Microwave Solid State Devices

Ch-7 -

Difference betn +ve resistance & -ve resistance solid-state devices : —

~~Transferred Electron Devices (TEDs)~~

The application of two-terminal semiconductor devices at microwave frequencies has been increased usage during past decades. The average and peak power o/ps of these devices at higher MW frequencies are much larger than those obtainable with the best power transistors.

The common characteristic of all active two-terminal solid-state devices is their -ve resistance. [The real part of their impedance is -ve over a range of frequencies].

2) In a +ve resistance the current through the resistance and the voltage across it are in phase. The voltage drop across a +ve resistance is +ve and a power of (I^2R) is dissipated in the resistance.

1) [In +ve resistance device, current increases with increase in voltage but in -ve resistance device, current decrease with increase in voltage.]

In a -ve resistance, however the current and voltage are out of phase by 180°. The voltage drop across a -ve resistance is -ve and power of $(-I^2R)$ is generated by power supply associated with the -ve resistance.

3) In other words, +ve resistances absorb power (passive devices), whereas -ve resistances generate

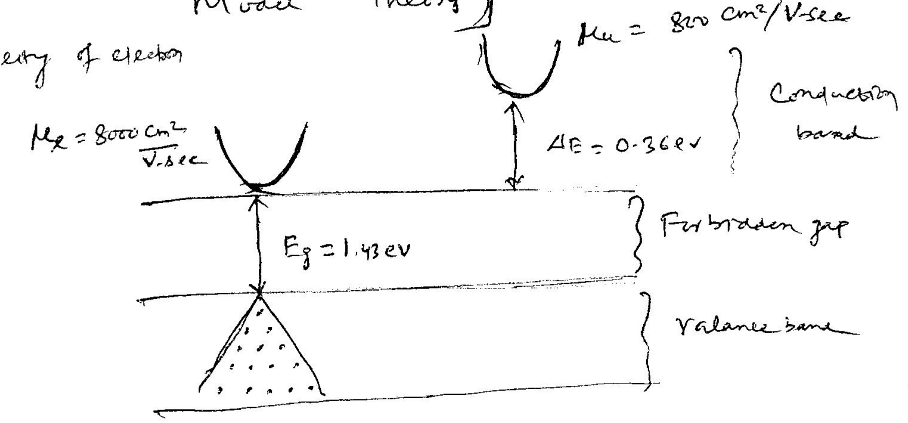
power (active devices).

What are TEDs [Transferred Electron Devices] ?

The Compound Semiconductors like Gallium Arsenide (GaAs), Indium Phosphide (InP), or Cadmium Telluride (CdTe) show -ve resistance characteristics.

e.g:- According to the energy band theory. of n-type GaAs, a higher mobility lower valley is separated by an energy of 0.36 eV from a low-mobility upper valley in conduction band. [Will be discussed in detail in Two-valley Model Theory]

μ = mobility of electron



→ Electron ~~density~~ densities in the lower and upper valleys remains the same under an equilibrium condition. When ~~an~~ the applied electric field is lower than the electric field of the lower valley ($E < E_e$), no electrons will transfer to the upper valley.

If the applied electric field is

higher than that of the lower valley and lower than that of upper valley ($E_L < E < E_U$), electrons will begin to transfer to the upper valley. And when the applied electric field is higher than that of upper valley ~~$E_L < E$~~ ($E > E_U$), all the electrons will transfer to the upper valley.

~~Since~~ Conductivity is directly proportional to the mobility, ~~So Conductivity decreases~~

$$\sigma \propto \mu$$

Since $\mu_u < \mu_e$, $\sigma \downarrow$

So Conductivity decreases with increase in Electric field E, Hence current decreases with increase in E field or voltage beyond a threshold value V_{th}.

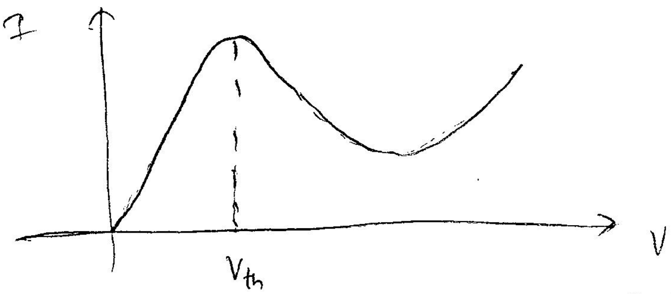


fig 1:- Current-voltage characteristic of GaAs

This is called transferred electron effect and the device is called 'Transferred Electron Device (TED)'.

~~ex:- Gunn diode (GaAs)~~

~~LSA (Limited Space-Charge Accumulation) diode~~

Ex:- of TEDs
→ GaAs Gunn diodes
→ InP diodes
→ LSA (Limited Space-charge Accumulation) diodes.
[works on LSA mode of the Gunn diode]
→ CdTe diodes

Difference between microwave transistors and TEDs

1) → Transistors operate with either junctions or gates, but TEDs are bulk devices having no junctions or gates.

