GOVERNMENT WOMEN ENGINEERING COLLEGE AJMER

B.TECH VI SEM

MID TERM EXAMINATION

TIME : 60 MIN. **MAX. MARKS=20**

INDUSTRIAL ELECTRONICS

Q.1 Explain the working of MOSFET with diagrams? How does the channel potential vary after applying the drain voltage? (5)

Q.2 What is two transistor analogy of SCR and show that when α_1+ α_2 =1 , the anode current suddenly attains a very high value approaching infinity? (5)

Q.3 What do you mean by GTO. Explain its applications, advantages & disadvantages? (5)

Q.4 Draw complete SCR protection circuit and explain different SCR protection methods? (5)

Solutions

Answer 1: The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOS structure can be thought of as a parallel-plate capacitor, with the top plate being the positive plate, oxide being the dielectric, and Si substrate being the negative plate as shown in Figure 1. (We are assuming P-substrate.)

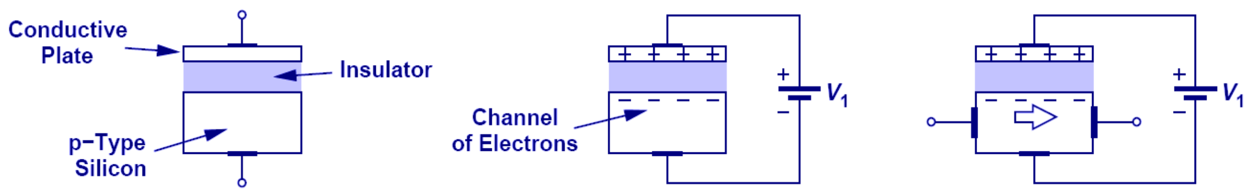


Figure: 1

The MOSFET is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals as shown in Figure 2. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits. This device is symmetric, so either of the n+ regions can be source or drain.

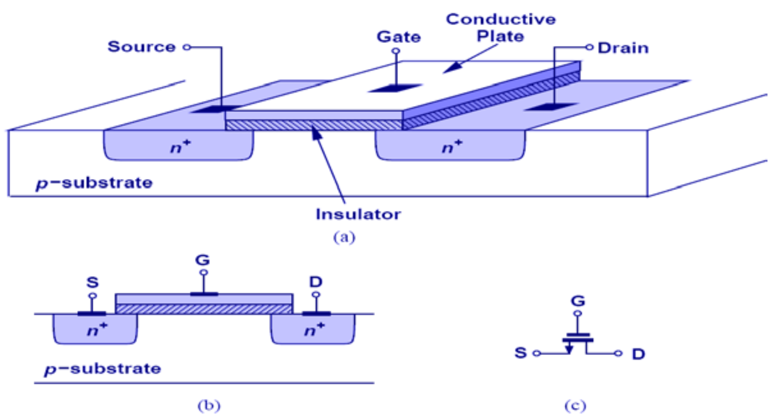


Figure : 2

Formation of Channel:

First, the holes are repelled by the positive gate voltage, leaving behind negative ions and forming a depletion region. Next, electrons are attracted to the interface, creating a channel (“inversion layer”) as shown in Figure 3.

