

## UNIT-II

### M-Type Tubes

#### Introduction:

Magnetron is a grouping of a simple diode vacuum tube together with built in cavity resonators and an exceptionally powerful magnet. There are three types of magnetrons:

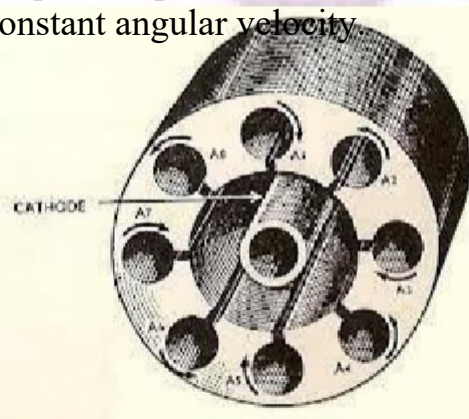
- Negative resistance type
- Cyclotron frequency type
- Travelling wave or Cavity type

Negative resistance magnetrons make use of negative resistance between two anode segments.

Cyclotron frequency magnetrons depends upon synchronism amid an alternating component of electric field and periodic oscillation of electrons in a direction parallel to this field.

Cavity type magnetrons depends upon the interface of electrons with a rotating electromagnetic field of constant angular velocity.

#### CONSTRUCTION



A magnetron consist of a cathode which is used to release the electrons and number of anode cavities and a permanent magnet is placed on the flipside of cathode and the space between the anode cavity and the cathode is called interacting space.

The electrons which are emitted from the cathode moves in diverse path in the interacting space depending upon strength of electric and magnetic fields applied to the magnetron.

## **Types of Magnetrons:**

There are three main types of Magnetrons.

### **Negative Resistance Type**

- The negative resistance between two anode segments, is used.
- They have low efficiency.
- They are used at low frequencies (< 500 MHz).

### **Cyclotron Frequency Magnetrons**

- The synchronism between the electric component and oscillating electrons is considered.
- Useful for frequencies higher than 100MHz.

### **Travelling Wave or Cavity Type**

- The interaction between electrons and rotating EM field is taken into account.
- High peak power oscillations are provided.
- Useful in radar applications.

### **Cavity Magnetron**

The Magnetron is called as Cavity Magnetron because the anode is made into resonant cavities and a permanent magnet is used to produce a strong magnetic field, where the action of both of these makes the device work.

### **Construction of Cavity Magnetron**

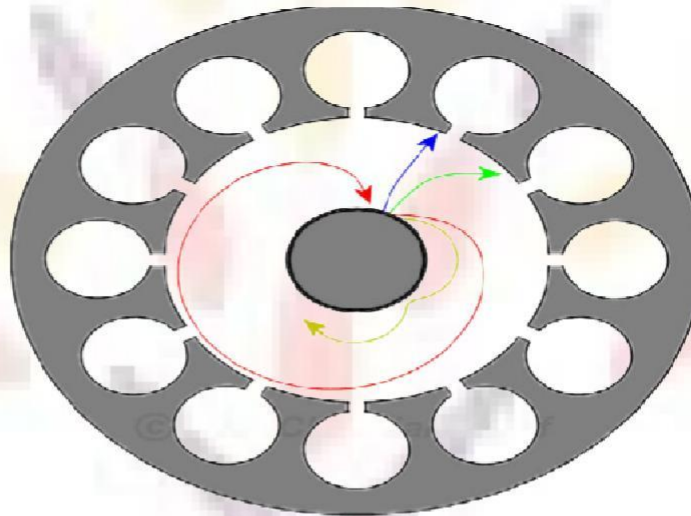
A thick cylindrical cathode is present at the center and a cylindrical block of copper, is fixed axially, which acts as an anode. This anode block is made of a number of slots that acts as resonant anode cavities.

The space present between the anode and cathode is called as Interaction space. The electric field is present radially while the magnetic field is present axially in the cavity magnetron. This magnetic field is produced by a permanent magnet, which is placed such that the magnetic lines are parallel to cathode and perpendicular to the electric field present between the anode and the cathode.

---

The following figures show the constructional details of a cavity magnetron and the magnetic lines of flux present, axially

This Cavity Magnetron has 8 cavities tightly coupled to each other. An N-cavity magnetron has N modes of operations. These operations depend upon the frequency and the phase of oscillations. The total phase shift around the ring of this cavity resonators should be  $2n\pi$  where n is an integer.



If  $\phi_v$  represents the relative phase change of the AC electric field across adjacent cavities, then

$$\phi_v = 2\pi n/N$$

Where  $n=0, \pm 1, \pm 2, \pm(N/2-1), \pm N/2$

Which means that  $N/2$  mode of resonance can exist if N is an even number. If,

$$n=N/2 \text{ then } \phi_v = \pi$$

This mode of resonance is called as  $\pi$ -mode.

$$n=0 \text{ then } \phi_v = 0$$

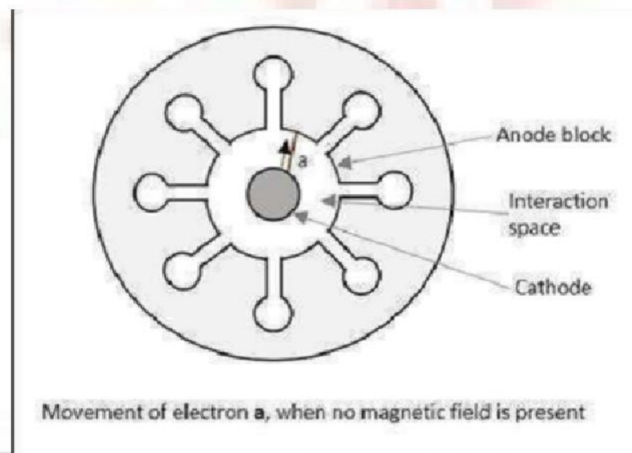
This is called as the Zero mode, because there will be no RF electric field between the anode and the cathode. This is also called as Fringing Field and this mode is not used in magnetrons.