2) → The majority of transistors are fabricated from the elemental semiconductors, such as Silicon or germanium, where as TEDs are fabricated from compound semiconductors, such as GaAs, InP, CdTe.

3) → 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, where as TEDs operate with 'hot' electrons whose energy is very much greater than the thermal energy.

→ Because of these fundamental differences, the theory ~~and~~ and technology of transistors can not be applied to TEDs.

Gunn Effect :-

→ It was observed by J. B. Gunn of IBM in 1963

→ A schematic diagram of a uniform n-type GaAs diode with ohmic contacts at the end surface is shown on fig 2.

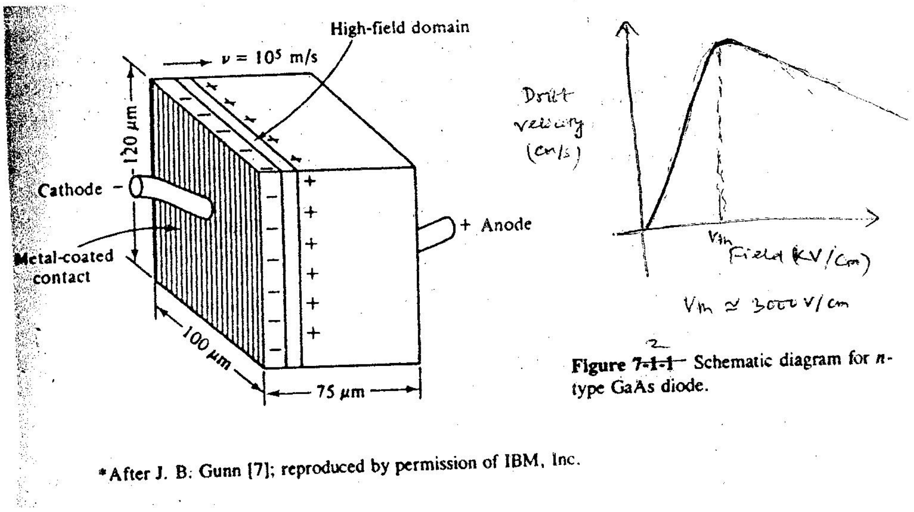


Figure ~~7-1-1~~ 2 Schematic diagram for n-type GaAs diode.

*After J. B. Gunn [7]; reproduced by permission of IBM, Inc.

→ From Gunn's observation ~~that~~ the carrier drift velocity is linearly increased from zero to a maximum when the electric field is varied from zero to a threshold value.

→ When the electric field is beyond the threshold value of 3000 V/cm for the n-type GaAs, the drift velocity is decreased and the diode exhibits -ve resistance.

→ Gunn also ~~observed~~ discovered that the threshold electric field E_{th} varied with the length and type of material.

Two-vally Model Theory :-

A few years before the Gunn effect was discovered, Kroemer proposed a -ve mass microwave amplifier in 1958 and 1959. According to the energy band of n-type GaAs, a high-mobility lower valley is separated by an energy of 0.36 eV from a low-mobility upper valley as shown in fig 3.

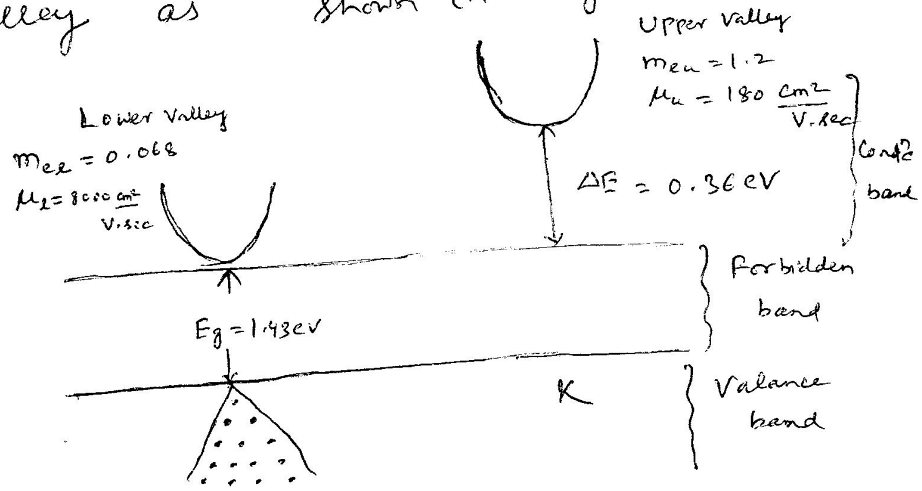
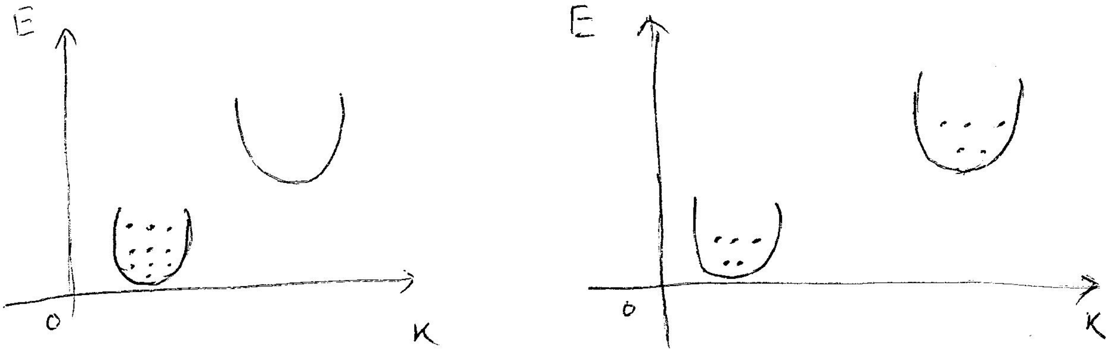