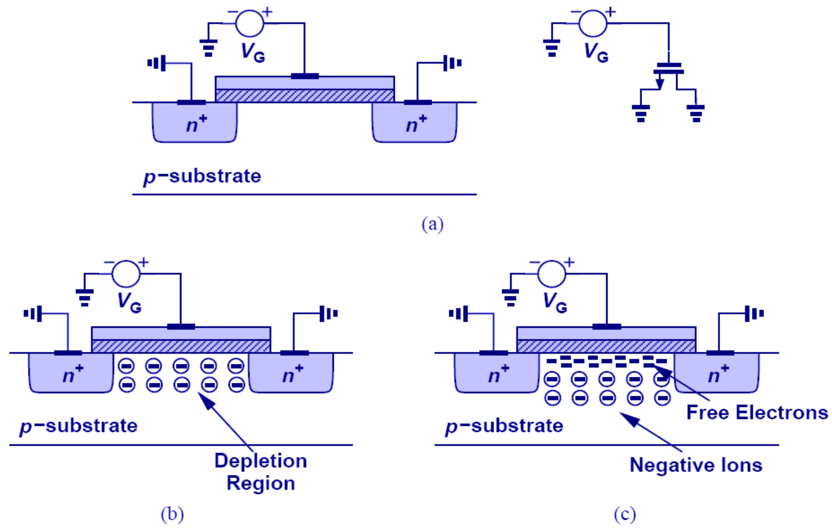
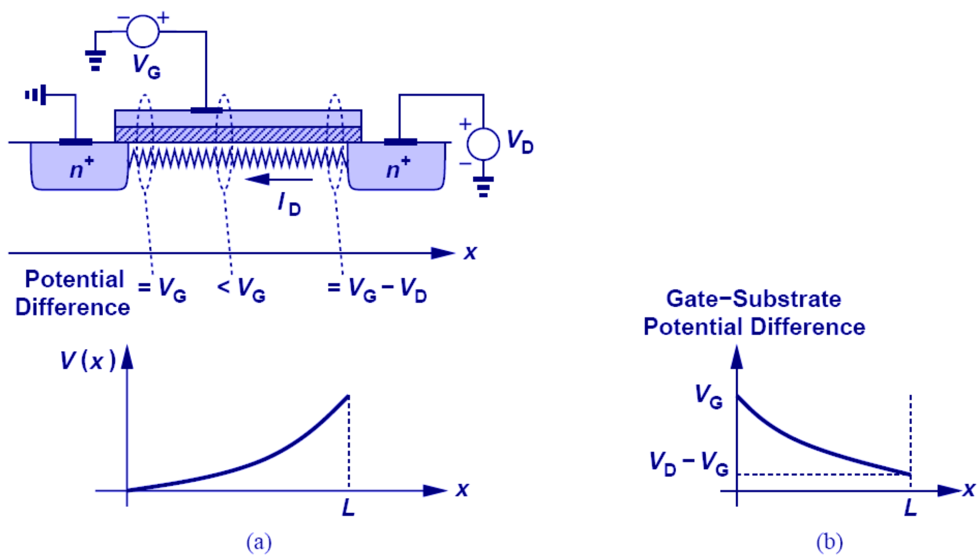


Figure : 3

<u>Channel Potential Variation:</u>

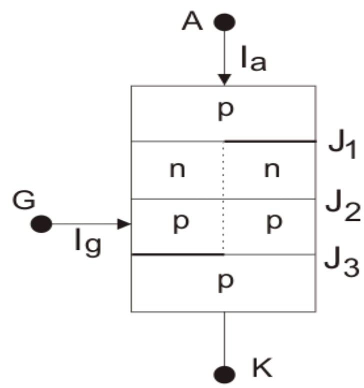
Since there's a channel resistance between drain and source, and if drain is biased higher than the source, channel potential increases from source to drain as shown in fig 4(a), and the potential between gate and channel will decrease from source to drain as shown in fig 4(b).



