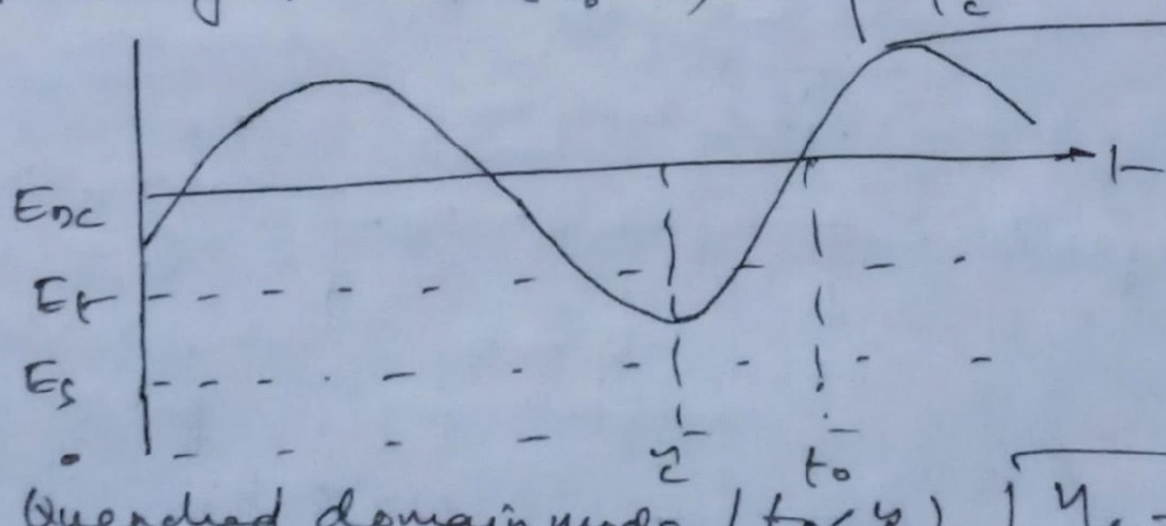
τ = Transit time of high field domain - Time in which it travels towards the anode

t_0 = Time of freq of oscillations. Both are same

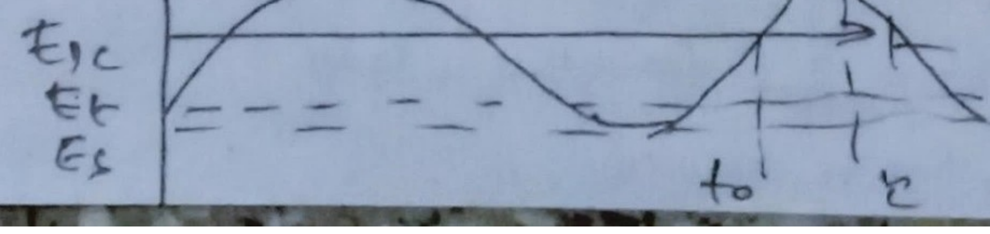
To get oscls we use a cavity. usually gunn diode is mounted inside the cavity.

η_c — conversion efficiency (dc to ac)

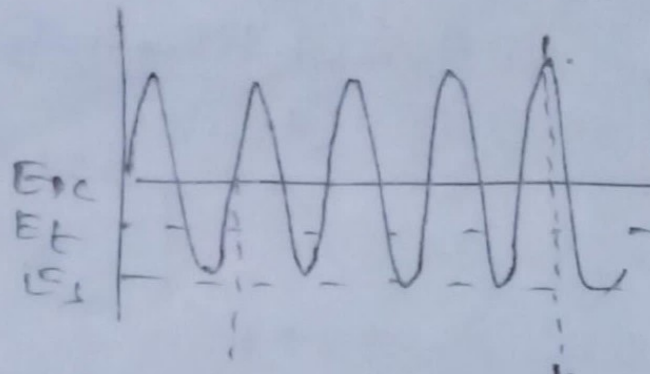
2) Delayed mode ($t_0 > \tau$): $\boxed{\eta_c = 20\%}$



3) Quenched domain mode ($t_0 < \tau$) $\boxed{\eta_c = 20\%}$

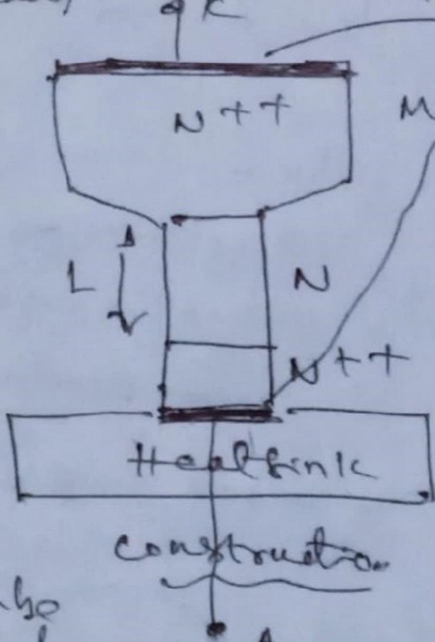


(4) LSA mode (or Limited Space Accumulation region). Here $\tau_c >> t_0$. This gives high power o/p. $\eta_c = 20\%$.



This is the most popular & efficient region of operation. As freq of operation is very high, no time for high freq domain formation; the diode is operated in the neg conduction state for entire period of operation at the middle. Here $\tau_c = n\tau_0$, n is the modal number n=1,2,3.... In this mode we get sustained oscillns & hence used as a source in clearance application. 'f' depends only on external resonant ckt.

Symbol:-



construction

Characteristics & Specifications

- Non linear V-I chars
- It is a wide band device
- *** It does not have any p-n jn.
- By varying 'L', 'f' of diode can be varied
- operated in
  - pulsed mode
    - at f = 1.7 GHz, $P_0 \ngtr 6$ kW
    - at f = 40 GHz, $P_0 \downarrow$ to 400 mW
  - CW mode
    - at f = 5 GHz, P_0 = 100 mW
    - at 35 GHz, P_0 = 1 W
- For $4\,GHz < f < 15\,GHz$, $6\,dB < A_v < 12\,dB$
- Low Noise device

Applications:-

[MW 1-5]

* As Gunn oscls. for microwave gens for radio comm., military & radar sources
* used as sensors for detection / door opening / process control
* as remote vibration detectors & rotational speed measuring (tachometers)
* as microwave current-generators.
* In microwave Tx. to generate microwave radio waves at very low power.
* As controlling component in fast electronics (eg: direct modulating SC injection lasers)
* Perimeter protection, pedestrian safety systems, linear distance indicators, level sensors, moisture content-measurement & intruder alarms.
* as pump source in parametric ampls.
* fast combinational & sequential logic ckts
* Broad band ampl.

Limitations:- * As it is a 2 terminal device, a circulator is needed. large compatibility

* It is a low power device in CW mode

* It has non linear chars.

Its chars are temp sensitive.