8.3 SCR (SILICON CONTROLLED RECTIFIER)

The basic structure and circuit symbol of SCR is shown in Fig. 8.3. It is a four layer three terminal device in which the end P-layer acts as anode, the end N-layer acts as cathode and P-layer nearer to cathode acts as gate. As leakage current in silicon is very small compared to germanium, SCRs are made of silicon and not germanium.

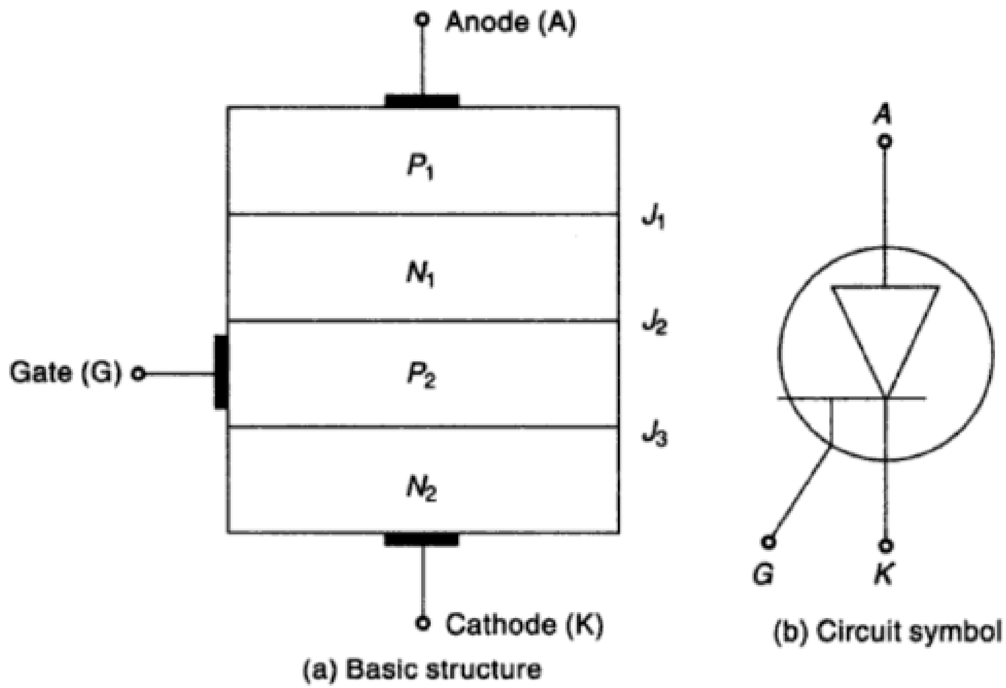


Fig. 8.3 Basic structure and circuit symbol of SCR

Characteristics of SCR The characteristics of SCR are shown in Fig. 8.4. SCR acts as a switch when it is forward biased. When the gate is kept open, i.e. gate current $I_G = 0$, operation of SCR is similar to PNPN diode. When $I_G < 0$, the amount of reverse bias applied to J_2 is increased. So the breakover voltage V_{BO} is increased. When $I_G > 0$, the amount of reverse bias applied to J_2 is decreased thereby decreasing the breakover voltage. With very large positive gate current breakover may occur at a very low voltage such that the characteristics of SCR is similar to that of