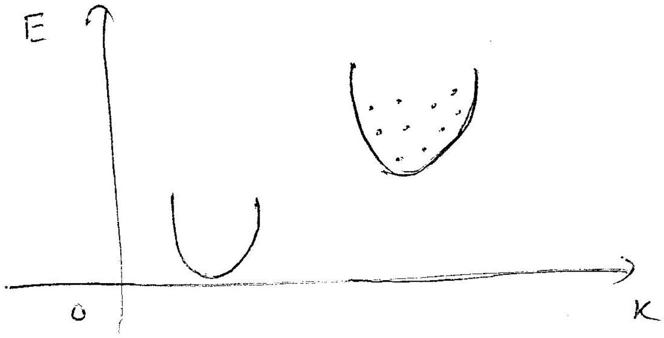
fig:-3:- Two-Valley model of electron energy versus wave number (K) for n-type GaAs.

Valley	Effective Mass (m_e)	Mobility (μ)	Separation (ΔE)
Lower	$m_{el} = 0.068$	$\mu_l = 8000\ cm^2/V.sec$	0.36 eV
Upper	$m_{eu} = 1.2$	$\mu_u = 180\ cm^2/V.sec$	0.36 eV

Electron densities in the lower and upper valleys remain the same under an equilibrium condition. When the applied electric field is lower than the electric field of lower valley ($E < E_l$), no electrons will transfer to upper valley shown on figure 4 (a).



(a) $E < E_l$ (b) $E_l < E < E_u$



(c) $E_u < E$

Fig 4:- Transfer of electron densities

→ When the applied electric field is higher than that of the lower valley and lower than that of the upper valley ($E_l < E < E_u$), electrons will begin to transfer to upper valley shown on fig 4 (b). And when the applied electric field is higher than that of the upper valley ($E_u < E$), all electrons will transfer to the upper valley as shown on fig 4(c).

If the electron densities in the lower and upper valleys are n_l and n_u, the conductivity of n-type GaAs is

$$\sigma = e(\mu_l n_l + \mu_u n_u) \quad \text{—①}$$

where $e =$ the electron charge

$\mu =$ the electron mobility

$n = n_l + n_u$ is the electron density.

Ex: 1-1 Conductivity of an n-type GaAs Gunn diode, Given

$n_l = 10^{10}\ cm^{-3}$, $n_u = 10^{8}\ cm^{-3}$, $T = 300°K$.

$\mu_l = 8000 \frac{cm^2}{V\text{-}sec}$, $\mu_u = 180 \frac{cm^2}{V\text{-}sec}$

Ans: $\sigma = e(\mu_l n_l + \mu_u n_u)$

$$= 1.6\times10^{-19}\left[8000\times10^{-4}\times\frac{10^{10}}{10^{-6}} + 180\times10^{-4}\times\frac{10^{8}}{10^{-6}}\right]$$

$cm^2 = 10^{-4} m^2$ $\quad$ $cm^3 = 10^{-6} cm^3$

$$= 1.6\times10^{-19}\left[8000\times10^{-4}\times10^{16} + 180\times10^{-4}\times10^{14}\right]$$

$$= 1.6\times10^{-19}\left[8\times10^{15} + 18\times10^{11}\right]$$

$$= 1.6\times10^{-19}\times10^{11}\left[80000+18\right]$$

$$\simeq 1.6\times10^{-19}\times10^{11}\times 8\times10^{4}$$

$$= 128\times10^{-4}$$

$$\boxed{\sigma = 1.28\ m\ mhos}$$

Electron- Field Interaction :-

When a sufficiently high field 'E' is applied to the specimen, electrons are accelerated and their effective temperature rises above the lattice temperature. Furthermore, the lattice temperature also increases. Thus electron density 'n' and mobility 'μ' are both functions of electric field 'E'. Differentiation of eqn ①, w.r.t E yields

$$\frac{d\sigma}{\partial E} = e\left(\mu_\ell \frac{dn_\ell}{dE} + \mu_u \frac{dn_u}{dE}\right) + e\left(n_\ell \frac{d\mu_\ell}{dE} + n_u \frac{d\mu_u}{dE}\right) \quad \text{——} ②$$

