<u>Power Devices -I</u>

Definition and Application of Power Electronics :-

Power electronics combine power, electronics end control. Power electronics may be defined as the applications of solid-state electronics for the control and conversion of electric power. The co-relationship of power electronics with power electronics and control is as shown in fig. 1.

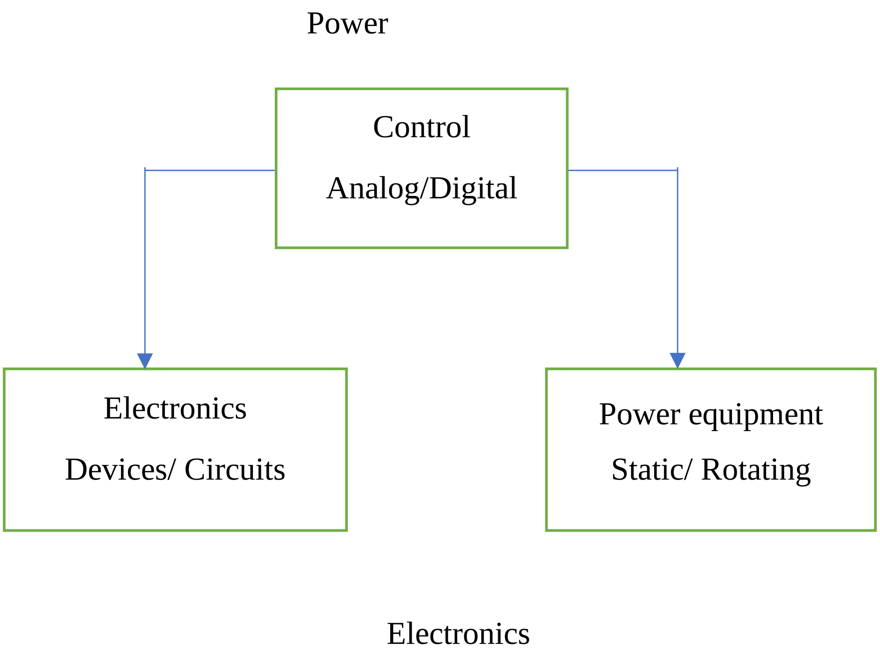


Fig 1: Relationship of Power electronics and control.

The power electronics is based on the switching of power semiconductor devices. With the development of power semiconductor technology, the power-handling capabilities and the switching speed of power devices have improved largely. The development of microprocessors/microcomputer technology has a great impact on the control and synthesizing the control strategy for the power semiconductors that devices.

Modern power electronics equipment uses,

1. Power semiconductors that can be regarded as the muscle and 2. Microelectronics that as the power and intelligence of a brain.

The power electronics have already found an important place in modern technology and are now used in a great variety of high-power applications such as heat, light & motor controls, Power supplies, and high voltage DC systems. It is difficult to decide the limits for the applications of power electronics.

Need for Semiconductor Power Devices:

The voltage, current and power ratings of semiconductor power devices are much higher than the corresponding ratings for low-power or signal devices. Power devices operate at lower switching speeds whereas signal devices operate at higher switching speeds. The powers semiconductor devices used extensively in power - electronic circuits. The power Semiconductor devices are diode, Thyristors, and Transistors. The brief description of power device is as follows:

1. **Power diode**:
   Diodes play a significant role in power electronics circuits. These are uncontrolled rectifying devices. It acts as a switch to perform various functions such as switches in rectifiers, change reversal of capacitor and energy transfer between components, voltage isolation, energy feedback from the load to power Source.

2. **Thyristors:**
   The thyristors are used extensively in power electronic circuits. They are operated as bistable switches, operating from of state to conducting state. The member of thy sister family are SCR, LASCR, RCT, GTO, SITH, and MCT.

3. **Transistors**:
   The power transistors have controlled turn-on and turn off characteristics. The switching speed of power transistor as much nigher than that of thyristors, and they are extensively used in dc-dc and dc-ac converters. The power transistors can classifieds BJT, MOSFETs, SITs and IGBTs.

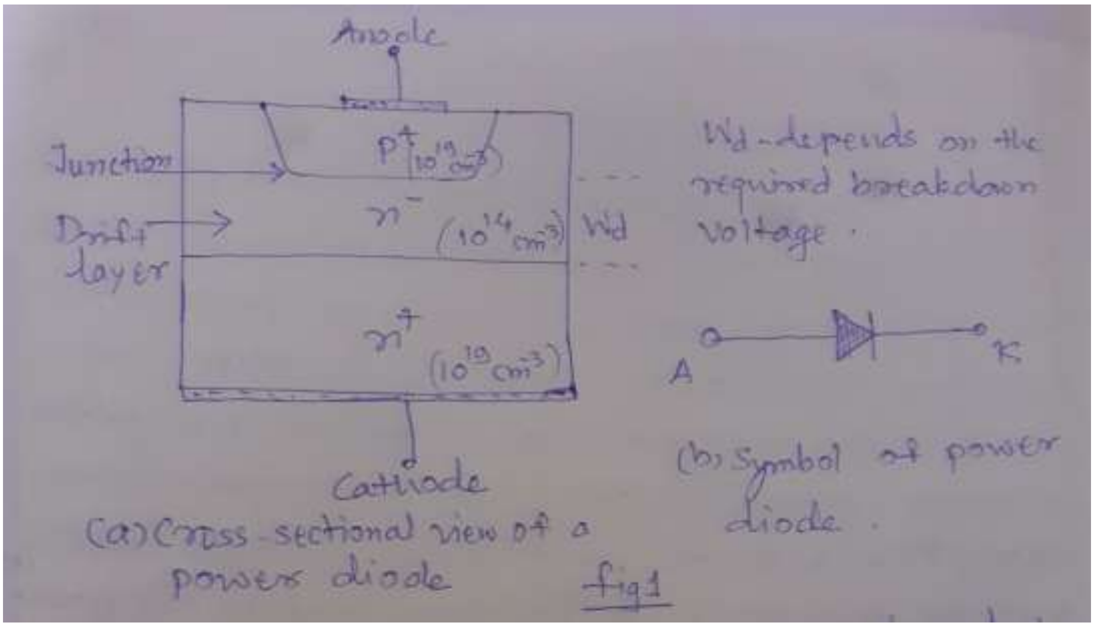
• Power Diodes

Power semiconductor diodes play a significant role in a power electronics circuits. A diode acts as a switch to perform various functions, such as switches in rectifiers, energy transfer between components, voltage isolation, energy feedback from the load to the power source.

The power diodes are similar to P-N junction signal diode. However, the power diodes have large power, voltage and current handling capabilities than that of the ordinary signal diodes. The frequency response (or switching speed) is slow compared to signal diodes.

Construction of Power diode:

The basic vertically oriented structure of a general purpose power diode is as shown in figure 1(a). The circuit symbol for the power diode is as shown in figure 1(b).



The vertically oriented structure is preferred in all the power devices as it increases the surface area for the forward current, therefore reduces the forward resistance and on State Power dissipation. Figure consists of a heavily doped (n+) substrate on the top of which a lightly doped (n-) layer of desired thickness is epitaxially grown. A heavily doped (p+) layer acts as anode. The lightly doped (n-) layer introduced between the heavily doped (p+) and (n+) layers is the major difference between the power diode and the low power diode. This layer is known as the "Drift" layer.

The important points from the basic structure are:

1. The anode and cathode layer are heavily doped whereas the drift layer is lightly doped.
2. The junction is formed between the anode layer (p+) and the drift layer (n-).
3. The width of drift layer (W_d) depends on the desired value of the breakdown voltage. The breakdown voltage of the power diode increases with increase in the width W_d.
4. The resistivity of the drift layer due to the low level of doping.
5. The circuit symbol for the power diode is identical to that used for the low power diode.