## Operation of Cavity Magnetron

When the Cavity Klystron is under operation, we have different cases to consider. Let us go through them in detail.

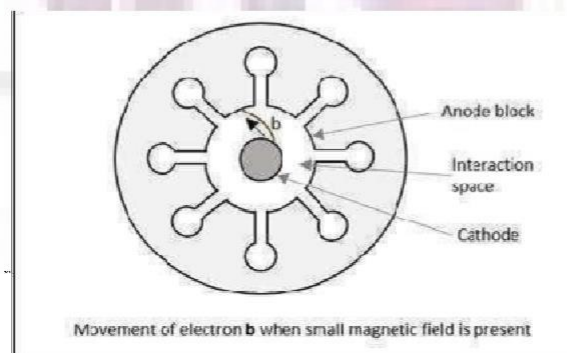
### Case 1

If the magnetic field is absent, i.e.  $B = 0$ , then the behavior of electrons can be observed in the following figure. Considering an example, where electron a directly goes to anode under radial electric force.



### Case 2

If there is an increase in the magnetic field, a lateral force acts on the electrons. This can be observed in the following figure, considering electron b which takes a curved path, while both forces are acting on it.



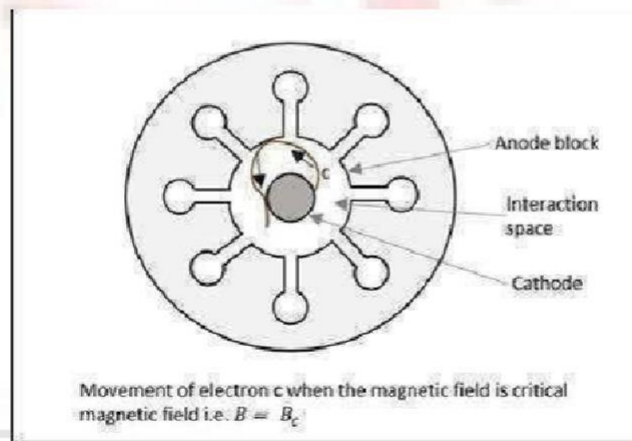
Radius of this path is

calculated as  $R = mv/eB$

It varies proportionally with the velocity of the electron and it is inversely proportional to the magnetic field strength.

### Case 3

If the magnetic field  $B$  is further increased, the electron follows a path such as the electron  $c$ , just grazing the anode surface and making the anode current zero. This is called as "Critical magnetic field" ( $B_c$ ), which is the cut-off magnetic field. Refer the following figure for better understanding.



### Case 4

If the magnetic field is made greater than the critical field,  $B > B_c$

Then the electrons follow a path as electron  $d$ , where the electron jumps back to the cathode, without going to the anode. This causes "back heating" of the cathode. Refer the following figure.

This is achieved by cutting off the electric supply once the oscillation begins. If this is continued, the emitting efficiency of the cathode gets affected.

### **Operation of Cavity Magnetron with Active RF Field**

We have discussed so far the operation of cavity magnetron where the RF field is absent in the cavities of the magnetron (static case). Let us now discuss its operation when we have an active RF field.

As in TWT, let us assume that initial RF oscillations are present, due to some noise transient. The oscillations are sustained by the operation of the device. There are three kinds of electrons emitted in this process, whose actions are understood as electrons a, b and c, in three different cases.

#### **Case 1**

When oscillations are present, an electron a, slows down transferring energy to oscillate. Such electrons that transfer their energy to the oscillations are called as favored electrons. These electrons are responsible for bunching effect.

#### **Case 2**

In this case, another electron, say b, takes energy from the oscillations and increases its velocity. As and when this is done,

- It bends more sharply.
  - It spends little time in interaction space.
-

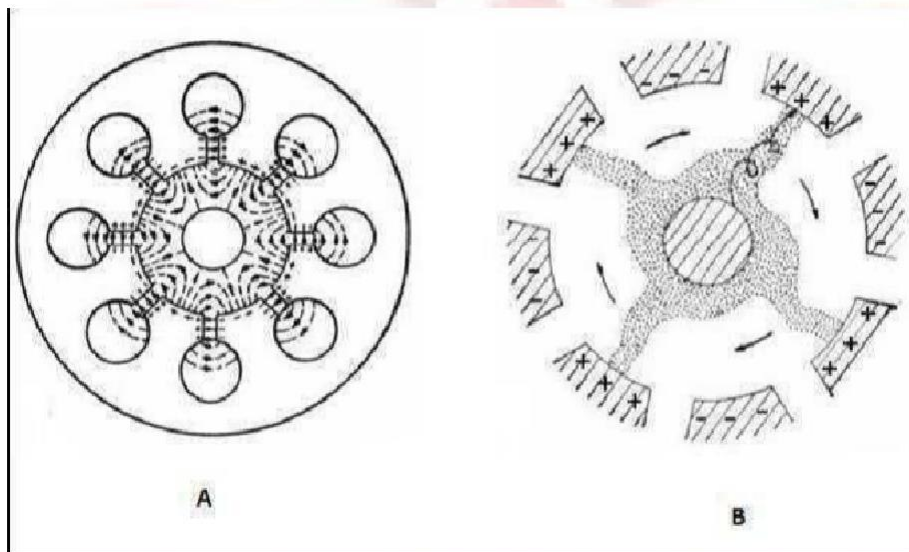
- It returns to the cathode.