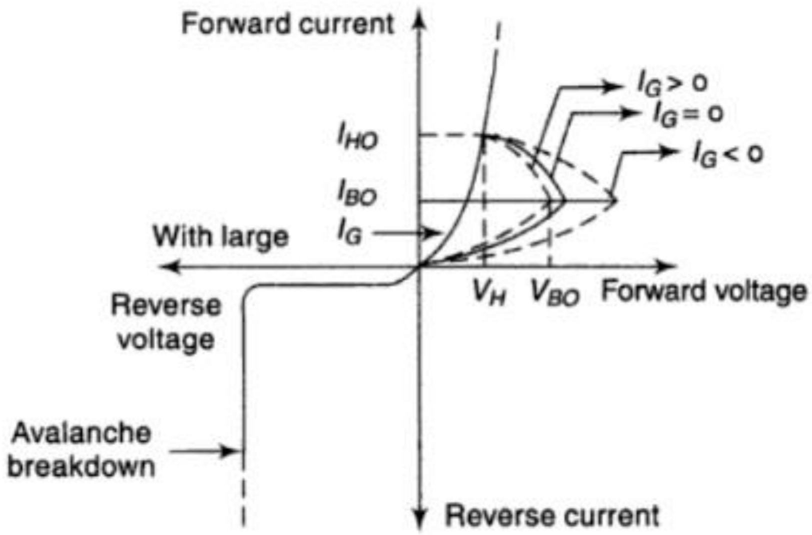


Fig. 8.4 Characteristics of SCR

ordinary PN diode. As the voltage at which SCR is switched 'ON' can be controlled by varying the gate current I_G, it is commonly called as controlled switch. Once SCR is turned ON, the gate loses control, i.e. the gate cannot be used to switch the device OFF. One way to turn the device OFF is by lowering the anode current below the holding current I_H by reducing the supply voltage below holding voltage V_H, keeping the gate open.

SCR is used in relay control, motor control, phase control, heater control, battery chargers, inverters, regulated power supplies and as static switches.

Two transistor version of SCR The operation of SCR can be explained in a very simple way by considering it in terms of two transistors, called as the two transistor version of SCR. As shown in Fig. 8.5, an SCR can be split into two parts and displaced mechanically from one another but connected electrically. Thus the device may be considered to be constituted by two transistors T_1 (PNP) and T_2 (NPN) connected back to back.

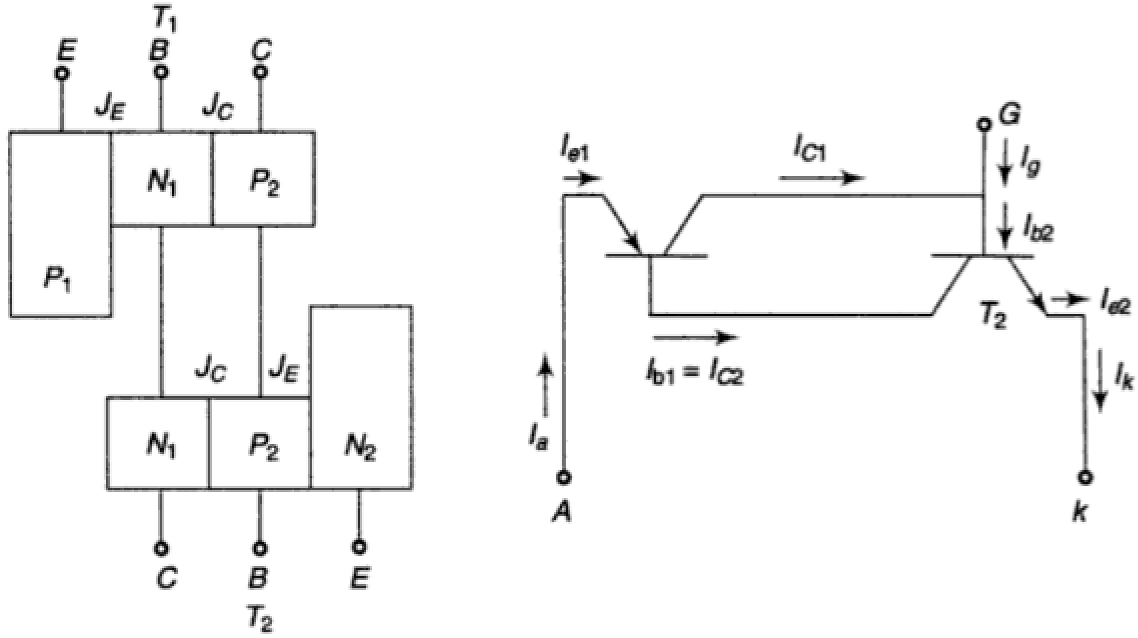


Fig. 8.5 Two transistor version of SCR

Assuming the leakage current of T_1 to be negligibly small, we obtain

$$I_{b1} = I_A - I_{e1} = I_A - \alpha_1 I_A = (1 - \alpha_1)\, I_A \tag{8.1}$$

Also, from the Fig. 8.5, it is clear that

$$I_{b1} = I_{C2} \tag{8.2}$$

and

$$I_{C2} = \alpha_2 I_K \tag{8.3}$$

Substituting the values given in Eqs (8.2) and (8.3) in Eq. (8.1), we get

$$(1 - \alpha_1)\, I_A = \alpha_2 I_K \tag{8.4}$$

We know that

$$I_K = I_A + I_g \tag{8.5}$$

Substituting Eq. (8.5) in Eq. (8.4), we obtain

$$(1 - \alpha_1)\, I_A = \alpha_2 (I_A + I_g)$$

i.e.