• Conductivity Modulation:
(Breakdown voltage and on state losses)

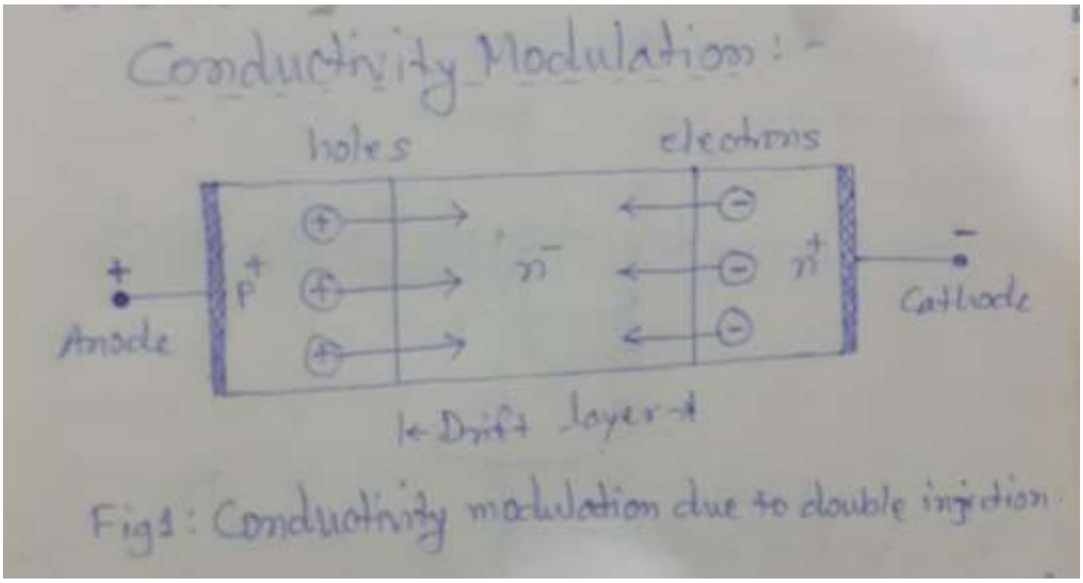
The breakdown voltage of a power diode in the reverse biased region depends on:

1. The doping profile of the junction (step, linearity graded, diffused etc), and the magnitudes of the doping densities (level).
2. With the structure, doping density on (n-) side much less than that on the (p+) side, the depletion region gets extended almost entirely in the lightly doped (n-) region.
3. In order to obtain a higher value of breakdown voltage at least one side of the PN junction must be lightly doped.

The on state power loss is the product of on state voltage across the device and the forward current through it. Whereas the switching loss takes place when the device is changing its state from off to on or on to off.

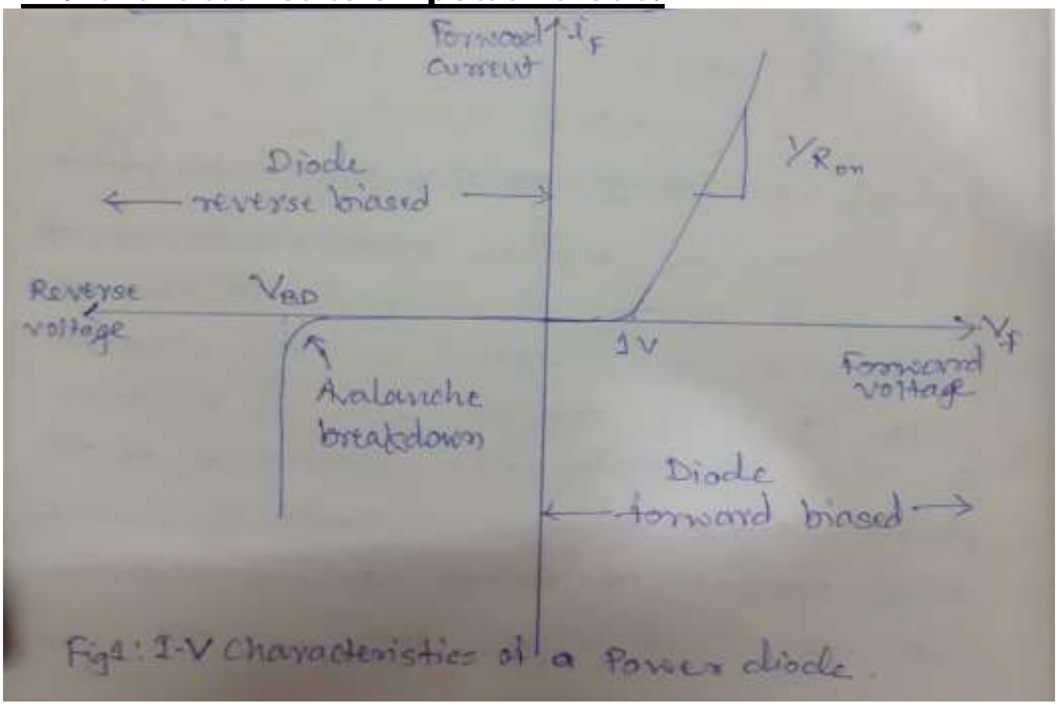
The on state power loss in power diodes is high due to the inclusion of the (n-) drift layer in the structure.

Conductivity modulation:



However, the on-state resistance of the drift region is much lower than the estimated value based on the physical size of this region. This is because in the on state, the resistance of the drift layer reduces substantially due to large amount of excess carrier injection into the drift region from both sides as shown in figure 1. In this, holes are injected from the (p+) layer and electrons are injected from the (n+) layer into the lightly doped drift layer (n-). Due to this excess charge injection, the conductivity of the drift layer increases. This phenomenon is known as “Conductivity Modulation” and it reduces the on state power dissipation to a great extent.

- **I-V characteristics of power diode:**

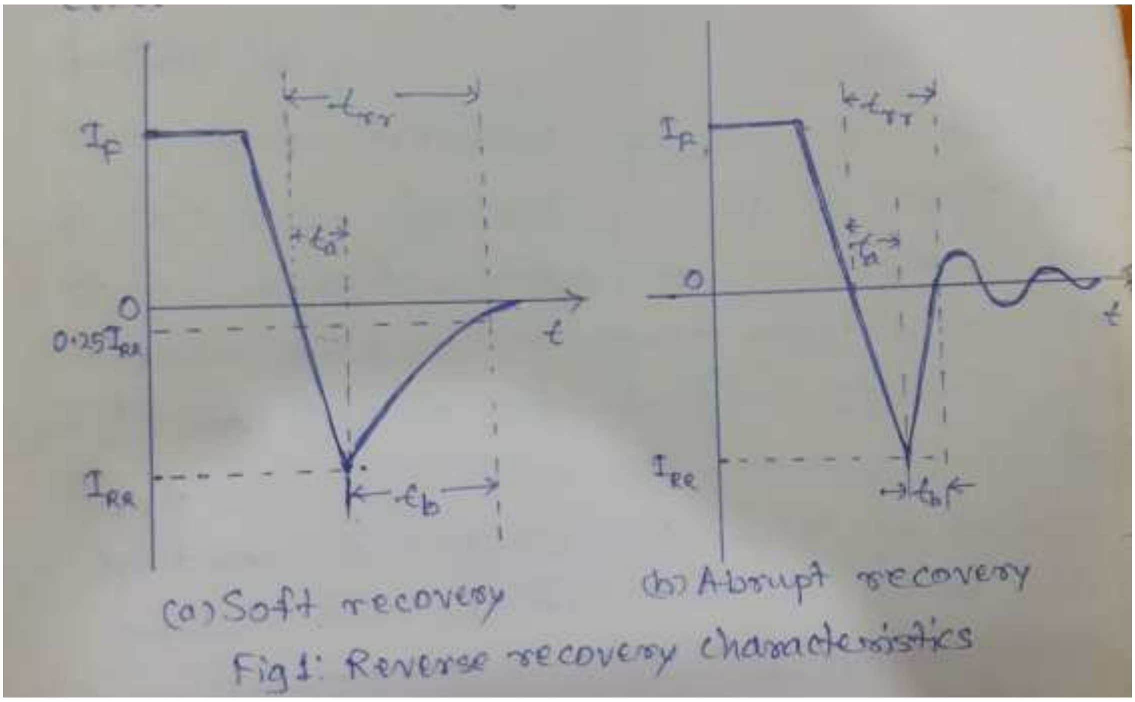


The I-V characteristic of a power diode is as shown in figure 1. The forward current appears to rise exponentially with increase in the forward bias voltage. The conclusions that can be drawn from characteristics are as follows:

(a) The on state voltage across a power diode is higher than 1 volt which is higher than the on state voltage across a low power diode.
(b) With the power diode reverse biased, a very small leakage current flows through it. The leakage current is independent of applied reverse bias Voltage.
(c) When the reverse voltage reaches the reverse breakdown voltage V_{BD}, avalanche breakdown takes place.
(d) As the voltage across and current through the device is large simultaneously, when the device breakdown, the power dissipation is dangerously high which can destroy the device. This must therefore be avoided,
(e) The on state resistance offered by the diode (Ron) can be found from the characteristics.