These electrons are called as unfavored electrons. They don't participate in the bunching effect. Also, these electrons are harmful as they cause "back heating".

### Case 3

In this case, electron c, which is emitted a little later, moves faster. It tries to catch up with electron a. The next emitted electron d, tries to step with a. As a result, the favored electrons a, c and d form electron bunches or electron clouds. It called as "Phase focusing effect".

This whole process is understood better by taking a look at the following figure.



### Phase Focusing Effect

Figure A shows the electron movements in different cases while figure B shows the electron clouds formed.

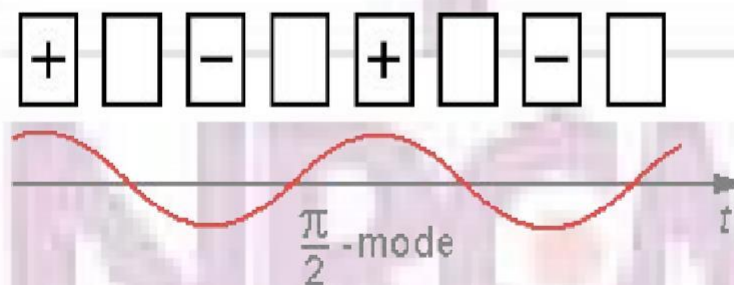
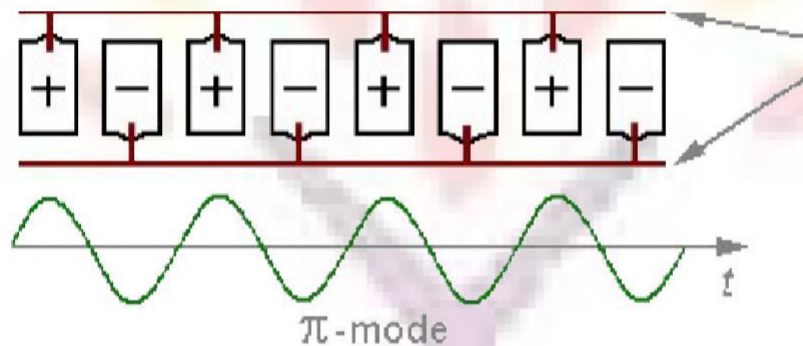
These electron clouds occur while the device is in operation. The charges present on the internal surface of these anode segments, follow the oscillations in the cavities. This creates an electric field rotating clockwise, which can be actually seen while performing a practical experiment.

While the electric field is rotating, the magnetic flux lines are formed in parallel to the cathode, under whose combined effect, the electron bunches are formed with four spokes, directed in regular intervals, to the nearest positive anode segment, in spiral

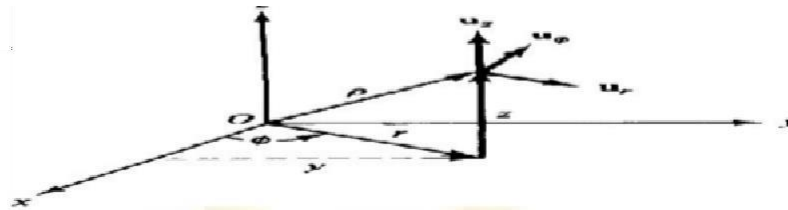
trajectories.

## Modes of Oscillation

The operation frequency depends on the sizes of the cavities and the interaction space between anode and cathode. But the single cavities are coupled over the interaction space with each other. Therefore several resonant frequencies exist for the complete system. Two of the four possible waveforms of a magnetron with 8 cavities are in the figure 6.13 represented. Several other modes of oscillation are possible ( $3/4\pi$ ,  $1/2\pi$ ,  $1/4\pi$ ), but a magnetron operating in the  $\pi$  mode has greater power and output and is the most commonly used.



## Hull Cut off Magnetic Fileds



Where  $x = r \cos\Phi$

$y = r \sin\Phi$  and  $z = z$

In a magnetron the electron is subjected to a force due to electric field and magnetic field. The expression for the force is

$$\mathbf{F} = -e\mathbf{E} - (e\mathbf{v} \times \mathbf{B}) \quad (6.27)$$

The equation of motion of electron is given by

$$\mathbf{F} = m \frac{d\mathbf{v}}{dt} = m \sqrt{\frac{dx^2}{dt^2} + \frac{dy^2}{dt^2}} \text{ in rectangular coordinates. } (6.28)$$

Velocity in cylindrical coordinates is expressed by

$$\mathbf{v} = \frac{dr}{dt} \mathbf{v}_r + r \frac{d\Phi}{dt} \mathbf{v}_\Phi \quad \text{neglecting } v_z \quad (6.29)$$

Where  $\mathbf{v}_r$  and  $\mathbf{v}_\Phi$  are unit vectors

$$\frac{d\mathbf{v}}{dt} = \left[ \frac{d^2r}{dt^2} - r \left( \frac{d\Phi}{dt} \right)^2 \right] \mathbf{v}_r + \left[ r \frac{d^2\Phi}{dt^2} + 2 \frac{dr}{dt} \frac{d\Phi}{dt} \right] \mathbf{v}_\Phi \quad (6.30)$$

$$= \left[ \frac{d^2r}{dt^2} - r \left( \frac{d\Phi}{dt} \right)^2 \right] \mathbf{v}_r + \frac{1}{r} \frac{d}{dt} \left[ r^2 \frac{d\Phi}{dt} \right] \mathbf{v}_\Phi \quad (6.31)$$