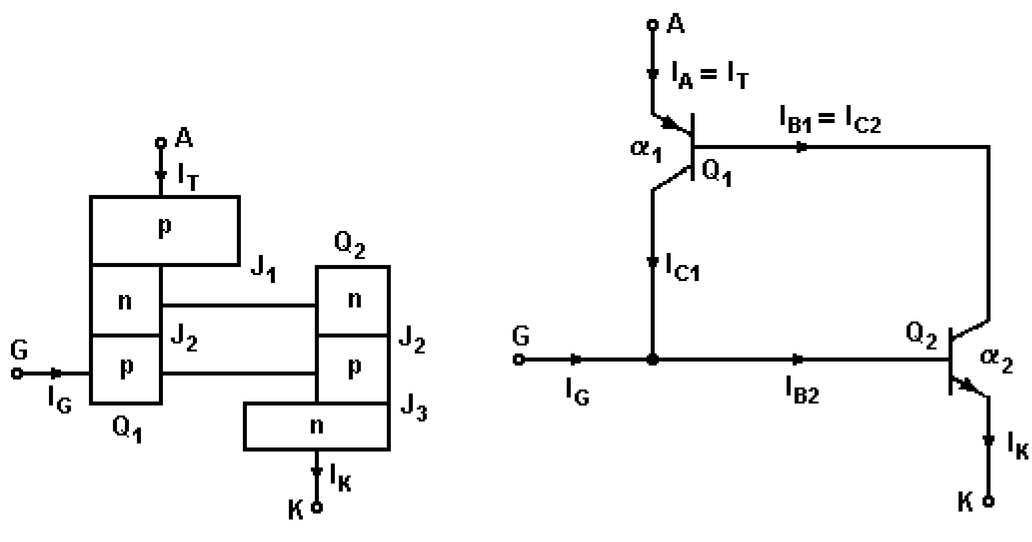
<u>Answer 2:</u> SCR (Silicon controlled rectifier) is a silicon based semiconductor device, which is used in electrical circuits for switching operation. Although there are many different members are available in thyristor family, but silicon controlled rectifiers are so widely used that as if thyristor and **SCR** become synonymous. The constructional and operational point of view, it is a four layer (PNPN) three terminals (Anode, Cathode, Gate) semi controlled device. This device has two states i.e. on and OFF. We can turn it ON by sending a gate current signal between second P layer and cathode. But we cannot turn it OFF by control signal. That means we have control upon its turn ON, once it goes to conduction mode, we lose control over it. It can block both forward and reverse voltage but can conduct only in one direction.

Two Transistor Model of SCR

Basic operating principle of SCR, can be easily understood by the two transistor model of SCR**.** It is also a combination of P and N layers, shown in figure below.



This is a pnpn thyristor. If we bisect it through the dotted line then we will get two transistors i.e. one pnp transistor with J_1 and J_2 junctions and another is with J_2 and J_3 junctions as shown in figure below.



(a) Basic structure (b) Equivalent circuit

The collector current $\mathbf{I}_C$ of a transistor is related to the emitter current $\mathbf{I}_E$ and the leakage current of the collector base junction $\mathbf{I}_{CBO}$ as

$$I_C = \alpha I_E + I_{CBO}$$

The emitter current of transistor **Q**$_1$ is the anode current **I**$_A$ of the thyristor and collector current **I**$_{C1}$ is given by

$$I_{C1} = \alpha_1 I_A + I_{CBO1}$$

where α_1 and I_{CBO1} are the current gain and leakage current respectively for transistor **Q**$_1$.

Similarly, the collector current for transistor **Q**$_2$ is **I**$_{C2}$ where

$$I_{C2} = \alpha_2 I_K + I_{CBO2}$$

where α_2 and **I**$_{CBO2}$ are the current gain and leakage current respectively for transistor **Q**$_2$.