• Reverse recovery effect of power diodes:

The current in a forward biased junction diode is due to the net effect of majority and minority carriers. Once a diode is in a forward conduction mode and then its forward current is reduced to zero (due to the natural behaviour of diode circuit or by applying a reverse voltage), the diode continues to conduct due to minority Carriers which remain stored in the PN junction and the bulk semiconductor material. The minority Carriers require certain time to recombined with opposite changes and to be neutralized. This time is called the reverse recovery time of the diode. Figure 1 shows the reverse recovery characteristics of junction diodes.



The soft recovery type is more common. The reverse recovery time is denoted as t_{rr} and is measured from the initial zero crossing of the diode current to 25% of maximum (or peak) reverse currentI_{RR}. The t_{rr} consists of two components t_a and t_b , t_a is due to charge storage in the depletion region of the junction(and represents the time between the zero crossing and the peak reverse current I_{RR}), t_b is due to charge storage in the bulk semiconductor material. The ratio t_b/t_a is known as the softness factor SF. For practical purposes, the total recovery time t_{rr} and the peak value of the reverse current I_{RR}.

$$t_{rr} = t_a + t_b \qquad (1)$$

The peak reverse current can be expressed in reverse di/dt as

$$I_{RR} = t_a \, di/dt \qquad (2)$$

Reverse recovery time t_{rr}, may be defined as the time interval between the instant the current passes through zero during the change over from forward conduction toreverse blocking condition and the moment the reverse current has decayed to 25% of its peak reverse value I_{RR}. The t_{rr} is dependent on the junction temperature, rate of fall of forward current and the forward current prior to commutation.

Reverse recovery Charge Q_{RR}, is the amount charge carriers that flow across the diode in the reverse direction due to changeover from forward conduction to reverse blocking condition.

The storage Charge,which is the area enclosed by the path recovery current is approximately

$$Q_{RR} \cong \frac{1}{2} I_{RR} t_a + \frac{1}{2} I_{RR} t_b = \frac{1}{2} I_{RR} t_{rr} \qquad (3)$$

or

$$I_{RR} = \frac{2 Q_{RR}}{t_{rr}} \qquad (4)$$

Equating eq^n (2) to (4) gives

$$t_a \frac{di}{dt} = \frac{2 Q_{RR}}{t_{rr}} \qquad \because I_{RR} = t_a \, di/dt$$

$$\therefore t_{rr} t_a = \frac{2 Q_{RR}}{di/dt} \qquad (5)$$

If t_b is negligible as compared to t_a, which is usually the case $t_{rr} \approx t_a$ and eq^n (5) becomes

$$t_{rr} \cdot t_{rr} = t_{rr}^2 = \left(\frac{2 Q_{RR}}{di/dt}\right)$$

$$\therefore t_{rr} \cong \sqrt{\frac{2 Q_{RR}}{di/dt}} \qquad (6)$$

and

$$I_{RR} = \frac{2 Q_{RR}}{t_{rr}} = 2 Q_{RR} \sqrt{\frac{di/dt}{2 Q_{RR}}}$$

$$= \sqrt{4 Q_{RR}^2 \cdot \frac{1}{2 Q_{RR}} \frac{di}{dt}} = \sqrt{2 Q_{RR} \frac{di}{dt}} \qquad (7)$$

From equation (6) and (7) the reverse recovery time t_{rr} and the peak reverse recovery current I_{RR} depend on the storage charge Q_{RR} and the reverse di/dt. The storage charge is dependent on the forward diode current I_F.

• Types of Power Diode :

Ideally a diode should have no reverse recovery time. However, the manufacturing cost of such a diode will increase. Depending on the recovery characteristics and manufacturing techniques the power diodes can be classified into three categories:

1. Standard or general-purpose Diodes
2. Fast recovery diode
3. Schottky diode

1. General-purpose Diodes:

The general purpose rectifier diodes have a relatively high reverse recovery time, typically 25 **µ**s and are used in low speed applications. These diodes cover current rating from less than 1A to several thousands of amperes, with voltage ratings from 50V to around 5kV. These diodes are generally manufactured by diffusion. However, alloyed types of rectifiers that are used in welding power supplies are most cost effective and their ratings can go up to 300A and 1000 V.

2. Fast Recovery Diodes:

The fast recovery diodes have low recovery time, normally less than 5**µs**. They are used in DC-DC and DC-AC converter circuits, where the spirit of recovery is often of critical importance. These diodes cover current ratings from less than 1A to hundreds of amperes, with voltage ratings from 50V to around 3kV.

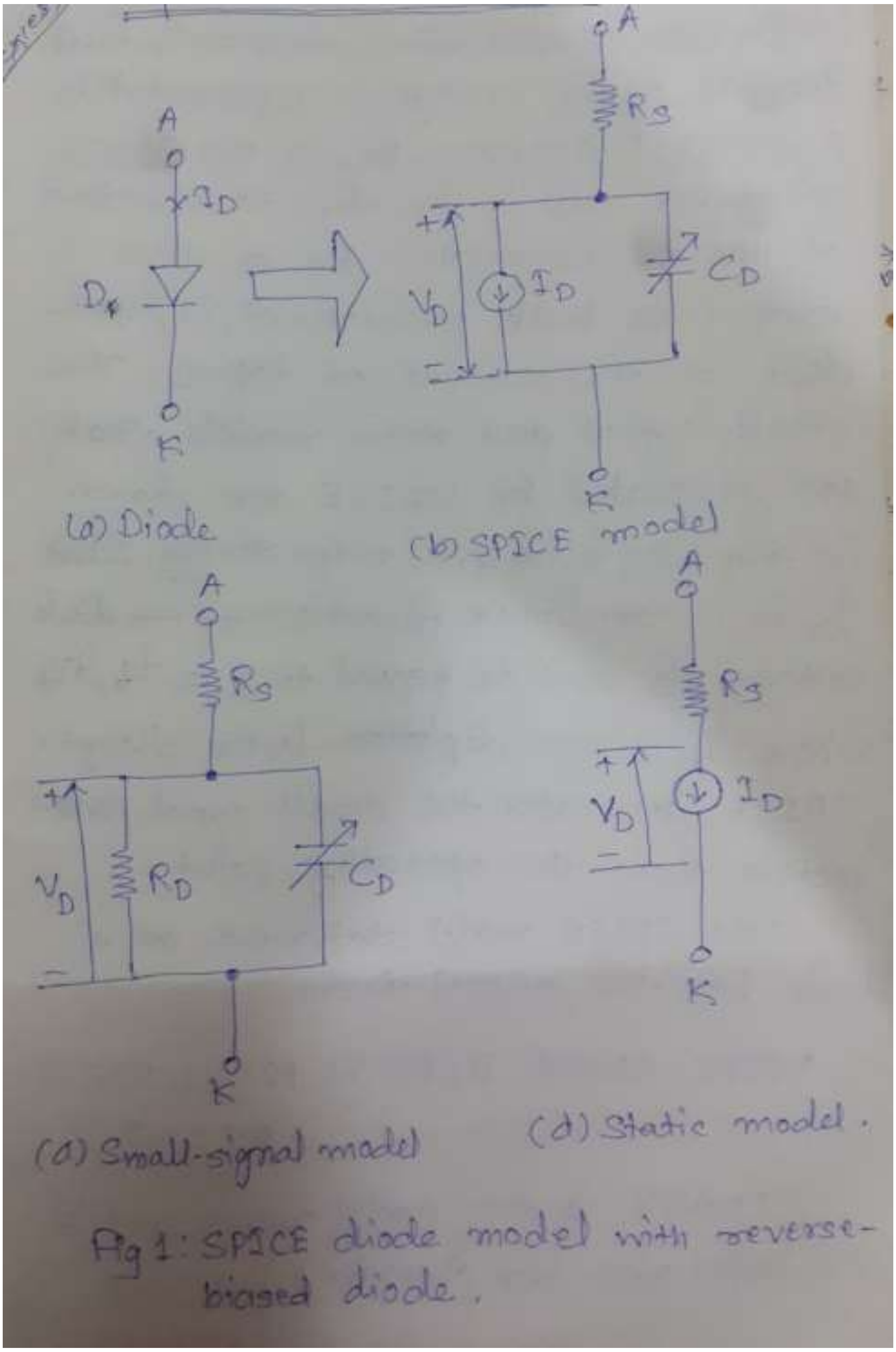
3. Schottky Diodes:

The charge storage problem of a PN junction can be eliminated or minimized in a Schottky diode. It is accomplished by setting up a barrier potential with a contact between a metal and a semiconductor. A layer of metal is deposited on a thin epitaxial layer of N type silicon. The potential barrier simulates the behaviour of a PN junction. (The rectifying action depends on the majority carriers only and as a result there are no excess minority carriers to recombine) the recovery effect is due solely to the self capacitance of the semiconductor junction.

The recovered charge of a Schottky diode is much less than that of an equivalent PN junction diode. (Since it is due only two the junction capacitance, it is largely independent of the reverse di/dt). A Schottky diode has a relatively low forward voltage drop.

The leakage current of a Schottky diode is higher than that of a PN junction diode. The Schottky diodes are ideal for high current and low voltage DC power supplies.

Spice Diode Model :



The SPICE model of a diode is shown in figure 1(a). The diode current I_D that depends on its voltage is represented by a current source. R_S is the series resistance and it is due to resistance of the semiconductor. R_S is also known as bulk resistance, is dependent on the amount of doping. The small signal and static models that are generated by SPICE are shown in Figure 1(b) ,(c) and (d) Respectively. Where C_D is a nonlinear function of the diode voltage V_D and is equal to $C_D=dq_d/dV_d$, Where q_d is the

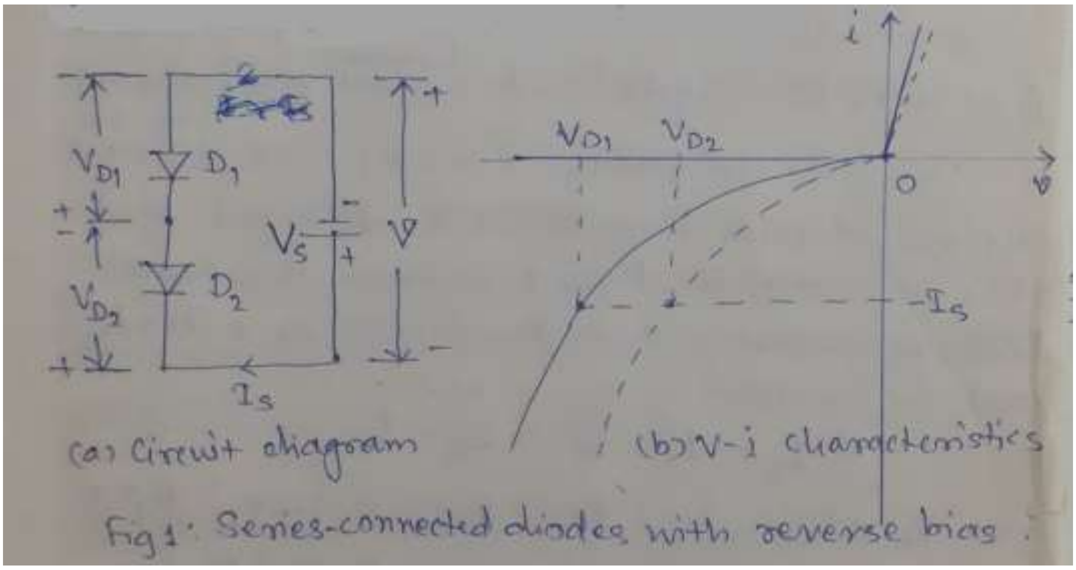
depletion layer Charge. SPICE generates the small signal parameters from the operating point.
The SPICE model statement of a diode has the general form

MODEL DNAME D(P1=V1 P2=V2 P3=V3........ PN=VN)

DNAME is the model name and it can begin with any character; but its word size is normally limited to 8. D is the type symbol for diodes. P1, P2,... and V1, V2,.... are the model parameters and their values respectively.

- **Series-connected Diodes:**

In many high voltage applications (e.g. HVDC transmission lines), one commercially available diode cannot meet the required voltage rating, then diodes are connected in series to increase the reverse blocking capabilities.



Let us consider two series connected diodes as shown in Figure 1(a). In practice, the V-I characteristics for the same type of diodes differ due to tolerances in their production process, as shown in figure 1(b). In the forward biased condition, both diodes conduct the same amount of current and the forward voltage drop of each diode would be almost equal. However, in the reverse blocking condition, each diode has to carry the same leakage current and as a result the blocking voltages will differ significantly.
A simple solution to this problem, is to force equal voltage sharing by connecting a resistor across each diode, as shown in figure 2(a).

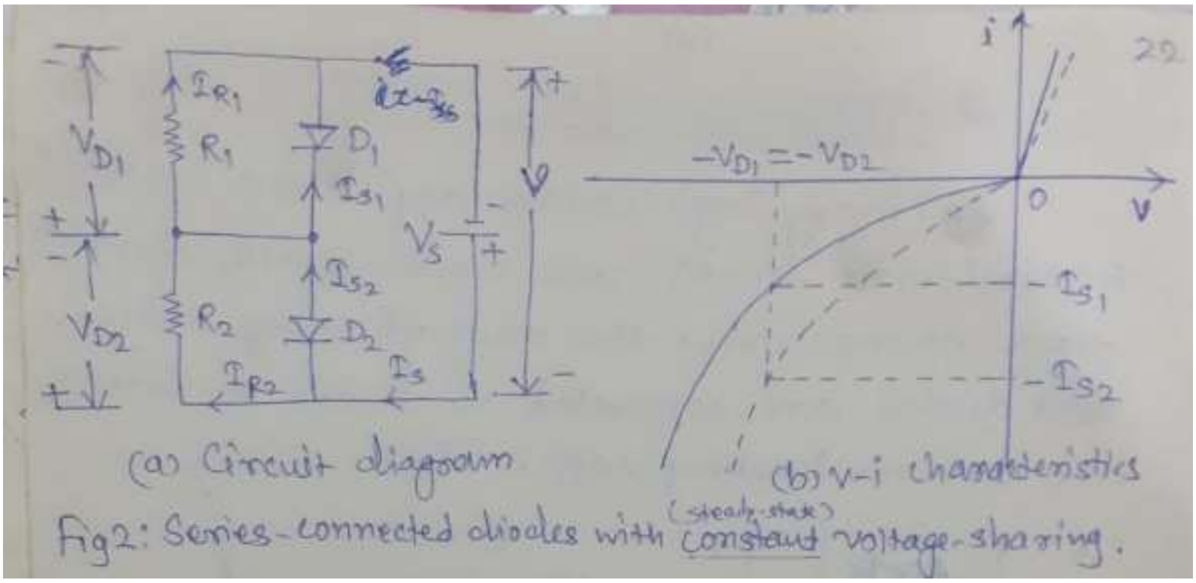


Fig2: Series-connected diodes with (steady-state) constant voltage-sharing.

Due to equal voltage sharing the leakage current of each diode would be different and this is shown in figure 2(b). Since the total leakage current must be shared by a diode and its resistor.

$I_s = I_{S1} + I_{R1} = I_{S2} + I_{R2}$ (1)

$V_{D1} + V_{D2} = V_S$

- **<u>Parallel Connected Diodes:</u>**

In high power application, diodes are connected in parallel to increase the current carrying capability to meet the desired current requirements. The current sharing of diodes would be in accord with their respective forward voltage drops. Uniform current sharing can be achieved by providing equal inductances(e.g. in the leads) or by connecting current sharing resistors(Which may not be practical due to power losses), as shown in Figure 1. It is possible to minimize this problem by selecting diodes with equal forward voltage drops or diodes of the same type. Since the diodes are connected in parallel, the reverse blocking voltages of each diode would be the same.