The term  $\mathbf{v} \times \mathbf{B}$  in cylindrical coordinates is given by (assuming  $\mathbf{B}$  exists in only direction.

$$\mathbf{v} \times \mathbf{B} = (B_z r \frac{d\Phi}{dt}) \mathbf{v}_r - (B_z \frac{dr}{dt}) \mathbf{v}_\Phi \quad (6.31)$$

Equating the  $v_r$  and  $v_\Phi$  terms from above equations, we can write

$$\frac{d^2 r}{dt^2} - r \left(\frac{d\Phi}{dt}\right)^2 = \frac{e}{m} E_r - \frac{e}{m} r B_z \frac{d\Phi}{dt} \quad (6.34)$$

$$\frac{1}{r} \frac{d}{dt} \left[ r^2 \frac{d\Phi}{dt} \right] = \frac{e}{m} r B_z \frac{dr}{dt} = \frac{1}{2} \frac{e}{m} B_z \frac{d}{dt} (r^2) = \frac{1}{2} \omega_c \frac{d}{dt} (r^2) \quad (6.35)$$

Where  $\omega_c = \frac{e}{m} B_z$  Cyclotron angular frequency

**Integrating equation 6.35**

$$r^2 \frac{d\Phi}{dt} = \frac{1}{2} \omega_c r^2 + \text{Constant} \quad (6.36)$$

Let  $a =$  radius of cathode of magnetron

$b =$  radius of anode

At  $r = a$ ,  $\frac{d\Phi}{dt} = 0$ , therefore the constant in equation 6.36 becomes

$$\text{Constant} = -\frac{1}{2} \omega_c a^2$$

$$\frac{d\Phi}{dt} = \frac{1}{2} \omega_c \left(1 - \frac{a^2}{r^2}\right) \quad (6.37)$$

Since the magnetic field does no work on electrons, the kinetic energy of electrons is given be

$$\frac{1}{2} m v^2 = e V \quad (6.38)$$

$$\text{Where } v^2 = \left(\frac{dr}{dt}\right)^2 + \left(r \frac{d\Phi}{dt}\right)^2 \quad (6.39)$$

$$\text{At } r = b, \quad V = V_0, \quad \frac{dr}{dt} = 0 \quad (6.40)$$

From Eqn 6.37

$$\frac{d\Phi}{dt} = \frac{1}{2} \omega_c \left(1 - \frac{a^2}{b^2}\right) \quad (6.41)$$

From equations 6.38 and 6.39

$$v^2 = \left(\frac{dr}{dt}\right)^2 + \left(r \frac{d\Phi}{dt}\right)^2 = \frac{2eV}{m}$$

$$\text{At } r = b, \quad \frac{dr}{dt} = 0, \quad \text{therefore } \left(b \frac{d\Phi}{dt}\right)^2 = \frac{2eV_0}{m} \quad (6.42)$$

Substituting for  $\frac{d\Phi}{dt}$  from equation 6.41

$$b^2 \left[\frac{1}{2} \omega_c \left(1 - \frac{a^2}{b^2}\right)\right]^2 = \frac{2eV_0}{m}$$

$$\therefore \omega_c^2 = \frac{8eV_0}{b^2} \left[\frac{1}{\left(1 - \frac{a^2}{b^2}\right)}\right]^2 = \left[\frac{\sigma}{m} B_z\right]^2$$

Active  
Go to S

$$\therefore B_z = \frac{\sqrt{8mV_0}}{b \left(1 - \frac{a^2}{b^2}\right)} \quad (6.43)$$

Hull cut-Off magnetic field ' $B_{oc}$ ' is the magnetic field value above which the anode current becomes zero for given  $V_0$ .

$$B_{oc} = \frac{\sqrt{8mV_0}}{b \left(1 - \frac{a^2}{b^2}\right)} \quad (6.44)$$

Similarly for given  $B_z$  of  $B_0$  the anode current becomes zero for  $V_0 < V_{oc}$

From equation 6.43, we can write the expression for  $V_{oc}$

$$V_{oc} = \frac{e}{8m} B_0^2 b^2 \left(1 - \frac{a^2}{b^2}\right)^2 \quad (6.45)$$

**Hartree Condition:** The hull cutoff condition determines the anode voltage or magnetic field necessary to obtain non-zero anode current as a function of magnetic field or anode voltage in the absence of electromagnetic field.

**Frequency Pushing:** It is the variation of the frequency of the magnetron due to the changes in anode voltage. The change in oscillator frequency produced by a change in the mode current for a fixed load is called pushing figure. A plot frequency versus current is called pushing characteristic and the slope of this curve represents the pushing figure. To avoid frequency pushing stabilized anode voltage power supply need to be used.

**Frequency Pulling:** It is the variation of the frequency of the magnetron due to the changes in load impedance. The change in oscillator frequency produced by a change in the mode current for a fixed load is called pushing figure. A plot frequency versus the load is called pulling characteristic and the slope of this curve represents the pulling figure. To avoid frequency pulling load should be stable.

## Transferred electron devices

The application of two-terminal semiconductor devices at microwave frequencies has been increased usage during the past decades. The CW, average, and peak power outputs of these devices at higher microwave frequencies are much larger than those obtainable with the best power transistor.

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

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

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

In other words, positive resistances absorb power (passive devices), whereas negative

---

resistances generate power (active devices).