If the total electron density is given by, $n = n_\ell + n_u$, and it is assumed that μ_ℓ and μ_u are proportional to E^p, where p is a constant, then

$$\frac{d}{dE}(n_\ell + n_u) = \frac{dn}{dE} = 0 \quad \text{——} ③$$

$$\Rightarrow \frac{dn_\ell}{dE} = -\frac{dn_u}{dE} \quad \text{——} ④$$

As said earlier,

$$\mu_\ell \propto E^p \quad \text{——} ⑤$$

$$\Rightarrow \frac{d\mu_\ell}{dE} \propto \frac{dE^p}{dE}$$

$$\Rightarrow \frac{d\mu_\ell}{dE} = p \cdot E^{p-1} \quad \left[\because \frac{dx^n}{dx} = n \cdot x^{n-1}\right]$$

$$\Rightarrow \frac{d\mu_\ell}{dE} = \frac{pE^p}{E} \quad \text{——} ⑥$$

Putting eqn ⑤ in eqn ⑥

$$\Rightarrow \frac{d\mu_l}{dE} = \frac{p.\mu_l}{E} \quad —⑦$$

Similarly, $\mu_u \propto E^p$ —⑧

$$\Rightarrow \frac{d\mu_u}{dE} = p.E^{p-1}$$

$$\Rightarrow \frac{d\mu_u}{dE} = \frac{p.E^p}{E} \quad —⑨$$

$$\Rightarrow \frac{d\mu_u}{dE} = \frac{p.\mu_u}{E} \quad —⑩$$ [Putting eqn 8 in eqn 9]

Substituting eqn ④, ~~and~~ ⑦ and ⑩ in eqn ②,

we have

$$\frac{d\sigma}{dE} = e\left[\mu_l \frac{dn_l}{dE} + \mu_u\left(-\frac{dn_l}{dE}\right)\right]$$

$$+ e\left[n_l.\left(\frac{p\mu_l}{E}\right) + n_u.\left(\frac{p\mu_u}{E}\right)\right]$$

$$\frac{d\sigma}{dE} = e\left[\mu_l - \mu_u\right]\frac{dn_l}{dE} + e\left[n_l\mu_l + n_u\mu_u\right].\frac{p}{E} \quad —⑪$$

The differentiation of Ohm's law $J = \sigma E$, w.r.to 'E'

yields

$$\frac{dJ}{dE} = \sigma + E\frac{d\sigma}{dE} \quad —⑫$$

$$\Rightarrow \frac{1}{\sigma}\frac{dJ}{dE} = 1 + \frac{E}{\sigma}\frac{d\sigma}{dE}$$

$$\Rightarrow \frac{1}{\sigma}\frac{dJ}{dE} = 1 + \frac{d\sigma/dE}{\sigma/E} \quad \text{——} ⑬$$

Cleaney, for −ve resistance, the current density J must decrease with increasing field E or the ratio of $\frac{dJ}{dE}$ must be −ve. Such would be the case only if the right hand form of eqn ⑬, is less than zero. In other words, the condn for −ve resistance is,

8]

$$1 + \frac{d\sigma/dE}{\sigma/E} < 0$$

eqn ②,

$$\Rightarrow \frac{d\sigma/dE}{\sigma/E} < -1$$

$$\Rightarrow -\frac{d\sigma/dE}{\sigma/E} > 1 \quad \text{——} ⑭$$

* Now substituting eqn ②, in eqn ⑪, gives

$$\frac{d\sigma}{dE} = e\,(\mu_e - \mu_h)\frac{dn_e}{dE} + \frac{\sigma\, P}{E} \quad \text{——} ⑮$$

Putting eqn ⑮ in eqn ⑭, we have

$\frac{P}{E}$ — ⑪

to E'

$$-\left[e\,(\mu_e-\mu_h)\frac{dn_e}{dE} + \frac{\sigma P}{E} \right] \times \frac{E}{\sigma} > 1$$

$$\Rightarrow -e\,(\mu_e-\mu_h)\cdot\frac{dn_e}{dE} \times \frac{E}{\sigma} - P > 1$$

)

$$\Rightarrow -\cancel{e}\,(\mu_e-\mu_h)\cdot\frac{dn_e}{dE} \times \frac{E}{\cancel{e}\,(\mu_e n_e + \mu_h n_h)} - P > 1$$