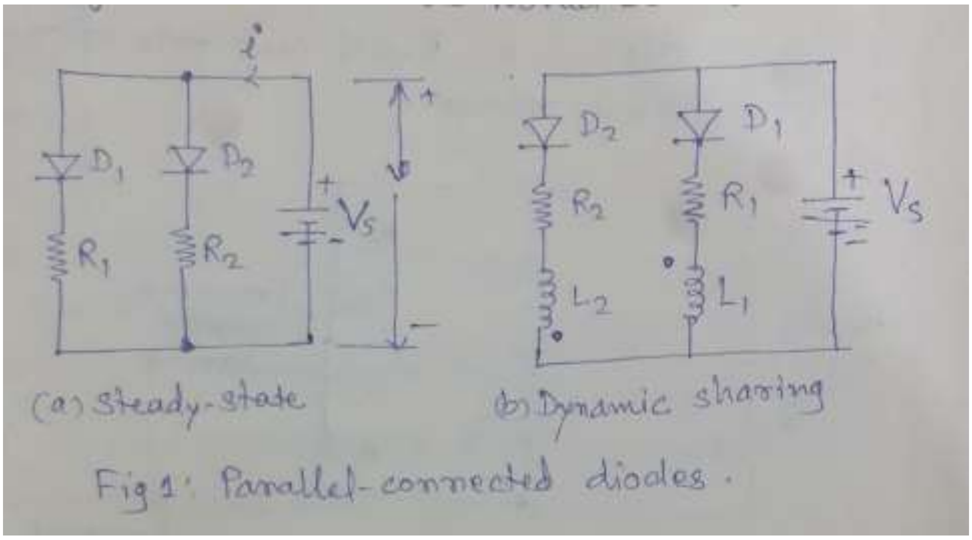


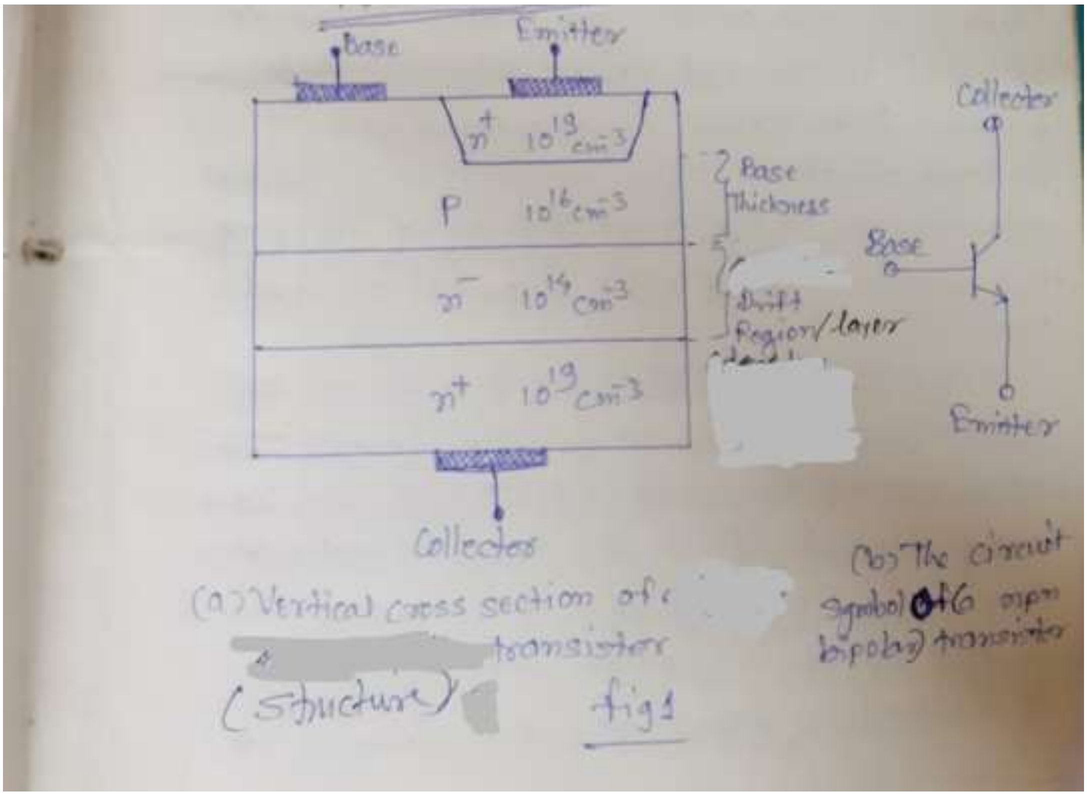
Fig 1: Parallel-connected diodes.

The resistors of figure 1(a) will help Current sharing under steady state conditions. Current sharing under dynamic conditions can be accomplished by connecting coupled inductors as shown in figure 1(b). If the current through diode D_1 rises, the L di/dt Across L_1 increases and a corresponding voltage of opposite polarity is induced across inductor L_2. The result is a low impedance path through diode D_2 and the current is shifted to D_2. The inductors would generate voltage spikes and they may be expensive and bulky, especially at high currents.

- ***Power Transistor:***

The power bipolar transistor is supposed to block a high voltage in the off state and have a high current carrying capacity in the on state. Power transistors have controlled turn on and turn off characteristics. In order to have these characteristics the power bipolar transistor (BJT), must have a substantially different structure than the small low power BJT.

Power BJT structure:



A power transistor has a vertically oriented four layer structure of P type and N type as shown in figure 1. The power transistor has three terminals collector, base and emitter. The circuit symbol for the BJT is as shown in figure 1(b). (The npn transistor are more widely used than the pnp transistors as power switches).

1. The vertical structure increases the cross sectional area through which the device current flows. This will reduce the on state resistance of the device and hence the on state power dissipation in the transistor. (The vertical structure also minimises the thermal resistance of the transistor, thus keeping the problem of power dissipation under control.)

2. Doping levels- Figure 1(a) shows the doping levels in each of the layers. The thickness of the different layers will have a significant effect on the characteristics of the device. As shown in figure 1(a), the emitter layer is heavily doped. The base is moderately doped. The (n-) region is known as the collector drift region and it is lightly doped. (The (n+) region that terminates the drift region has doping level similar to that of emitter). The (n+) region serves as collector terminal.
3. If the structure of power transistor is compared with that of transistor, it is found that the (n-) drift layer is included in the power transistor. Due to the low doping level the (n-) drift layer will increase the voltage blocking capacity of the transistor. The width of this layer will decide the breakdown voltage of power transistor. The disadvantage of including this layer is that the on state device resistance increases, increasing the on state power loss.
4. The current gain β of a transistor depends on the base thickness. As the base thickness reduces the gain increases but the breakdown voltage of the transistor will decrease. Thus the base thickness is a compromise between these two factors. In power transistors high breakdown voltage is more important than high current gain. Therefore the base thickness is much larger in power transistors. This reduces the current gain β of power transistors 5 to 10.

Operation of Power Transistor

The difference between the power transistor and that of logic level (low power) transistor is that in the power transistor an additional region called collector drift region is included. However the basic mechanism operation for the power transistor is same as that in the logic level transistors, even the current gain mechanism is similar. The collector drift region does not play any role when the power BJT is in the active region. The drift region will affect the breakdown voltage, on state losses and switching time of power BJT. A very important factor in the operation of a power transistor is the mechanism to obtain a high value of current gain β. There are three prime requirements for large values of β in a BJT.

(1) Heavy doping of emitter region
(2) Long minority carrier lifetime in the base and
(3) Short base Thickness

These factors will conflict with the other characteristics desired for the power transistor and hence a compromise will be required between the large gain and other parameters such as fast switching times, breakdown voltage etc. The effect of this compromise is that the thickness of base region in power transistor is larger than that in the logic level transistors and the β of power transistor is typically 5 - 20 i.e. 10.

The β of the power transistors as well as the logic level transistors is not constant, in fact it is dependent on the value of collector current as shown in figure 2. The two important reasons for this are(1) conductivity modulation in the base region and (2) emitter current crowding .