The differences between microwave transistors and transferred electron devices (TEDs) are fundamental. Transistors operate with either junctions or gates, but TEDs are bulk devices having no junctions or gates. The majority of transistors are fabricated from elemental semiconductors, such as silicon or germanium, whereas TEDs are fabricated from compound semiconductors, such as gallium arsenide (GaAs), indium phosphide (InP), or cadmium telluride (CdTe).

TEDS operate with 'hot' electrons whose energy is much greater than thermal energy.

### **Gunn Diode**

Gunn Diode is a one kind of transferred electronic device and exhibits negative resistance characteristic.

Gunn-effect diodes are named after J. B. Gunn, who in 1963 discovered periodic fluctuations of current passing through then-type gallium arsenide (GaAs) specimen when the applied voltage exceeded a certain critical value.

These are bulk devices in the sense that microwave amplification and oscillation are derived from the bulk negative-resistance property of uniform semiconductors rather than from the junction negative-resistance property between two different semiconductors, as in the tunnel diode.

#### **GUNN EFFECT:**

A schematic diagram of a uniform n-type GaAs diode with ohmic contacts at the end surfaces are shown in Fig.1.

J. B. Gunn observed the Gunn effect in the n-type GaAs bulk diode in 1963.

Above some critical voltage, corresponding to an electric field of 2000-4000 volts/cm, the current in every specimen became a fluctuating function of time. In the GaAs specimens, this fluctuation took the form of a periodic oscillation superimposed upon the pulse current. The frequency of oscillation was determined mainly by the specimen, and not by the external circuit. The period of oscillation was usually inversely proportional to the specimen length and closely equal to the transit time of

---

electrons between the electrodes, calculated from their estimated velocity of slightly over 107 cm/s.

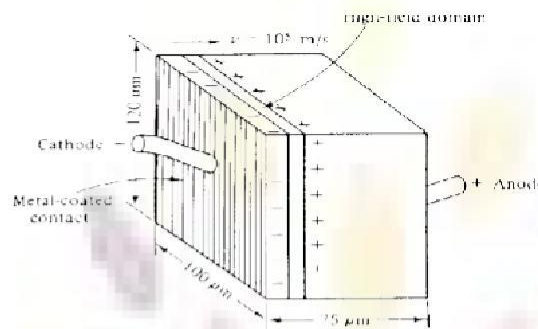


Figure 1. Schematic diagram for n type GaAs diode.

From Gunn's observation 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 negative resistance.

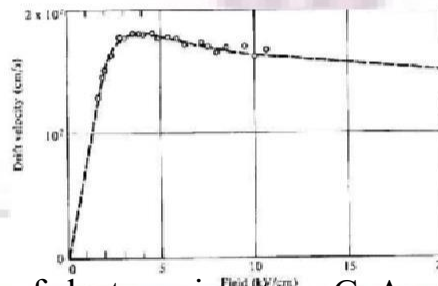


Figure 2. Drift velocity of electrons in n-type GaAs versus electric field.

**RIDLEY-WATKINS-HILSUM (RWH) THEORY**

The fundamental concept of the Ridley-Watkins-Hilsum (RWH) theory is the 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. There are two modes of negative-resistance devices: voltage-controlled and current-controlled modes as shown in Fig.3.a and Fig.3.b

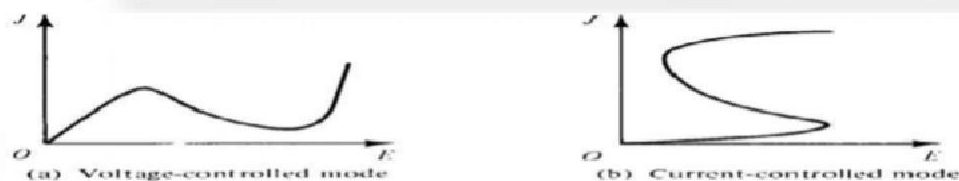


Figure 3. Diagram of negative resistance

In the voltage-controlled mode the current density can be multivalued, whereas in the current-controlled mode the voltage can be multivalued. The major effect of the appearance of a differential negative-resistance region in the current density-field curve is to render the sample electrically unstable. As a result, the initially homogeneous sample becomes electrically heterogeneous in an attempt to reach stability. In the voltage-controlled negative-resistance mode high-field domains are formed, separating two low-field regions. The interfaces separating low and high-field domains lie along equipotential; thus they are in planes perpendicular to the current direction as shown in Fig. 4(a). In the current-controlled negative-resistance mode splitting the sample results in high-current filaments running along the field direction as shown in Fig. 4(b).

UNIT II: SEMICONDUCTOR MICROWAVE DEVICES AND APPLICATIONS

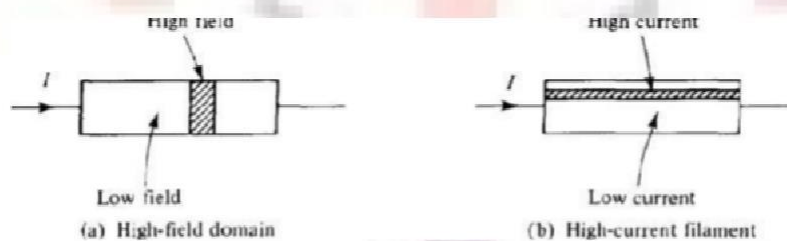


Figure 4. Diagrams of high field domain and high current filament.

