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Lecture for M. Sc. Physics II Semester students

Paper-IV: Electronic Devices

Unit-1 Transistors and Microwave Devices

Transfer of electron from Central Valley to the Statite valley is Called Transfer electrons Mechanism.

Gunn Diodes (Transfer Electron Devices)

With the help of junction diodes high microwave power Can not be obtained. While studying the properties of thin speicemen's of GaAs, J. B. Gunn in 1963 discovered that under high electric Stress there is periodic fluctuations in the current passed by the material. This effect is known as Gunn effect or as bulk-transfered electron effect. T.E.D are bulk-effect devices that utilizes hot electrons to produce a Voltage control differential negative resistance. The phenomena that gives rise to differential negative resistance is the decrease in electron mobility with the electric field. This decrease is caused by the transfer of conduction electron from high mobility low energy state to a low mobility high energy state under the action of high electric fields.

Fig (A) shows the Construction of a typical Gunn diode when a small D.C voltage is applied across thin slies of GaAs, negative resistance manifates it self under Certain condition.

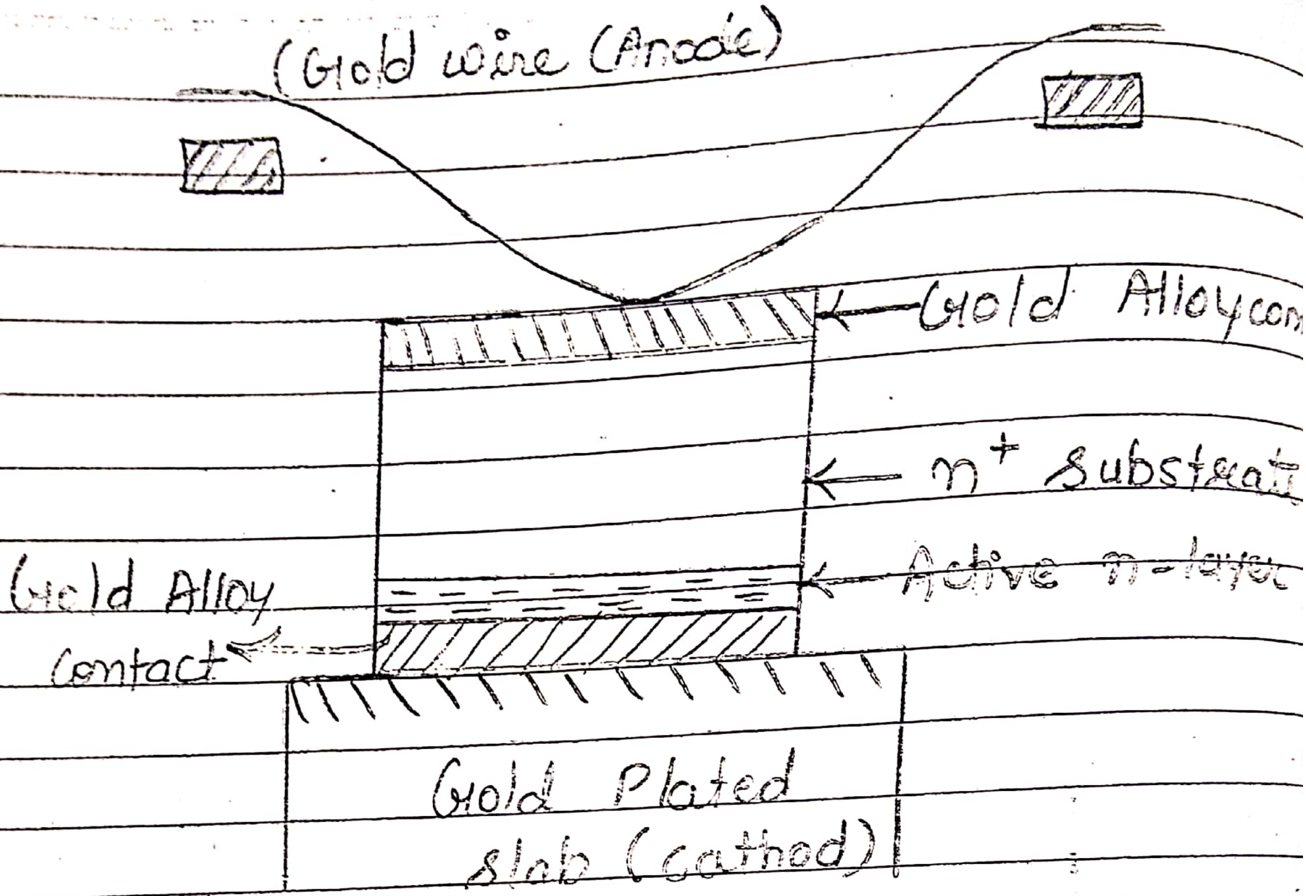
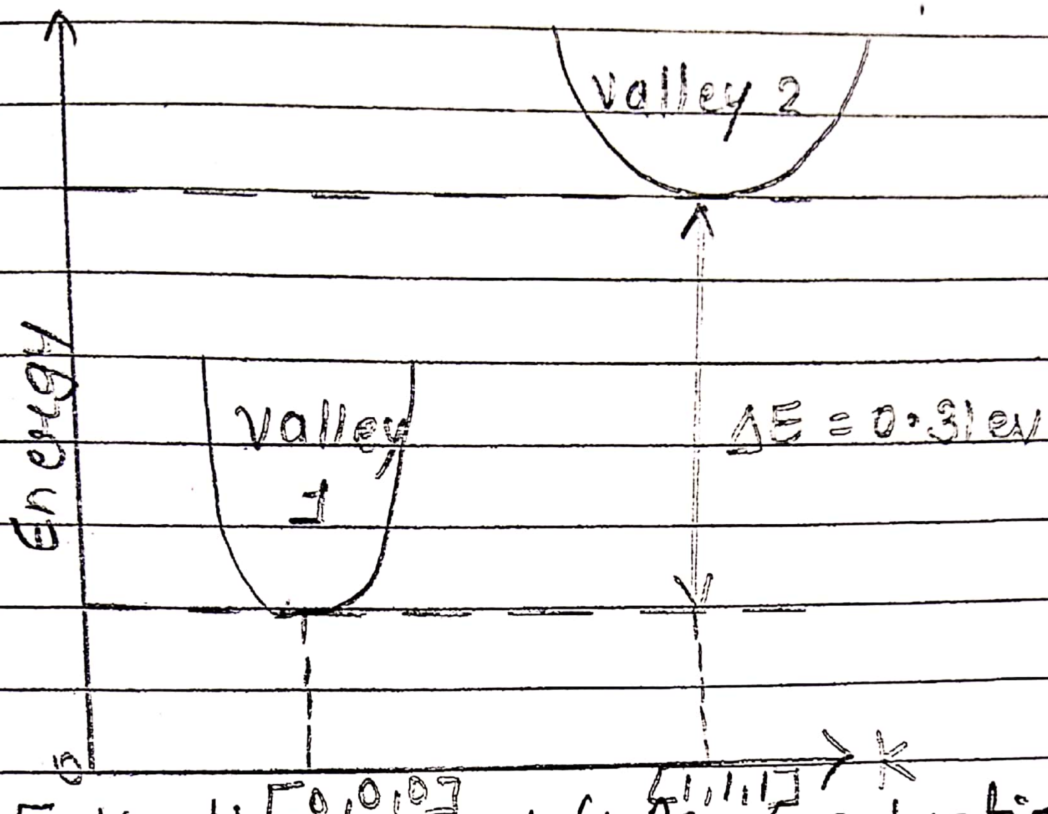