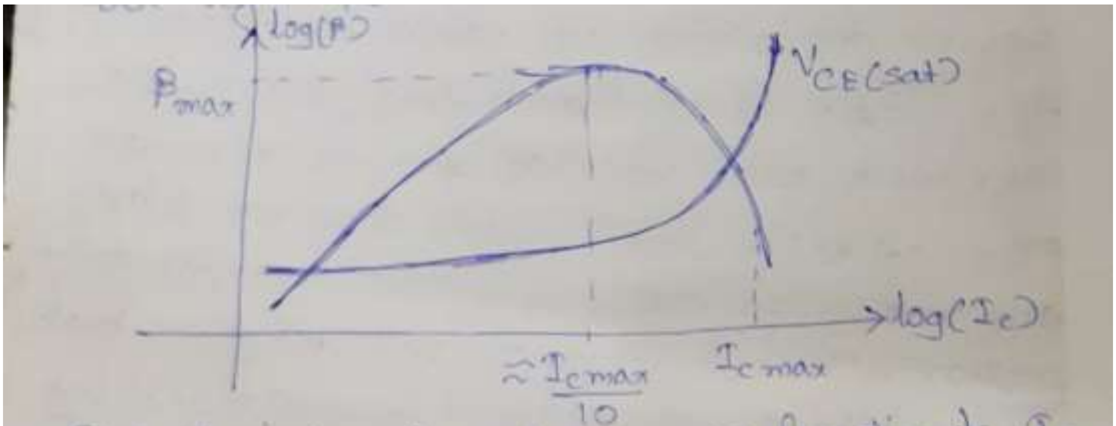


Fig 2: Variation of β and $V_{CE(sat)}$ as function dc I_c showing the fall out of β & increase in $V_{CE(sat)}$.

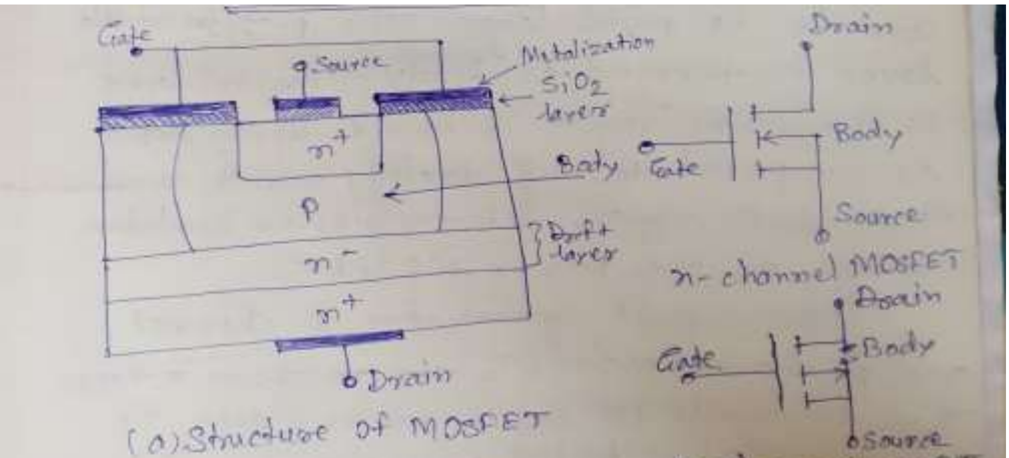
At large value of collector current the β is approximately inversely proportional to the I_C. The effect of emitter current crowding on the β values can be reduced by using a structure in which the emitter is separated into many rectangular areas. The value of $V_{CE(sat)}$ increases sharply after the collector current exceeds the value of $I_{C(max)}$. This fact is utilized to design the protection circuit against overcurrent condition.

- **Power MOSFET**

A Power MOSFETs (Metal oxide semiconductor field effect transistors) with improved on the state current carrying capacity and off state blocking voltage capability are now available and are replacing the power BJTs in the many applications, especially where high switching speeds are important.

MOSFETs are two types (1) Depletion MOSFET and (2) Enhancement MOSFET

Structure of power MOSFET



(a) Structure of MOSFET

Fig 1

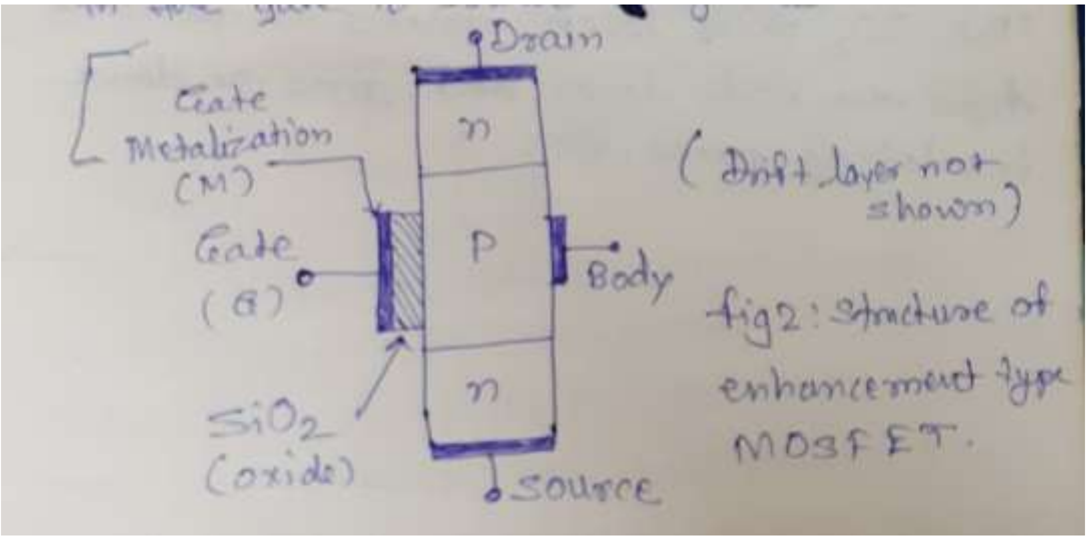
(b) Symbol of MOSFET

The power MOSFET has the vertically oriented four layer structure as shown in figure 1(a) and the circuit symbol is shown in figure 1(b). The vertically oriented structure reduces the on state resistance and therefore on state loss. The n+ p n- n+ Structure shown in Figure 1, is termed as enhancement mode n-channel MOSFET. A structured with the opposite doping profile can also be fabricated and is termed as p-channel MOSFET. The doping in the two n(+)regions of figure 1(a) labelled “source and drain” is approximately the same in the both layers and it is quite large. The p-type middle layer is termed as ‘body’. The n- layer is the ‘drift region’ and it is lightly doped as compared to the drain and source layers. This drift region determines the breakdown voltage of the power MOSFET.

[The circuit symbol for n- channel and p-channel MOSFETs are shown in figure1(b). Three terminals are Drain, Source and gate. The body Terminal is shorted with the source terminal internally.]

The direction of arrow on the body lead indicates the direction of current flow. (If the body source pn junction were forward biased by removing the short link between the body and source.) Therefore n-channel MOSFET has a p-type body region and the arrow points into the MOSFET symbol.

The MOSFET has two different modes of operation. If $V_{GS}>0$ it works in the enhancement mode where the conductivity increases with increase in the gate to source voltage. If $V_{GS}<0$ the device work in the depletion mode where the conductivity decreases with increase in the gate to source voltage (V_{GS}).