Combining the two collector currents **I**$_{C1}$ and **I**$_{C2}$ yields

$$I_A = I_{C1} + I_{C2}$$

$$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$$

When a gate current **I**$_G$ is applied to the thyristor

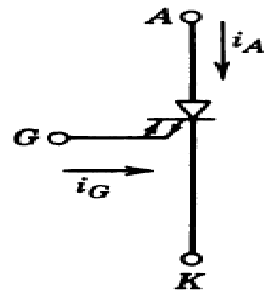
$$I_K = I_A + I_G$$

Solving for anode current I_A

$$I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

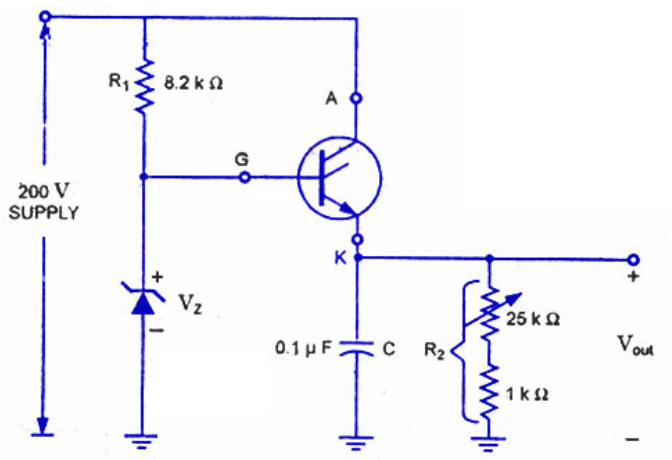
When
$\alpha_1 + \alpha_2 = 1$, the anode current suddenly attains a very high value approaching infinity.

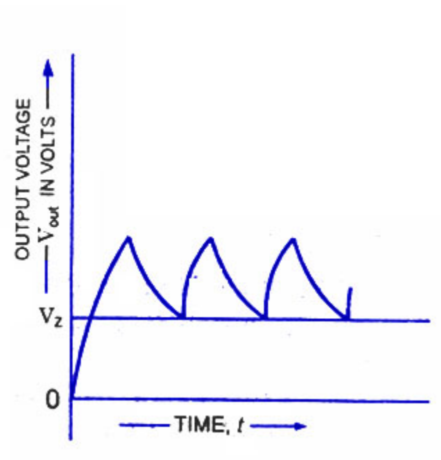
Answer: 3 The Gate turn off thyristor (GTO) is a four layer PNPN power semiconductor switching device that can be turned on by a short pulse of gate current and can be turned off by a reverse gate pulse. This reverse gate current amplitude is dependent on the anode current to be turned off. There is no need for an external commutation circuit to turn it off. So inverter circuits built by this device are compact and low-cost. The device is turned on by a positive gate current and it is turned off by a negative gate cathode voltage. The two-way arrow convention on the gate lead distinguishes the GTO from the conventional thyristor.



Applications of GTO:

They are used in motor drives, AC/DC power supplies with high power ratings. It is used as a sawtooth waveform generator.





When the supply is switched on, the GTO will turn on, resulting in the short-circuit equivalent from anode to cathode. As a consequence the capacitor C will begin to charge toward the supply voltage, as illustrated in figure. As the voltage across the capacitor C exceeds the Zener potential, there will be a reversal in gate-to-cathode voltage resulting in a reversal of gate current. Eventually, the negative gate current will be large enough to turn the GTO off. Now the capacitor C will begin to discharge through resistor R„, because turning off of GTO results in the open-circuit equivalent from anode to cathode. The discharge time will be determined by the circuit time constant $T = CR_2$. The proper choice of R_2 and C will result in the sawtooth waveform shown in figure. Once the output voltage V_{out} drops below Zener voltage V_Z the GTO will turn on and the process will repeat.

Disadvantages of GTO :

Compared to a conventional SCR, the device has the following disadvantages

- Magnitude of latching, holding currents is more. The latching current of the GTO is several times more as compared to conventional thyristors of the same rating.
- On state voltage drop and the associated loss is more.

- Due to multicathode structure of GTO, triggering gate current is higher than that required for normal SCR.
- Gate drive circuit losses are more. Its reverse voltage blocking capability is less than the forward voltage blocking capability.