$$(1 - \alpha_1 - \alpha_2) I_A = \alpha_2 I_g$$

Substituting Eq. (8.5) in Eq. (8.4), we obtain

$$(1 - \alpha_1) I_A = \alpha_2 (I_A + I_g)$$

i.e. $$(1 - \alpha_1 - \alpha_2) I_A = \alpha_2 I_g$$

i.e. $$I_A = \left[\frac{\alpha_2 I_g}{1-(\alpha_1 + \alpha_2)}\right] \tag{8.6}$$

Equation (8.6) indicates that if $(\alpha_1 + \alpha_2) = 1$, then $I_A = \infty$, i.e. the anode current I_A suddenly reaches a very high value approaching infinity. Therefore, the device suddenly triggers into ON state from the original OFF state. This characteristic of the device is known as its *regenerative action.*

The value of $(\alpha_1 + \alpha_2)$ can be made almost equal to unity by giving a proper value of positive current I_g for a short duration. This signal I_g applied at the gate which is the base of T_2 will cause a flow of collector current I_{C2} by transferring T_2 to its ON state. As $I_{C2} = I_{b1}$, the transistor T_1 will also be switched ON. Now, the action is regenerative since each of the transistors would supply base current to the other. At this point even if the gate signal is removed, the device keeps on conducting, till the current level is maintained to a minimum value of holding current.

8.4 THYRISTOR RATINGS

Latching current (I_L) Latching current is the minimum current required to latch or trigger the device from its OFF-state to its ON-state.

Holding current (I_H) Holding current is the minimum value of current to hold the device in ON-state. For turning the device OFF, the anode current should be lowered below I_H by increasing the external circuit resistance.

Gate current (I_g) Gate current is the current applied to the gate of the device for control purposes. The minimum gate current is the minimum value of current required at the gate for triggering the device. The maximum gate current is the maximum value of current applied to the device without damaging the gate. More the gate current, earlier is the triggering of the device and vice-versa.

Voltage safety factor (V_f) Voltage safety factor V_f is a ratio which is related to the PIV, the RMS value of the normal operating voltage as,

$$V_f = \frac{\text{peak inverse voltage (PIV)}}{\sqrt{2} \times \text{RMS value of the operating voltage}}$$

The value of V_f normally lies between 2 and 2.7. For a safe operation, the normal working voltage of the device is much below its PIV.

8.5 RECTIFIER CIRCUITS USING SCR

SCRs are much superior in performance than ordinary diode rectifiers. They find their main applications as rectifiers. Some of the rectifier circuits have been explained in the following sections.

8.5.1 SCR Half Wave Rectifier

Though the SCR is basically a switch, it can be used in linear applications like rectification. Fig. 8.6 shows the circuit of an SCR half wave rectifier.