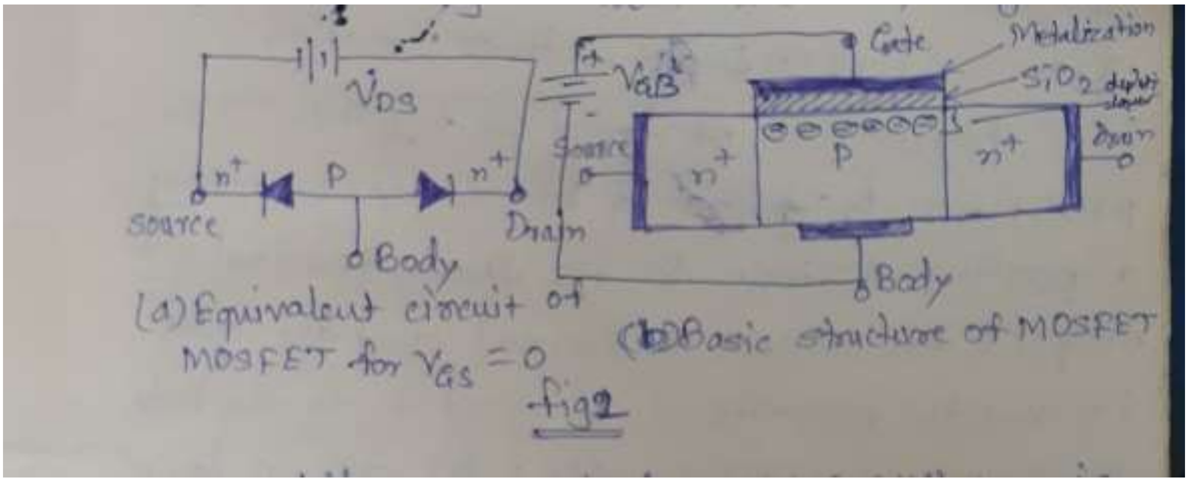


The simplified structure of enhancement MOSFET is shown in figure 2 the structure is very much same as a transistor. The p-type layer is known as the body layer that gives the MO normally off nature.

As seen from figure2, the gate terminal is not connected directly to the semiconductor (p-layer), instead there exist an oxide layer (SiO_2) between the metal and semiconductor. The oxide layer acts as a layer of dielectric between the metal and the semiconductor to form a MOS (metal oxide semiconductor) capacitance at the input of the MOSFET. This MOS capacitance does not exist in the low power JFET. The input capacitance of MOSFET is large (greater than 1000 pf). The SiO_2 oxide layer isolates the gate terminal from the body layer and gives the device insulating properties.]

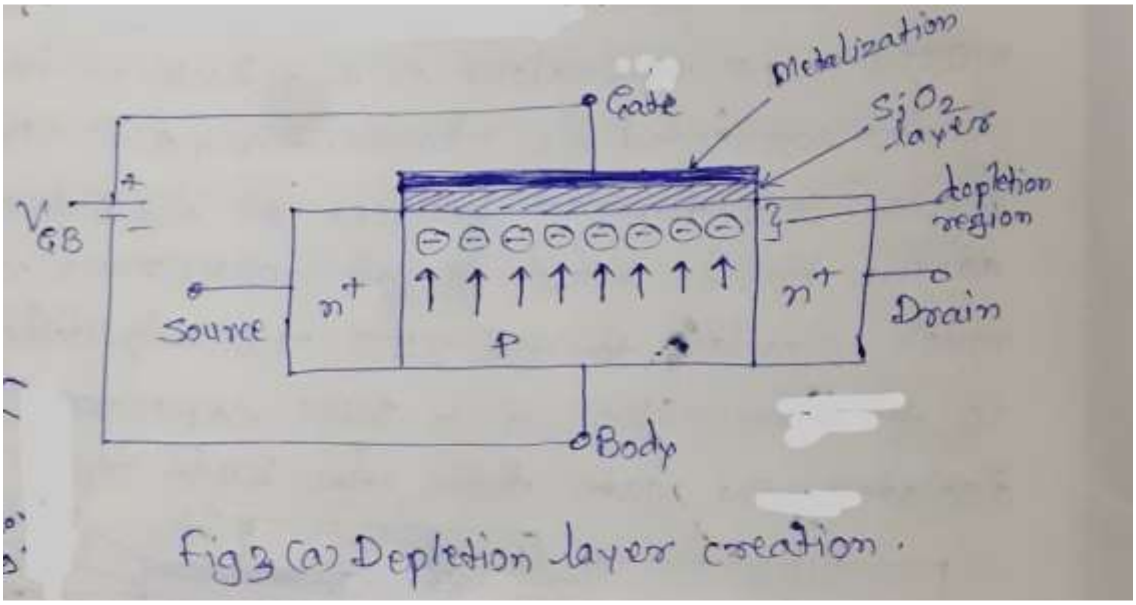
Operation of Power MOSFET

With gate to source voltage V_{GS}=0 the MOSFET is equivalent to two back to back diodes connected as shown in figure 2(a). The diodes are formed between n+ and P layers. The basic structure of MOSFETis very much similar to the BJT. The only difference is the presence of a MOS capacitor that isolates the gate from the body region.



When the gate to source voltage is applied, the MOSFETs turns on. The operation takes place as explained below.

The basic structure of the N type MOSFET as shown in figure 2(b). Due to the presence of P-layer (base layer) it is consider that the conduction cannot takes place through MOSFET from drain to source. But practically it is possible due to a phenomenon called “Inversion layered creation.”



Formation of depletion region:

The MOSFET is forward biased by connecting a positive voltage to its drain terminal with respect to source terminal and the gate is made positive with respect to the body layer as shown in figure 2(b). the P-layer consist of a large number of holes and few electrons. (Even though the number of electrons is far less as compared to the number of holes, still the number of electrons present in the P- layer is sufficiently large.)

Due to the positive voltage applied between gate and body, these electrons are attracted towards the gate and greater below the SiO2 layer and produce depletion layer by combining with the holes**.**

Creation of inversion layer:

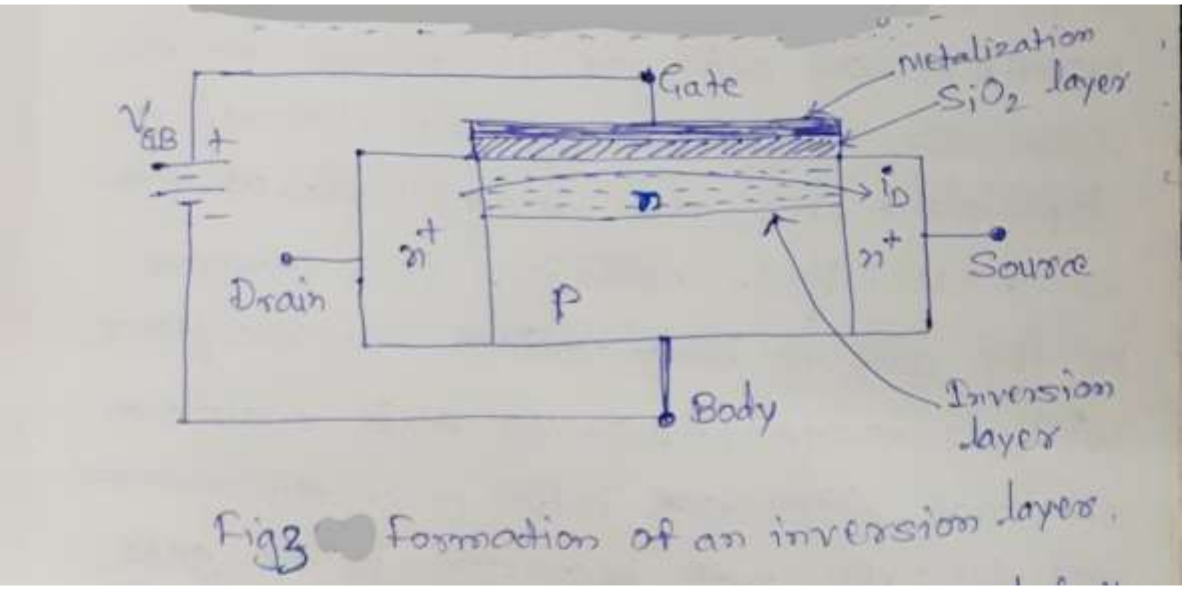
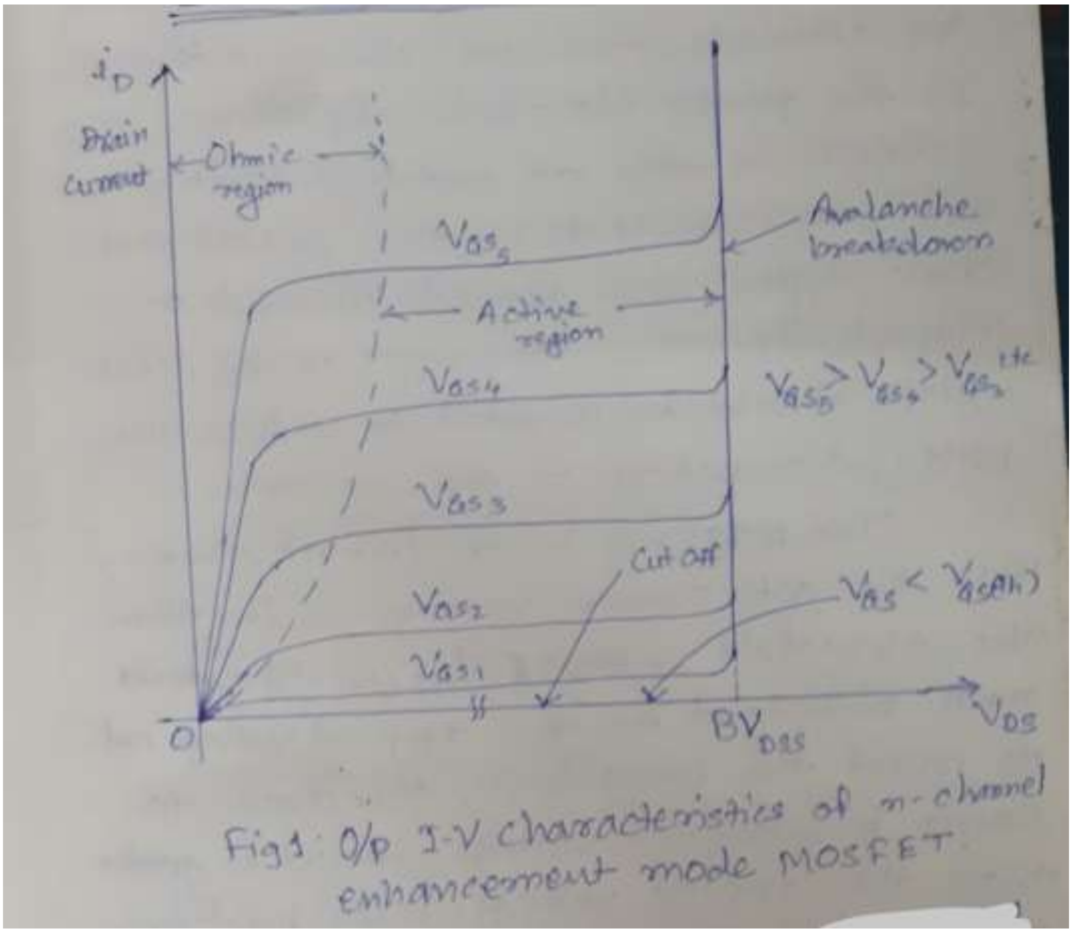