If $f = \frac{n_u}{n_e}$, then

$$\left[- \frac{(\mu_e - \mu_u)}{n_e(\mu_e + \mu_u f)} \times E \frac{dn_e}{dE} - p \right] > 1 \quad \Bigg]^{*}$$

* In Book (china) directly written the below eq^n, you can write directly. But you should know the derivation

$$\Rightarrow \left[\frac{(\mu_e - \mu_u)}{(\mu_e + \mu_u f)} \cdot \left(- \frac{E}{n_e} \frac{dn_e}{dE} \right) - p \right] > 1 \quad \text{———} ⑯$$

To satisfy the inequality,

$\frac{dn_e}{dE} < 0$ [Carrier density of lower valley should decrease with increase in 'E', as discussed in Two-valley model]

and $\mu_e > \mu_u$ [mobility in upper valley < mobility in lower valley]

Thus, the band structure of a semiconductor must satisfy three criteria in order to exhibit -ve resistance.

1. The separation energy bet^n the bottom of the lower valley and the bottom of upper valley must be several times larger than the thermal energy (about 0.026 eV) at room temperature.

   i.e $\Delta E > KT$ or $\Delta E > 0.026$ eV.

2. The separation energy between the valleys must be smaller than the gap energy bet^n conduction band and valance bands. This means $\Delta E < E_g$.

[Otherwise the semiconductor will break down and become highly conductive before the electrons begin to transfer to upper valleys because hole-electrons pair formation is created]

*

for should the derivation

3. Electrons in the lower valley must have high mobility small effective mass and low density of state where as those on the upper valley must have low mobility, large effective mass and a high density of state.

(16)

wer
rease
, as
model
y
alley
ductor
exhibit
f the
ust
rgy
ys
$E < E_g$.

Note :-

1) Si, Ge don't satisfy all these criteria.

2) Compound semiconductors like GaAs, InP, CdTe do satisfy these criteria.

Ex :- 2 A typical GaAs Gunn diode has the following parameters

Threshold field $E_{th} = 2800\ V/cm$

Applied field $E = 3200\ V/cm$

Device length $L = 10\mu m$

Doping concentration $n_0 = 2 \times 10^{14}\ cm^{-3}$

Operating freq $f = 10\ GHz$

(a) Compute the electron drift velocity

(b) Calculate current density

(c) Estimate the -ve electron mobility

Ans: (a) Electron drift velocity (v_d)

$$v_d = \frac{\text{Length}}{\text{Time}} = \text{Length} \times \text{freq}$$

$$v_d = (10\,\mu m) \times (10\,GHz)$$

$$= 10 \times 10^{-6} \times 10 \times 10^{9}$$

$$\boxed{v_d = 10^{5}\ \frac{m}{sec}} \boxed{= 10^{7}\ \frac{cm}{sec}}$$

(b) Current density (J) $= \sigma E = n q \mu E$

$$\Rightarrow J = n q . \frac{v_d}{\cancel{E}} . \cancel{E}$$

μ = mobility
$= \frac{v_d}{E}$
$= \frac{\text{drift velocity}}{\text{Electric field}}$

$$\Rightarrow J = n q v_d$$

$$= \frac{2 \times 10^{14}}{cm^3} \times 1.6 \times 10^{-19} \times 10^{5}$$

$$= \frac{2 \times 10^{14}}{10^{-6}\ m^3} \times 1.6 \times 10^{-19} \times 10^{5}$$

$$= 3.2 \times \left(10^{14} \times 10^{6} \times 10^{-19} \times 10^{5}\right)$$

$$\boxed{J = 3.2 \times 10^{6}\ \frac{A}{m^2}} \boxed{= 320\ \frac{A}{cm^2}} \quad (\because 1m = 10^{2}cm)$$

(c)

−ve electron mobility

$$\mu_n = -\frac{v_d}{E} = -\frac{10^{7}\ \frac{cm}{sec}}{3200\ \frac{Volt}{cm}} = 3125\ \frac{cm^2}{V.sec.}$$

$$\boxed{\therefore \mu_n = -3125\ \frac{cm^2}{V.sec}}$$

[unit of mobility is important] (Ans)

Gunn Oscillation Modes

A mode is defined in terms of two factors

1. Product of length and freq : L × freq or (fL)
2. Product of length and doping : $L \times n_0$ or $(n_0 L)$

For Gunn Oscillation mode is defined on the region where $(f.L)$ is about $10^7 \frac{cm}{sec}$ and $(n_0 L) > 10^{12}/cm^2$

→ When the applied voltage is above the threshold ~~voltage~~ value, which was measured at about $3000 \frac{V}{cm}$, a high-field domain is formed near the cathode that → [see fig 2 :- Gunn's experiment] reduces the electric field on the rest of the material and causes the current to drop to about $\frac{2}{3}$ of its max^m value. This situation occurs because the applied voltage is given by

$$V = - \int_0^L E_x \, dx$$

→ The high field domain then drifts with carrier stream across the electrodes and disappears at the cathode contact. When the electric field increases, the electron drift velocity decreases and the GaAs exhibits negative resistance

→ The freq of oscillation is given by

$$\boxed{f = \frac{v_{dom}}{L_{eff}}}$$

where V_{dom} = domain velocity

L_{eff} = Effective length that the domain travels from the time it is formed until the time that a new domain began to form.