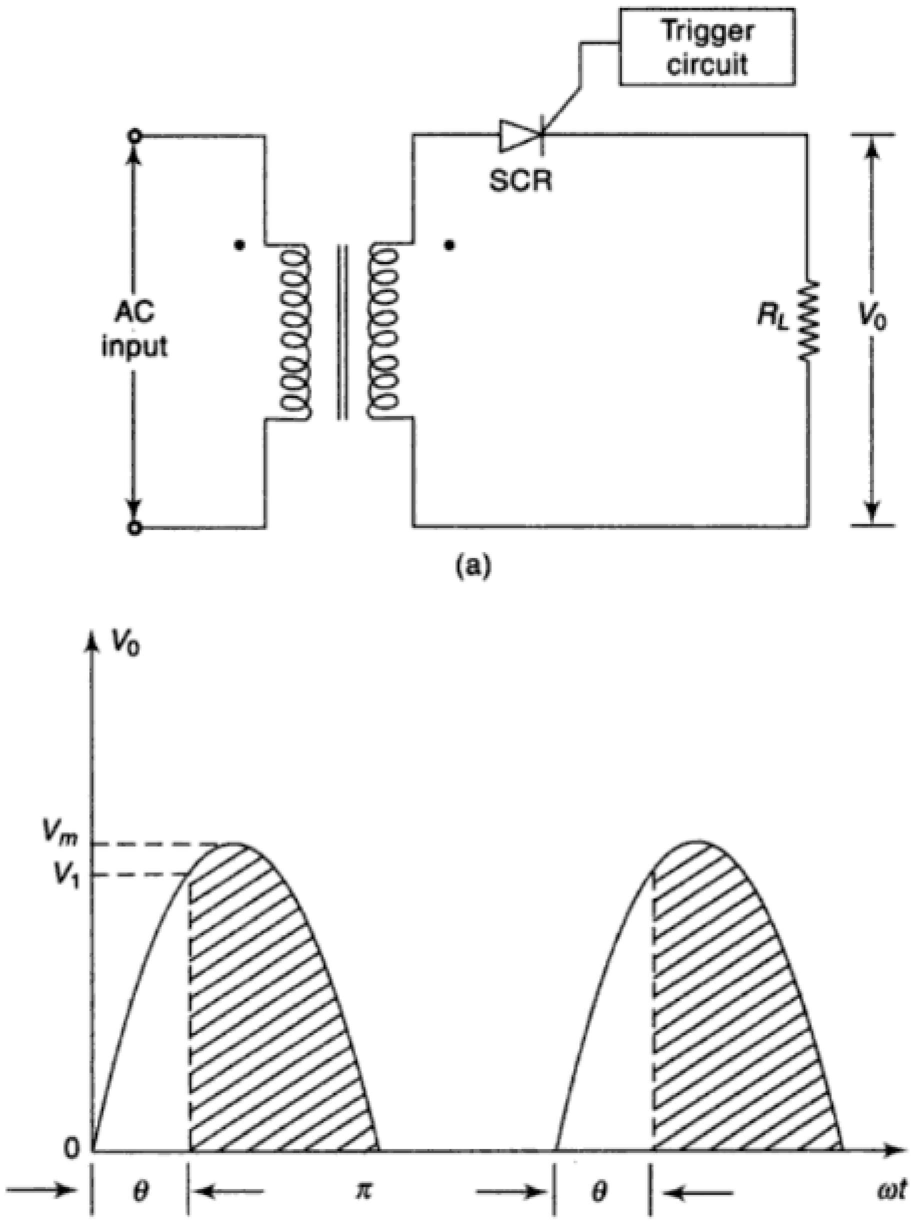


Fig. 8.6 SCR half wave rectifier

During the negative halfcycle, the SCR does not conduct irrespective of the gate current, as the anode is negative with respect to cathode and also PIV is less than the reverse breakdown voltage.

During the positive half cycle of a.c. voltage appearing across secondary, the SCR will conduct provided proper gate current is made to flow. The greater the gate current, the lesser the supply voltage at which the SCR is triggered ON. Referring to Fig. 8.6(b), the gate current is adjusted to such a value that SCR is turned ON at a positive voltage V_1 of a.c. secondary voltage which is less than the peak voltage V_m. Beyond this, the SCR will be conducting till the applied voltage becomes zero. The angle at which the SCR starts conducting during the positive half cycle is called firing angle θ. Therefore, the conduction angle is $(180° - \theta)$.

The SCR will block not only the negative part of the applied sinusoidal voltage, but will also block the part of the positive waveform up to a point SCR is triggered ON. If the angle θ is zero, this will be an ordinary half wave rectification. Therefore by proper adjustment of gate current, the SCR can be made to conduct full or part of a positive half cycle, thereby controlling the power fed to the load.