Expressed mathematically, the negative resistance of the sample at a particular region is

$$\frac{dI}{dV} = \frac{dJ}{dE} = \text{negative resistance} \quad \dots(1)$$

If an electric field  $E_0$  (or voltage  $V_0$ ) is applied to the sample, for example, the current density  $J_0$  is generated. As the applied field (or voltage) is increased to  $E_2$  (or  $V_2$ ), the current density is decreased to  $J_2$ . When the field (or voltage) is decreased to  $E_1$  (or  $V_1$ ), the current density is increased to  $J_1$ . These phenomena of the voltage-controlled negative resistance are shown in Fig. 5(a). Similarly, for the current-controlled mode, the negative-resistance profile is as shown in Fig. 5(b).

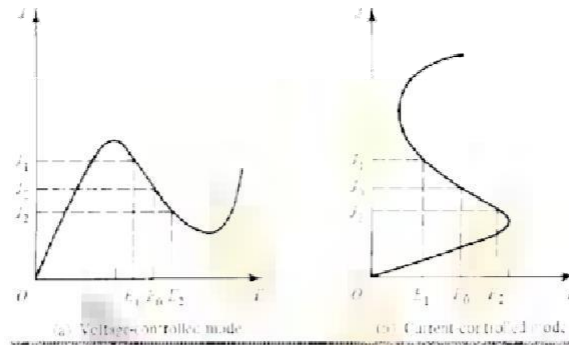
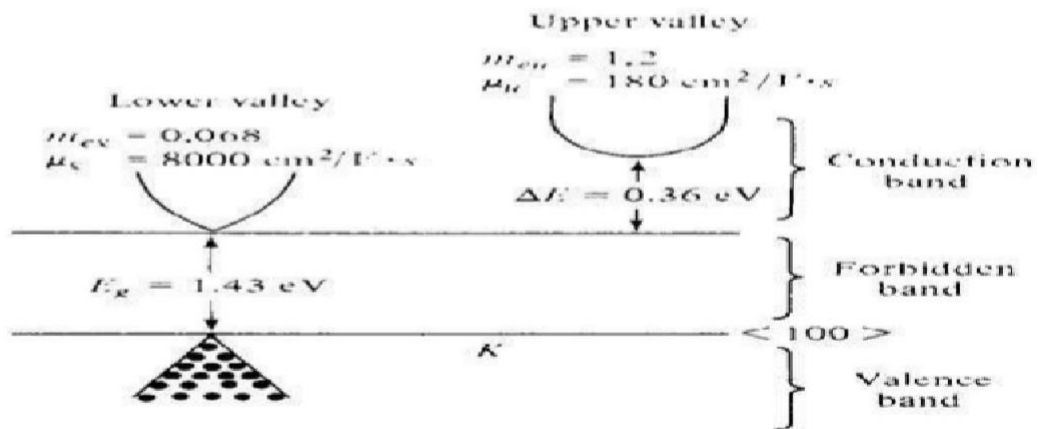


Figure 5. Multiple values of current density for negative resistance.

**TWO-VALLEY MODEL THEORY**

According to the energy band theory of then-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



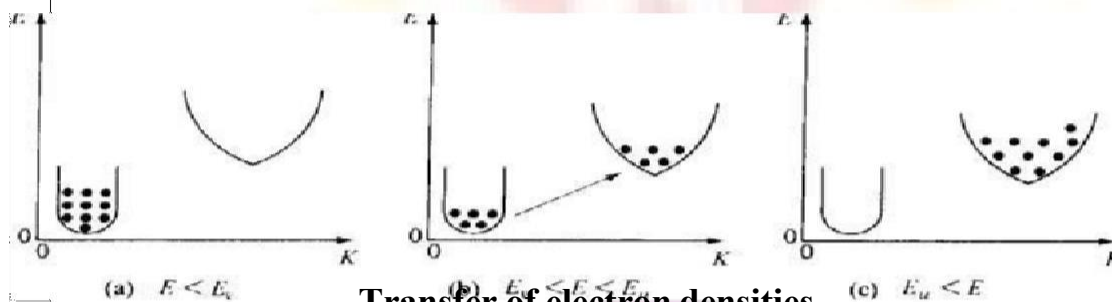
Two-valley model of electron energy versus wave number for n-type GaAs.

DATA FOR TWO VALLEYS IN GaAs

Valley	Effective Mass $m_e^*$	Mobility $\mu$	Separation $\Delta E$

Lower	$m_{e1} = 0.068$	$\mu_l = 8000 \text{ cm}^2/\text{v-sec}$	$\Delta E \text{ eV}$ = 0.36
Upper	$m_{e2} = 1.2$	$\mu_u = 180 \text{ cm}^2/\text{v-sec}$	$\Delta E \text{ eV}$ = 0.36

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 the lower valley ( $E < E_e$ ), no electrons will transfer to the upper valley as shown in Fig. 7(a).