Prob-3 [BPUT-2007

A Gunn diode has drift length 10 μm. Determine the freq of oscillation.

Ans :- Given

$L_{eff} = 10\,\mu m$

$V_d = 10^5\ \frac{m}{sec}$ [If not given take drift velocity 10^5 m/sec]

$$f = \frac{1}{\cancel{t_d}} = \frac{V_d}{L_{eff}} = \frac{10^5}{10 \times 10^{-6}} = 10^{10} = 10\ GHz$$

(Ans).

V.Imp

Q) [BPUT-2010

Explain 3 possible domain modes of Gunn oscillation mode with proper diagrammatical representation.

Ans :- The Gunn Oscillation mode is operated with electric field greater than the threshold (E > Eth). The high-field domain drifts along the specimen until it reaches the anode or until the low-field value drops below the sustaining field 'Es' required to maintain V_s as shown in figure 5. The sustaining drift velocity for GaAs is $v_s = 10^7 \frac{cm}{sec}$. Since the electron drift velocity v varies with electric field, there are '3' possible domain modes for Gunn oscillation mode [shown on fig 6]

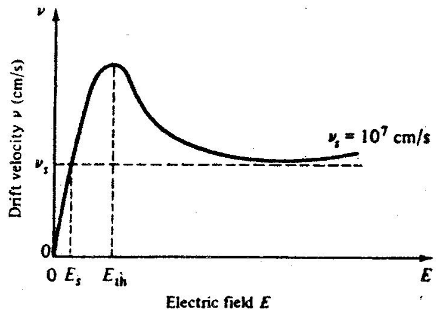


Figure ~~7-3-3~~ 5 Electron drift velocity versus electric field.

1) Transit-time domain mode :- $\left(f L \simeq 10^7 \frac{cm}{sec} \right)$

When the electron drift velocity v_d is equal to the sustaining velocity v_s, the high-field domain is stable. In other words, the electron drift velocity is given by

$$v_d = v_s = fL \simeq 10^7 \frac{cm}{sec}.$$

Then the oscillation period is equal to the transit time i.e $\tau_0 = \tau_t$. This situation is shown on fig 6 (a).

The efficiency is below 10% because the current is collected only when the domain arrives at the anode.

2) Delay domain mode:-

10^6 cm/sec $< fL < 10^7$ cm/sec

When the transit time is chosen so that the domain is collected while $E < E_{th}$ [fig 6(b)], a new domain can't form until the field rises above threshold again, In this case, the oscillation period is greater than the transit time i.e $\tau_0 > \tau_t$.

→ This delayed mode is also called inhibited mode. The efficiency of this mode is about 20%.

3) Quenched domain mode ($fL > 2 \times 10^7 \frac{cm}{sec}$). If the bias field drops below the sustaining field E_s

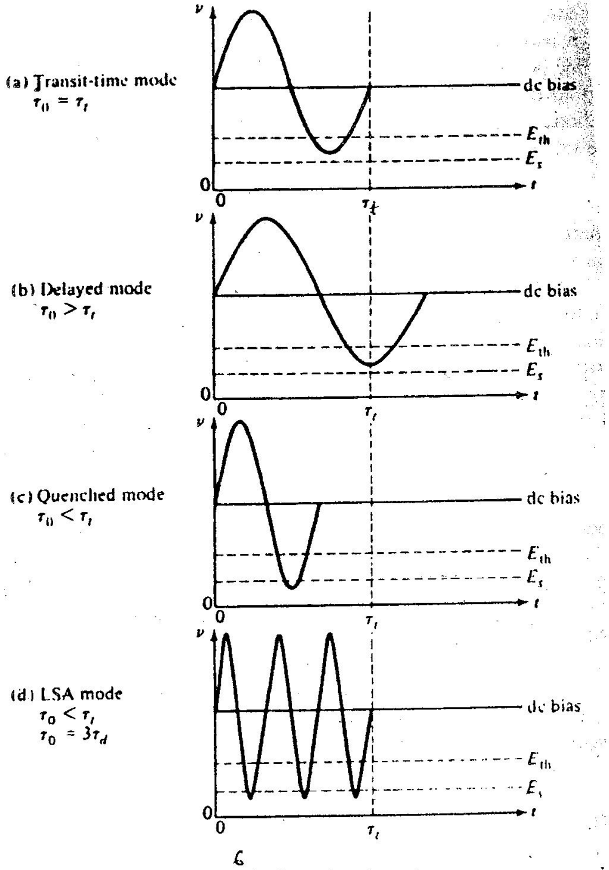


Figure ~~7-3-4~~ 6 Gunn domain modes.

during the -ve half cycle [fig 6 (c)], ~~the~~ the domain collapses before it reaches the anode.