Fig3 formation of an inversion layer.

If the gatevoltage is increased further, the number of electrons below the SiO_2layer will be greater than the number of holes. Thus the conductivity of portion of the layer close two SiO_2 layer will change from positive to negative. That means on n-type of sub layer is formed below the SiO_2layer as shown in figure 3. This process is known as creation of the inversion layer and the process of generation of an inversion layer due to the externally applied gate voltage is known as the field effect .

In this way now the n-type channel gets created in the p-type body layer and conduction can take place through this layer. The MOSFET now acts as a variable resistor where the resistance of the channel is dependent on the magnitude of gate to base (body) voltage. With increase in the gate to body voltage, the resistance will decrease. (However this resistance cannot decrease below a certain minimum value; Even with the increase in the gate. To body voltage. There is a limitation on the maximum value of voltage applied between gate and body. If it is exceeded the SiO_2 dielectric will breakdown).

I-V characteristics of MOSFET:



The MOSFET is a three terminal device like power BJT, in which the gate terminal controls the drain current of the device. The source terminal is common between the input and output of the MOSFET. The output characteristics i.e. drain current i_D as a function of drain to source voltage V_{DS} with gate to source voltage V_{GS} as a parameter.

The active, cut off and ohmic regions of the characteristics are shown in figure. In the power electronic applications the MOSFET is used as switch, the device must be operated in the cut off and ohmic region when turned off and on respectively. The operation in the active region should be avoided to reduce the power dissipation in the on state.

The MOSFET is in cut off state when the gate source voltage is less than the threshold voltage $V_{GS(th)}$. The device must withstand to the applied voltage and to avoid the breakdown, the drain to source breakdown voltage should be greater than the applied voltage. When breakdown occurs it is due to the avalanche breakdown of the drain body junction. When longer gate to source voltage is applied the device is driven into the ohmic region where the drain to source voltage $V_{DS(on)}$ is small (In this regions of operation the power dissipation can be kept reasonably low, by minimising the on state voltage).

In the active region the drain current i_D is almost independent of the drain to source voltage V_{DS}. It is only dependent the gate to source voltage V_{GS} as shown . The gate voltage V_{GS} greater than the threshold voltage $V_{GS(th)}$. The power dissipation in the MOSFET is high in the active region.

The important conclusions from the I-V Characteristics of MOSFET are as follows:

(i) The MOSFETs are voltage controlled devices in the output current can be controlled by varying the gate-to-source voltage.

(ii) with increase in V_{GS} the drain current will increase

(iii) The gate- to-source voltage (V_{GS}) should be large enough to drive the MOSFET into ohmic region. (Practically the minimum V_{GS} required is about 12V. If V_{GS} is less than 12V, the MOSFET will operate in the active region which is not desired).

(iv) When the forward voltage applied to the MOSFET exceeds the beakdown voltage BV_{DSS}, the avalanche breakdown takes place. (Operation above the breakdown voltage must be avoided).

(v) The second breakdown does not exist in MOSFETS.

*** Advantages of power MOSFET over power BJTs are as follows:**

1 Fast switching

2. Absence of second breakdown

3. Wide safe operating area

4. Extremely high gain.

***Applications of Power MOSFETs:**

1. High frequency switching power supplies.

2. Chopper of inverter systems for dc and acmotor speed control.

3. High frequency generators for induction heating.

4. Ultrasonic generators, audio amplifiers.

Exercise:

01) Select the correct Alternative:

a) The process of conductivity modulation results in ________________.
i) Increase in the switching frequency
ii) Increase in the on state loss.
iii) Increase in the breakdown voltage.
iv) Reduction in on state loss.
b) Operation of MOSFET is basically dependent on __________________
i) the principle of conductivity modulation
ii) the principle: of current multiplication
iii) principle of creation of inversion layer
iv) none of the above
c) The process of conductivity modulation results in the reduction in__________________
i) current ii) on state loss iii) voltage iv) voltage and current
d) A TRIAC is equivalent to__________________
i) two diodes in antiparallel
ii) two thyristor in parallel
iii) two thyristor in antiparallel
iv) two diodes in parallel

e)________modulation is a process where holes and electrons both are injected into the drift layer.

i) Conductivity ii) Resistivity iii) Amplitude iv) Phase

f) The MOSFET is a ____________controlled device

i) Current ii) Voltage iii)Power iv) None of these

g) Which of the following device has the terminals collector , emitter, gate?
i) BJT
ii) MOSFET
iii) SCR
iv) IGBT
h) A power diode uses the vertically oriented structure as_________________
i) It reduces on state voltage drop
ii) It increases the switching frequency
iii) It gives the device properties of majority carrier device
iv) It decreases the size of the diode

I) Secondary breakdown occurs in_________________
i) MOSFET
ii) MOSFET & BJT
iii) BJT
iv) none of these

02) Attempt any Two (Eight marks each):

a) Explain the basic structure and working of power MOSFET.

b) Explain the basic structure and working of power diode.

c) Explain the basic structure of power MOSFET and give its principle of operation

d) Explain the basic structure and I-V characteristics of Power diode with necessary diagrams

03) Attempt any Four (Four marks each);

a) Explain with neat diagram the construction of a p-n junction power diode.

b) Explain the operation of Power MOSFET.

c) Explain the operation of parallel connected diodes.

d) Explain the basic structure of power diode.

e) What is meant by conductivity modulation and what is its effect on the on state power loss of the device?