Fig. (A)

If a slice is ~~connect~~ to the Suitably tunned circuit oscillation occurs. Hence the slice is very thin, voltage gradia accross the Slice become very high. Due to this reason the electron velocity i also very high which causes the Oscillatio to occur at microwave frequency.

fig (b) Shows the corresection to the E-K diagram of the GaAs Conduction band. The diagram has following feature -

1) The lowest minimum Occurs at K=0 (valley 1) here the E-K diagram has



fig(b) E-K diagram of GaAs conduction band

a Sharp curvature and the electrons in this lower valley has a low effective mass m_1 and hence high mobility μ_1. Besides the lower valley there are energy maxima along [1,1,1] axis known as Satellite Valley each of which is Seprated from the lower valley by an energy $\Delta E = 0.31eV$. In a Satellite valley the electron effective mass m_2 is high and the mobility μ_2 considerably lower than μ_1.

2) The density of state in Satelite valley is considerably higher than that in

the lower valley.

3) The energy difference ΔE is large compa to the thermal energy kT of the e^- at the room temperature. Thus the transfer of e^- from the lower to th statelite valley by thermal agitatio is not very lightly. Further more Since ΔE is small compare to energ gap E_g, electron transfer can occur at field much lowerer than those required for avalanche breakdown.

Consider now that an electric field $\vec{E}$ is applied to a sample of GaAs. At low fields all the conduction electron are located in the lower valley 1. However, as $\vec{E}$ is increased, electrons gain energy from the field and make a transistion to the low mobility satellite valleys. As a result, the conductivity o the material decreases at high fields. The electron transfer sets in abruptl after the field has reached the thres value E_T. This causes a decrease in the average drift velocity of the electron and results in a region of negative differential mobility (NDM). The Conductivity in a two-valley semiconductor can be written as

$$\sigma = q\left[n_1(\vec{E})\mu_1 + n_2(\vec{E})\mu_2 \right] = \frac{q n_0 V_n(\vec{E})}{\vec{E}} \longrightarrow ①$$

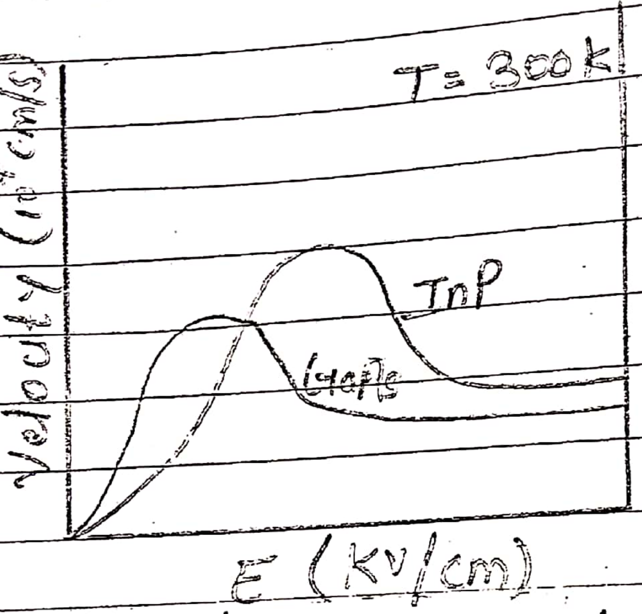
where n_1 and n_2 are the electron Concentrations in the lower and the upper Valley respectivly and $n_0 = (n_1 + n_2)$. From eqⁿ ①, the average drift velocity $V_n(\vec{E})$ is obtained as

$$V_n(\vec{E}) = \frac{\{n_1(\vec{E})\mu_1 + n_2(\vec{E})\mu_2]\,\vec{E}}{n_0} \longrightarrow ②$$

It can be seen from this relation that the differential mobility $\frac{dV_n}{d\vec{E}}$ can become negative at a sufficiently high field. Since n_1 decreases and n_2 increases with $\vec{E}$. At very high fields when all the electrons have made a transistion to the upper valley, $V_n(\vec{E})$ again starts increasing, with $\vec{E}$ making $\frac{dV_n}{d\vec{E}}$ positive.

Static I-V characteristic of a DNM crystal

Let us consider a sample of length l of a semiconductor whose velocity field characteristic is shown in fig.



Let voltage V be applied to the sample. If V is increased gradually, we can expect to obtain the I-V characteris similar to that of a tunnel diode, prov the field is uniform throughout. Howev In real crystals, local fluctuations in th mobile carrier concentration occur du to doping inhomogeniety. This causes th field to become non-uniform and as a result, the negative resistance charac istic is not observed. The one-dimensional equations governing the

I-V characteristic of the sample are the possion equation.

$$\frac{\partial E}{\partial x} = \frac{q}{\varepsilon_s}\left[n(x) - n_0 \right] \quad — ③$$

and the current density equation

$$J(x) = q\, n(x) V_n(x) \quad — ④$$

Where n_0 = thermal equillibrium electron Concentration

$n(x)$ = Concentration at any point x

From the above two relation we obtain

$$n(x) = \frac{J(x)}{V_n(x) q}$$

∴ eqⁿ ③ becomes

$$\frac{\partial E(x)}{\partial x} = \frac{q}{\varepsilon_s}\left[\frac{J(x)}{V_n(x) q} - n_0 \right] \quad — ⑤$$

A computer solution of this non-linear differential equation reveals that in the steady state, $E(x)$ increases monotonically with x and no negative resistance characteristic is observed. This is because an internal space charge exists in the sample and $n(x)$ varies with E such