Gunn Diode Oscillator

Aim:-
To learn Transferred electron oscillator or Gunn diode oscillator and use of two terminal devices based on transferred electron effect.

Objective: To study modes of operation of Gunn diode

Transferred Electron Effect:

Materials like gallium arsenide (GaAs) exhibit a negative differential mobility (i.e., a decrease in the carrier velocity with an increase in the electric field) when biased above a threshold value of the electric field. The electrons in the lower energy-band will be transferred to higher energy band. This is called transferred electron effect or Gunn effec

The device is called as Transferred Electron Device (TED) or transferred electron oscillator or Gunn diode oscillator.

* Negative res device - over a range of applied voltages and can be used in microwave oscillators.
* In the high-energy band, the effective electron mass is larger and hence the electron mobility is lower than low-energy band.
* The conductivity is directly proportional to the mobility & hence the current decreases with an increase in electric field strength.

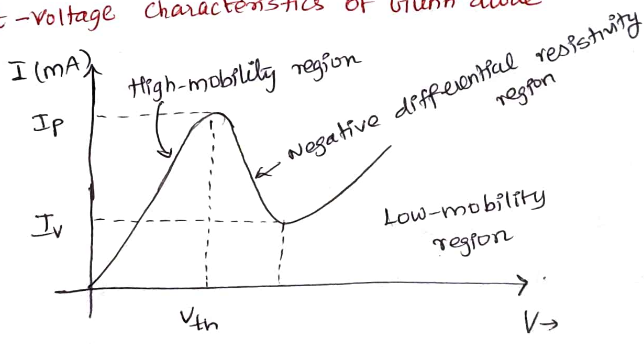
Em

GaAs, InP, CdTe

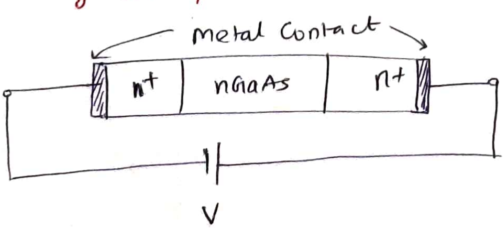
Applications of Gunn Diode:

* Low power oscillator at μwave freq in Txr. Local oscillator in Rxr front ends.
* Used in parametric amplifiers as pump source
* Radar transmitters (Police radar, CW Doppler radar)
* In broadband μwave amplifier
* pulsed gunn diode oscillators used in transponders for air traffic control (ATC) and in industry telemetry systems.
* Fast combinational and sequential logic circuits
* Low and medium power oscillator in μwave oscillators.

Current-Voltage Characteristics of Gunn diode



Working Principle:



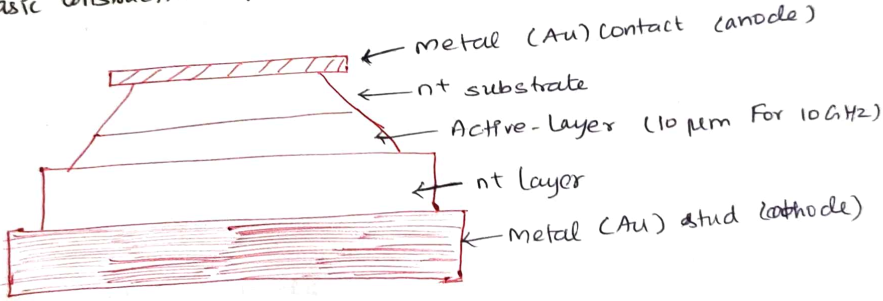
Eventhough there is no junction this is called a diode with reference to the positive end (anode) and negative end (cathod of the dc voltage (V) applied across the device.

* When the diode voltage exceeds a certain threshold value (V_{th}) a high electric field (3.2 KV/m for GaAs) is produced across active regions and electrons are excited from their initial lower valley to higher valley when they become virtually immobile.

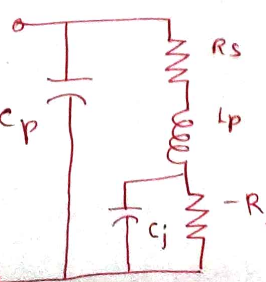
* If the rate at which electrons are transferred is very high, the current will decrease with an increase in voltage,

⇒ Negative resistance effect.