When the applied electric field is higher than that of the lower valley and lower than that of the upper valley ( $E_e < E < E_u$ ), electrons will begin to transfer to the upper valley as shown in Fig. 7(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 in Fig. 7(c). If electron densities in the lower and upper valleys are  $n_l$  and  $n_u$ , the conductivity of the n-type GaAs is

$$\sigma = e(n_l \mu_l + n_u \mu_u) \quad \dots(2) \text{ Where, } e = \text{the electron charge } \mu = \text{electron mobility}$$

$n = n_l + n_u$  is the electron density

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  $\mu$  are both functions of

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

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

$$\frac{d}{dE} (n_l + n_u) = \frac{dn}{dE} = 0 \dots(4)$$

$$\frac{dn_l}{dE} = - \frac{dn_u}{dE} \quad \dots(5)$$

and  $\frac{d\mu}{dE} \propto \frac{dE^p}{dE} = pE^{p-1} = p \frac{E^p}{E} \propto p \frac{\mu}{E} = \mu \frac{p}{E} \quad \dots(6)$

Substitution of Equation (4) to (6) into Eq. (3) results in

$$\frac{d\sigma}{dE} = e(\mu_l - \mu_u) \frac{dn_l}{dE} + e(n_l \mu_l + n_u \mu_u) \frac{p}{E} \dots(7)$$

Then differentiation of Ohm's law  $J = \sigma E$  with respect to  $E$  yields

$$\frac{dJ}{dE} = \sigma + \frac{d\sigma}{dE} E \quad \dots(8)$$

Equation (8) can be rewritten

$$\frac{1}{\sigma} \frac{dJ}{dE} = 1 + \frac{d\sigma/E}{\sigma/E} \quad \dots(9)$$

Clearly, for negative resistance, the current density  $J$  must decrease with increasing field  $E$  or the ratio of  $dJ/dE$  must be negative. Such would be the case only if the right-hand term of Eq.

(9) is less than zero. In other words, the condition for negative resistance is

$$-\frac{d\sigma/E}{\sigma/E} > 1 \quad \dots(10)$$

Substitution of Equation (2) and (7) with  $f = nu/nl$  results in [2]

$$\left[ \left( \frac{\mu_l - \mu_n}{\mu_l + \mu_n f} \right) \left( -\frac{E}{n_l} \right) \frac{dn_l}{dE} - p \right] > 1 \quad \dots(11)$$

### APPLICATIONS OF GUNN DIODE

- In Radar Transmitters (police Radar, CW Doppler radar).
- Pulsed Gunn diode oscillators used in transponders, for air traffic control and in industry telemetry system.
- Fast combinational and sequential logic amplifier. As pump source in preamplifier.
- In microwave receiver as low and medium power oscillator.

### Domain Formation:

Differential resistance occur when an electric field of a certain range is applied to a multivalley semiconductor, such as then-type GaAs. due to that decrease in drift velocity with increasing electric field. Its leads to formation of a high-field domain for microwave generation and amplification.

In the n-type GaAs diode the majority carriers are electrons. When a small voltage is applied to the diode, the electric field and conduction current density are uniform diode.

$$J = \sigma E_x = \frac{\sigma V}{L} U_x = \rho \theta_x U_x$$

Where

J = conduction current density  $\sigma$  = conductivity

$E_x$  = electric field in the x direction

L = length of the diode

V = applied voltage

$\rho =$  charge density

$v =$  drift velocity

$U =$  unit vector

The current is carried by free electrons that are drifting through a background of fixed positive charge.

When the applied voltage is above the threshold value, which measured about 3000 V/cm times the thickness of the GaAs diode, a high-field domain is formed near the cathode that reduces the electric field.

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

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

As shown fig 1(b) below there exists an excess (or accumulation) of negative charge that could be caused by a random noise fluctuation or possibly by a permanent non uniformity in doping in the n-type GaAs diode.

An electric field is then created by the accumulated charges as shown in Fig 1(d). The field to the left of point A is lower than that to the right. If the diode is biased at point EA on the J-E curve, implies that the carriers (or current) flowing into point A are greater than those flowing out of point A, therefore increasing the excess negative space charge at A.

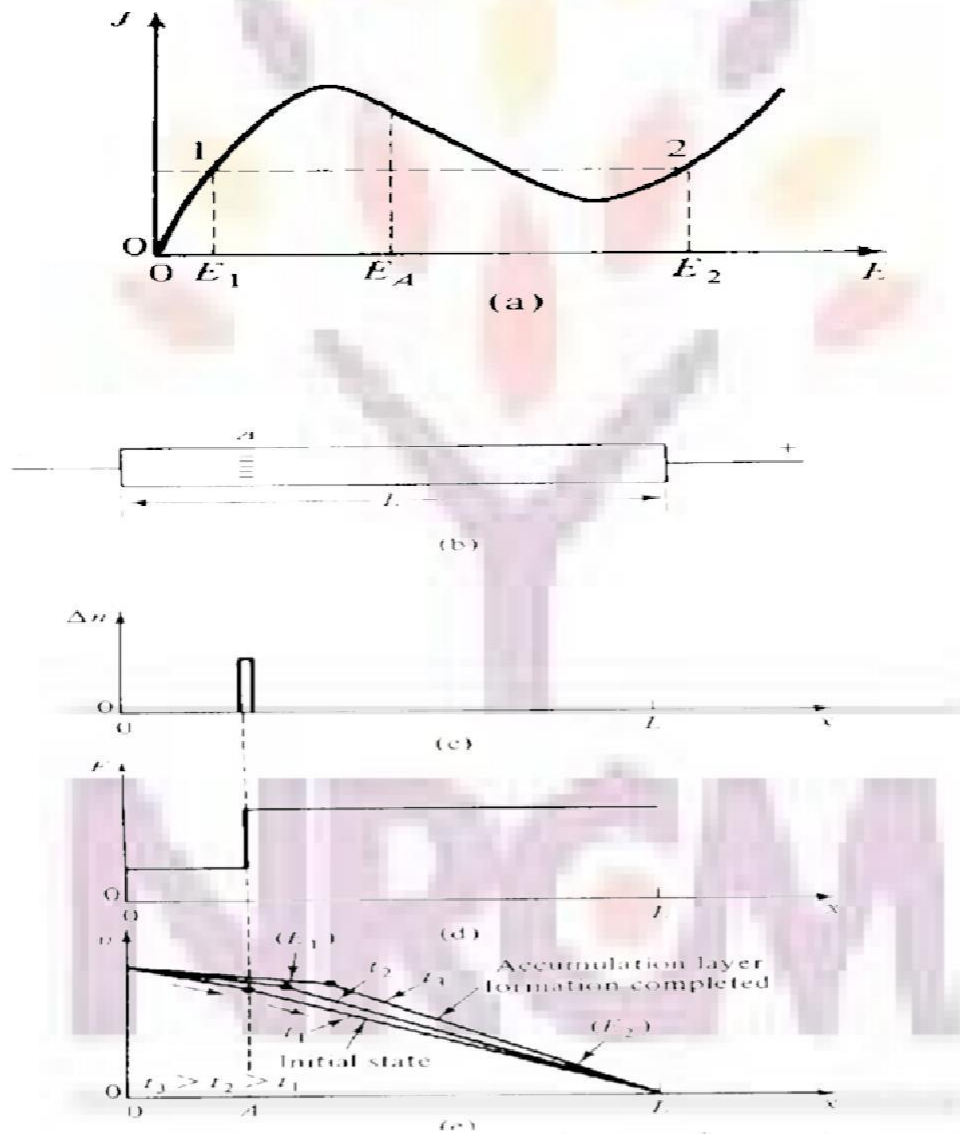
when the electric field to the left of point A is lower than it was before, the field to the right is then greater than the original one, resulting in an even greater space-charge accumulation. process continues until the low and high fields both reach outside the differential negative- resistance region Fig1(a).