<u>Advantages of GTO :</u>

The GTO's turn off occurs by removal of excess holes in the cathode base region by reversing the current through the gate terminal. Compare to BJT the GTO has the following advantages:

- High blocking voltage capabilities
- High over current capabilities
- exhibits low gate currents
- fast and efficient turn off
- better static and dynamic dv/dt capabilities

Answer 4: Protection of a device is an important aspect for its reliable and efficient operation. SCR is a very delicate semiconductor device. So we have to use it in its specified ratings to get desired output. SCR may face different types of threats during its operation due to over voltages, over currents etc. There are different types of thyristor protection schemes available for satisfactory operation of the device like

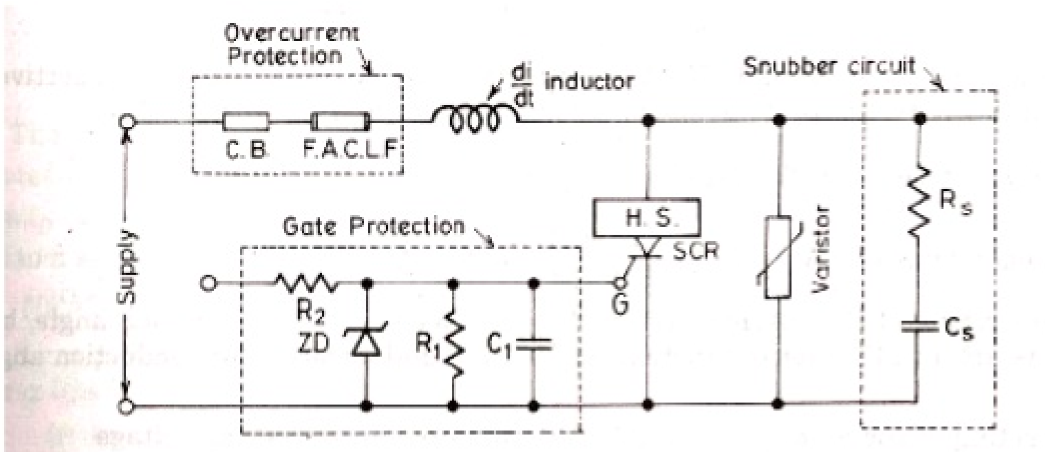
1. <u>Over voltage protection</u> - Maximum time thyristor failures happen due to over-voltage transients. The effect of over-voltages can be minimized by using non-linear resistors called voltage clamping devices like metal oxide like metal oxide varistor. At the time of normal operation it offers high impedance and acts as it is not present in the circuit. But when the voltage exceeds the rated voltage then it serves as a low impedance path to protect SCR.

2. <u>Over current protection</u> - Over current mainly occurs due to different types of faults in the circuit. Due to over current i^2R loss will increase and high generation of heat may take place that can exceed the permissible limit and burn the device. SCR can be protected from over current by using fuses.

3. <u>High dv/dt protection</u> - When a thyristor is in forward blocking state then only J_2 junction is reverse biased which acts as a capacitor having constant capacitance value C_j (junction capacitance). As we know that current through capacitor depends on voltage change with respect to time. Hence leakage current through the J_2 junction which is nothing but the leakage current through the device will increase with the increase in dv_a/dt i.e. rate of change of applied voltage across the thyristor. This current can turn-on the device even when the gate signal is absent. This is called dv/dt triggering and must be avoided which can be achieved by using Snubber circuit in parallel with the device. It consists of a capacitor connected in series with a resistor which is applied parallel with the thyristor.

4. <u>High di/dt protection</u> - When a thyristor is turned on by gate pulse then charge carriers spread through its junction rapidly. But if rate of rise of anode current, i.e. di/dt is greater than the spreading of charge carriers then localized heat generation will take place which is known as local hot spots. This may damage the thyristor. To avoid local hot spots we use an inductor in series with the device as it prevents high rate of change of current through it.

5. <u>Thermal protection</u> - With the increase in the temperature of the junction, insulation may get failed. So we have to take proper measures to limit the temperature rise. We can achieve this by mounting the thyristor on heat sink which is mainly made by high thermal conductivity metals like aluminium (Al), Copper (Cu) etc.



Complete SCR protection circuit