Basic construction of Gunn diode



Negative resistance : carrier drift velocity is linearly increased from zero to a max. when the electric field is varied from zero to threshold value. When E > 3000V/cm, V_d is decreased and the diode exhibits negative res. (value b/w -5 to -20 Ω)

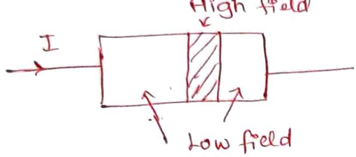


Ridley - Watkins - Hilsum (RWH) Theory:

Differential Negative resistance - developed in a bulk - solid state III - V compound, when either a voltage (or electric field) or a current is applied to the terminals of the sample.

2 - modes
i) Voltage controlled negative-res mode
ii) Current controlled negative-res mode

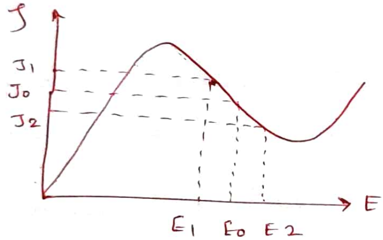
i) voltage controlled mode



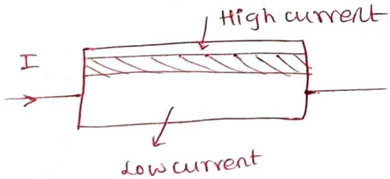
High field domain

Current density can be multivalued.

High field domains are formed by separating a two low field regions.



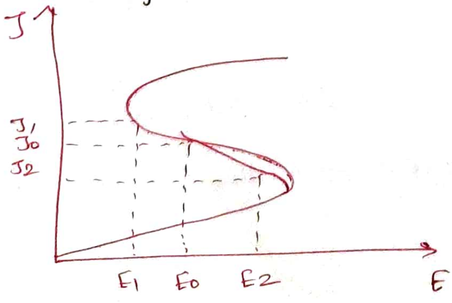
ii) Current controlled mode



High current filament

The voltage value can be multivalued.

The mode splitting the sample results in high current filaments running along the field direction.



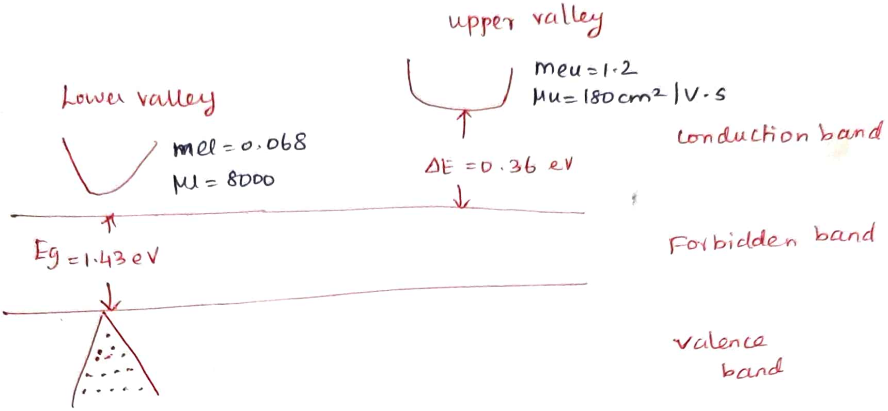
Negative resistance of sample at a particular region is,

$$\text{Neg. Res} = \frac{dI}{dV} = \frac{dJ}{dE} \rightarrow ($$

Multivalues of current density for negative res.

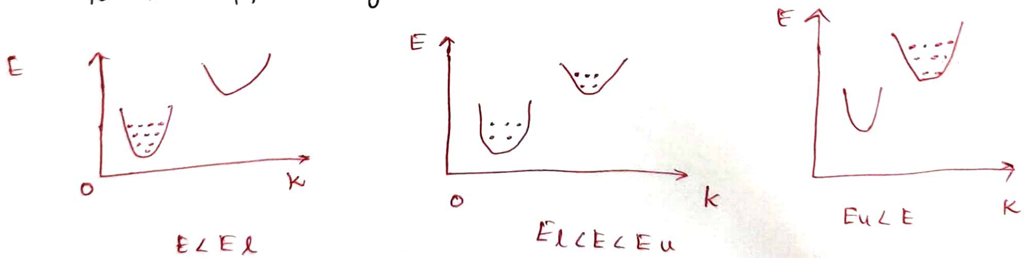
Two-Valley Model theory

According to energy band theory of the n-type GaAs, a high-mobility lower valley is separated by energy 0.36eV from a low-mobility upper valley.