This process depends on condition that the number of electrons inside the crystal is large enough to allow the necessary amount of space charge to be built up during the transit time of the space-charge layer.

The electric field in side the dipole domain would be greater than the fields on

either side of the dipole in Fig 2.(c). Because of the negative differential resistance, the current in the low- field side would be greater than that in the high-field side.

Then the dipole field reaches a stable condition and moves through the specimen toward the anode. When the high-field domain disappears at the anode, a new dipole field starts forming at the cathode and the process is repeated.



**formation of an electron accumulation layer in GaAs.**

### **Properties of High field domain**

Will start to form whenever the electric field in a region of the sample increases above the threshold  $E$ . When the electric field increases, the electron drift velocity decreases and the GaAs diode exhibits negative resistance.

If additional voltage is applied, the domain will increase in size and absorb more voltage than was added and the current will decrease.

domain will not disappear before reaching the anode unless the voltage is dropped

four basic modes of operation of uniformly doped bulk diodes with low-resistance contact are as follows

- Transit Time Domain mode
- Delayed Domain mode
- Quenched Domain mode
- Limited space charge accumulation mode

#### **1. Transit Time Domain mode:**

in the region where the product of frequency multiplied by length is about  $10^7$  cm/s and the product of doping multiplied by length is greater than  $10^{12}/\text{cm}^2$ , the device is unstable because of the cyclic formation of either the accumulation layer or the high-field domain.

$f = V_d/L$  in these mode is slightly sensitive to the applied voltages since the drift velocity  $V_d$  depends on the bias voltages.

$V_d = f \cdot L = 10^7$  cm/s when  $V_d = V_S$ , then high field domain is stable. Bias voltage is normally maintain little higher  $E_{th}$ .

At this instant Oscillation period = Transit Time ( $\tau_o = \tau$ ). Operating 'f' depends on 'Vd' hence on bias voltage  $> E_{th}$ .

It is a low power, low efficiency mode and requires that operating frequency laser

---

then 30GHz.

These limit on frequency is due to that device length .

## 2. Delayed Domain mode:

This mode is defined in the region where the product of frequency times length is about  $10^7$  cm/s and the product of doping times length is between  $10^{11}$  and  $10^{12}/\text{cm}^2$ .

When transit time is chosen that domain is collected  $E < E_{th}$ , new domain can not form until field rises again above threshold.

Oscillation period is greater than transit time  $\tau_o < \tau_t$  This delay inhabited mode has an 20 %

Efficiency.

Operating frequency can be less than or equal to Gunn Mode frequency

## 3. Quenched Domain mode:

This mode is defined in the region where the product of frequency times length is above  $10^7$  cm/s and the quotient of doping divided by frequency is between  $2 \times 10^4$  and  $2 \times 10^5$ .

It is bias field drops below sustaining field  $E_s$  during the negative half cycle domain collapses before it reaches the anode. i.e The domain disappear somewhere in the sample itself.

Operating frequency will be higher than Gunn Mode and delayed mode, certainly this depend on the external circuit.

When bias field swings back above threshold value  $V_{th}$ , new domain formed and process repeats, hence in that mode domain is quenched before it reaches the anode.

Frequency of resonant circuit then the transit time frequency is 13%.

## 4. Limited Space Charge Accumulation mode:

This mode occurs only when there is either Gunn or LSA oscillation, and it is usually at the region where the product of frequency time's length is too small to appear in the figure. When a bulk diode is biased to threshold, the average current suddenly drops as Gunn oscillation begins.

It gives high power upled high efficiencythe domain is not allowed to form

RF voltage and frequency are so chosen that they do not have sufficient time to form domainabove threshold.

IN LSA mode high power and high  $\eta$ (20%),16 to 23% compare to 5% for gunn mode Thefield No peak value permits high operating voltage.

Operating frequency is 0.5-50 times more than Gunn Mode.

It can be used up to 100 GHz and is dependent on external resonating circuits.High Power and High Efficiency.