→ When the bias field swings back above threshold, a new domain is nucleated and the process repeats. Therefore, the oscillation occurs at the freq of resonant circuit rather than at the transit-time freq.

→ It has been found that the resonant freq of the ckt is several times the transit-time freq.

→ The efficiency of quenched domain oscillato~~r~~ can reach 13%.

LSA (Limited-Space-Charge Accumulation) mode.

$$f.L > 2\times10^{7}\ \frac{cm}{sec}$$

When the freq is very high, the domains don't have sufficient time to form while the field is above threshold. As a result, most of the domains are maintained in the -ve conductance state during a large fraction of the voltage cycle

Any accumulation of electrons near the cathode has time to collapse while the signal is below threshold. Thus the LSA mode is simplest mode of operation and it consists of a uniformly doped semiconductor without any internal space charges.

In this instance, the internal electric field would be uniform and proportional to the applied voltage. The current in the device is then proportional to the drift velocity at this field level. The efficiency of the LSA mode can reach 20%.

→ The oscillation period τ_0 should be no more than several times larger than the magnitude of the dielectric relaxation time (τ_d) in the −ve conductance region. [As shown in figure 6 (a)

$\tau_0 = 3\tau_d$]

⇒ Note :- Comparison ~~bet~~ among different modes.

	Time rel'ship	$n_0 . L$	$f.L$
1) Transit-time domain mode	$\tau_0 = \tau_t$	$> 10^{12}/cm^2$	$\simeq 10^7 \frac{cm}{sec}$
2) Delay domain mode	$\tau_0 > \tau_t$	$> 10^{12}/cm^2$	$10^6 \frac{cm}{sec} < f.L < 10^7 \frac{cm}{sec}$
3) Quenched domain mode	$\tau_0 < \tau_t$	$> 10^{12}/cm^2$	$fL > 2 \times 10^7 \frac{cm}{sec}$
4) LSA mode	$\tau_0 < \tau_t$ $\tau_0 > 3\tau_d$	$> 10^{12}/cm^2$	$fL > 2 \times 10^7 \frac{cm}{sec}$

τ_0 = oscillation period, τ_t = Transit time, τ_d = dielectric relaxation time

→ n-type GaAs diode yield 200 watt pulses at 3.05 GHz and 780 mW CW (continuous wave) power at 8.7 GHz.

→ Efficiency 29 % in pulsed operation at 3.05 GHz and 5.2 % in CW at 24.8 GHz.

Advantage

Small size, ruggedness ~~and~~, low cost, low power supply

Disadvantage :-

1) Low efficiency at frequencies above 10GHz.
2) Small tuning range
3) Large dependence of freq on temperature
4) High noise

Appln :-

1) In radar transmitter
2) Pulsed Gun diode Oscillators.
3) Broad band linear amplifier
4) ~~Fast Combinational~~ Low and medm power Oscillator in microwave receivers.

P.T.O

Microwave Transistors :-

→ Microwave solid-state devices are becoming increasingly important at microwave frequencies. Microwave transistor have advantage of low cost, low power supply, reliability, high CW power output, light weight.

→ Used in L-band transmitters for telemetry system and phased array radar systems.

→ Used in L and S band transmitters for communications systems.

→ ~~Since the~~ Transistors and related semiconductors devices have replaced vacuum tubes for lower power sources. The microwave transistor is a nonlinear device, and its principle of operation is similar to that of the low-freq device, but requirements for dimensions, process control, heat sinking and packaging are much more severe.

→ For microwave applications, The Silicon (Si) bipolar transistors dominate for freq range from UHF to about S band (about 3 GHz).

→ As the technology improves, the upper freq limit for these devices is continuously being extended, and at present time the devices are capable of producing useful power up to

22 GHz.

→ The majority of bipolar transistors of current interest are fabricated from 'Si', although GaAs devices offer prospects for improvement in operating freq., in high temperatures and in radiation hardness.

→ The Si bipolar transistor is inexpensive, durable, integrative and offers gain much higher than available with competiting field effect devices.

2 type

1) p-n-p
2) n-p-n

3 different configuration

[Common base
" Emitter
" Collector]

1) CB 2) CE 3) CC

Mode of operation :-

A bipolar transistor can operate in 4 different mode depending on the voltage polarities across 2 junctions.

	Emitter jn	Collector jn
1) Normal mode (Active mode)	F.B	R.B
2) Saturation mode	F.B	F.B
3) Cut off mode	R.B	R.B
4) Inverse mode	R.B	F.B

Heterojunction Bipolar Transistors (HBTs)

→ Bipolar transistors can be constructed as homojunction or heterojunction types of transistors.