Electron densities in the lower and upper valleys remain the same under an equilibrium condition.

i) Applied electric field E is lower than the electric field of the lower valley ($E < E_l$). No electrons will transfer to the upper valley.



ii) $E_l < E < E_u$. Electrons will begin to transfer to upper valley

iii) $E_u < E$, all electrons will transfer to the upper valley

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

$$\sigma = e(\mu_l n_l + \mu_u n_u) \rightarrow (2)$$

e - electron charge

μ - electron mobility

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

The electron density 'n' and mobility 'μ' are both functions of an electric field $\vec{E}$.

Diff. σ wrt E as,

$$\frac{d\sigma}{dE} = e\left(\mu_l \frac{dn_l}{dE} + \mu_u \frac{dn_u}{dE}\right) + e\left(n_l \frac{d\mu_l}{dE} + n_u \frac{d\mu_u}{dE}\right) \rightarrow (3)$$

If the total electron density

$$n = n_l + n_u \rightarrow (4)$$

It is assumed that μ_l and μ_n are propt. to E^P, where p is a constant, then

$$\frac{d}{dE}(n_l + n_u) = \frac{dn}{dE} = 0 \rightarrow (5)$$

$$\frac{dn_l}{dE} = -\frac{dn_u}{dE} \rightarrow (6)$$

$$\frac{d\mu}{dE} \propto \frac{dE^P}{dE} = PE^{P-1}$$

$$= \frac{PE^P}{E} \propto \frac{P.\mu}{E}$$

$$\frac{d\mu}{dE} = \frac{P.\mu}{E} \rightarrow (7)$$

From (6) and (7)

$$\frac{dn_u}{dE} = -\frac{dn_l}{dE} \quad \text{--- (8a)}$$

$$\frac{d\mu}{dE} = \mu \frac{P}{E} \; ; \quad \frac{d\mu_l}{dE} = \frac{\mu_l P}{E} \quad \text{--- (8b)}$$

sub (8) in eqn (3)

$$\frac{d\sigma}{dE} = e\,\mu_l \frac{dn_l}{dE} - e\,\mu_u \frac{dn_l}{dE} + e\,n_l \mu_l \frac{P}{E} + e\,n_u \mu_u \frac{P}{E}$$

$$\frac{d\sigma}{dE} = e(\mu_l - \mu_u)\frac{dn_l}{dE} + e(n_l\mu_l + n_u\mu_u)\frac{P}{E} \quad \text{--- (9)}$$

ohm's law is $J = \sigma E$ --- (10)

Diff. wrt E

$$\frac{dJ}{dE} = \sigma + E \cdot \frac{d\sigma}{dE} \quad \text{--- (11)}$$

Eqn (11) can be rewritten as,

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

1 - 2

-1

$$\frac{1}{\sigma}\frac{dJ}{dE} = 1 + \frac{d\sigma/dE}{\sigma/E} \quad \text{--- (12)}$$

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

For negative resistance, the current density 'J' must be decrease with increasing field E or the ratio of $\frac{dJ}{dE}$ must be -ve.

The condition for negative resistance

$$\boxed{\frac{-d\sigma/dE}{\sigma/E} > 1} \quad \text{--- (13)}$$

Modes of operation:

i) Gunn oscillation mode,

ii) Stable amplification mode

iii) LSA oscillation mode

iv) Bias circuit oscillation mode

Criterion for classifying modes of operation

$$n_0 L > \frac{\varepsilon v_d}{e|\mu_n|}$$

Outcome : Able to analyze the negative resistance device based on Transferred electron effect and modes of operation.

—x—x—

IMPATT Diode

Aim : To understand the working principle of IMPATT Diode and to design oscillator and amplifier.

objective : To study the properties of IMPATT devices

Avalanche Transit - Time devices:

p-n junction diode with the highly doped p and n regions.

Produce negative res. at μwave freq by using a carrier impact ionization avalanche breakdown and carriers drift in the high field intensity region under the reverse biased condition.

modes of avalanche device :

i) IMPATT - Impact Ionization Avalanche Transit Time Devic

dc-to RF η = 5 to 10 %, 100 GHz

ii) TRAPATT - Trapped plasma Avalanche Triggered transit Devic