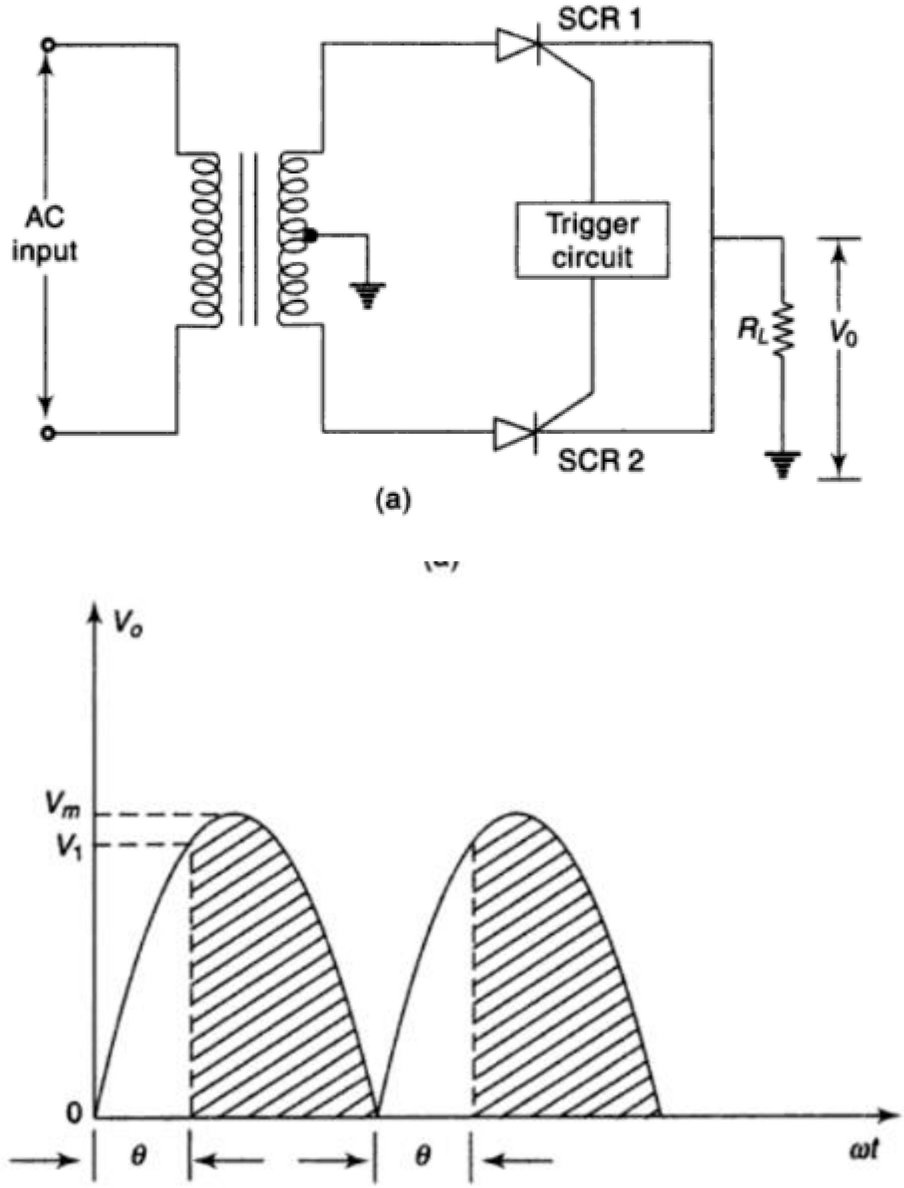
8.5.2 SCR Full Wave Rectifier

The SCR full wave rectifier is shown in Fig. 8.7. It is exactly similar to an ordinary full wave rectifier except that the two diodes have been replaced by two SCRs. The angle of conduction can be changed by adjusting the gate currents.

During the positive half cycle of the input signal, anode of SCR1 becomes positive and at the same time the anode of SCR2 becomes negative. When the input voltage reaches V_1 as shown in Fig. 8.7(b), SCR1 starts conducting and therefore only the shaded portion of positive half cycle will pass through the load.

During the negative half cycle of the input, the anode of SCR1 becomes negative and the anode of SCR2 becomes positive. Hence, SCR1 does not conduct and SCR2 conducts when the input voltage becomes V_1.

The main advantage of this circuit over ordinary full wave rectifier circuit is that any voltage can be made available at the output by simply changing the firing angle of the SCRs.