→ When the transistor junction is jointed by two similar materials such as silicon to silicon or germanium to germanium, it is a ~~homogeneous~~ homojunction transistor.

→ The transistor junction formed by 2 different materials such as Ge to GaAs, is called a heterojunction transistors.

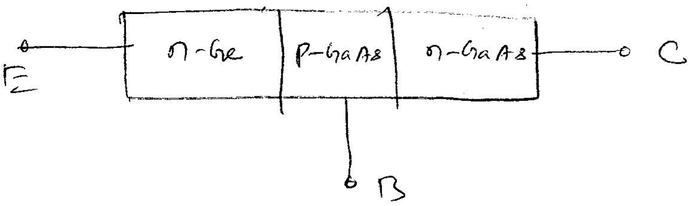
→ Currently, Ge and GaAs are 2 materials commonly used for heterojunction structures because 2
their lattice constants (a = 5.646 A° for Ge and a = 5.653 A° for GaAs) are matched to within 1%.

→ Since each material may be either p type ~~or~~ or n type, there are 4 possible heterojunction combinations;

1) p-Ge to p-GaAs junction
2) p-Ge to n-GaAs " 5
3) n-Ge to p-GaAs "
4) n-Ge to n-GaAs junction

Fig '7', shows model diagram of a heterojunction

Transistor formed by n-Ge, p-GaAs and n-GaAs materials.



Q BPUT 2012

1) Difference betn TED (Transferred Electron device) and Avalanche transit-time devices.

TED	Avalanche Transit-time Devices (ATTD)
1) They are fabricated from Compound semiconductors such as GaAs, InP, CdTe etc.	1) They are fabricated from the elemental semiconductor such as Si and compound semiconductor like GaAs.
2) TED are bulk devices having no junctions	2) ATTD have junctions in their structures e.g $n^+-p-i-p^+$ structure i → intrinsic n^+, p^+ → (+) sign denote very high doping
3) Operate simply by the appln of d.c voltage to a bulk semiconductor	3) Rely on effect of voltage breakdown across a reverse-biased p-n junction to produce a supply of holes and electrons.
4) Show -ve resistance characteristic.	4) Show -ve resistance characteristics.
5) Example: Gunn diode, LSA diode, InP diode	5) ex:- IMPATT (Impact Ionization Avalanche transit time) diode TRAPATT → Trapped Plasma Avalanche transit time) diode BARITT → Barrier Injected transit time diode.

Q How Gunn diode produces Oscillation ?

[See the correct fig from fig 5]

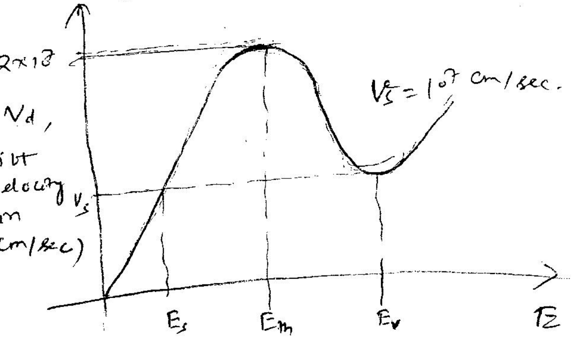


fig 7 :- Electron drift velocity Vs Electric field.

- Oscillations are produced as a result of –ve resistance formed by slower drift velocity of electrons.

→ At low voltages the drift velocity is proportional to electric field and current stream due to electron drift across the +ve charge of the donor atoms. This is the straight line ~~por~~ portion of fig 7.

When the electric field exceeds the threshold value of 3000 $\frac{V}{cm}$, a high field domain is formed at the cathode, as the short length of the material has higher electric gradient than in the rest of the bulk, $E = \frac{V}{l}$. As L is extremely thin for a constant V, E is very high. The current in the rest of the bulk drops to $\frac{2}{3}$ of the initial value. The high field domain at the cathode drifts through the sample along with charge carrier at drift velocity and collapses at the anode.

This sudden collapse ~~of~~ at anode gives rise to an anode pulse current. The pulse freq is the same as transit time of electrons in the materials and falls in the microwave range.

When the high field disappears at the anode, there is a simultaneous formation of another high field domain at the cathode [see fig 2 - Gunn's experiment - ~~$~~ High field domain] and the process repeats. Thus microwave oscillations are obtained

The drift velocity which is proportional to the applied voltage. is given by,

$$V_d = fL$$

where L = Effective length through which high-field domain travels.

f = freq of oscillations.

For Microwave freq, 'L' should be as thin as possible so that the high field domain collapses at the anode. The lengths are of order of 10 to 20 μm. The thinner the material the greater should be the doping so that sufficient number of space charge carriers are built up within the transit time of electrons.

—o—