(b)

Fig. 8.7 SCR full wave rectifier

8.6 LASCR (LIGHT ACTIVATED SCR)

The LASCR shown in Fig. 8.9 is triggered by irradiating with light. The arrows represent incoming light that passes through a window and falls on the depletion layer closer to the middle junction J_2 of SCR. The incident light generates electron-hole pairs in the device thus increasing the number of charge carriers. This leads to the instantaneous flow of current within the device and the device turns ON. For light triggering to occur, the device must have high value of rate of change of voltage with time, dV/d*t*.

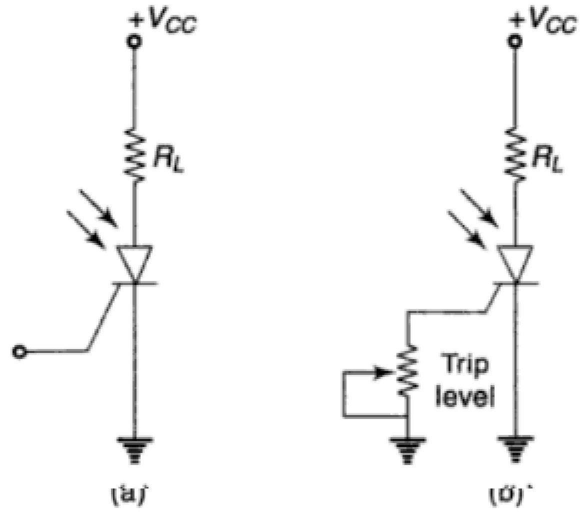
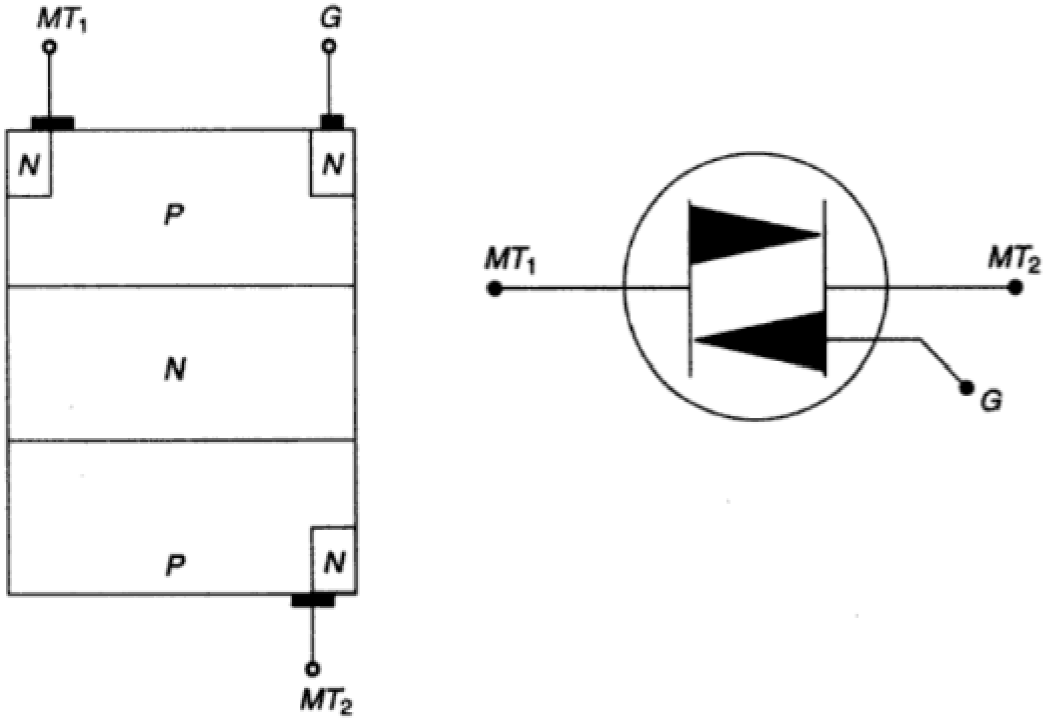


Fig. 8.9 Light activated SCR

8.7 TRIAC (TRIODE A.C. SWITCH)

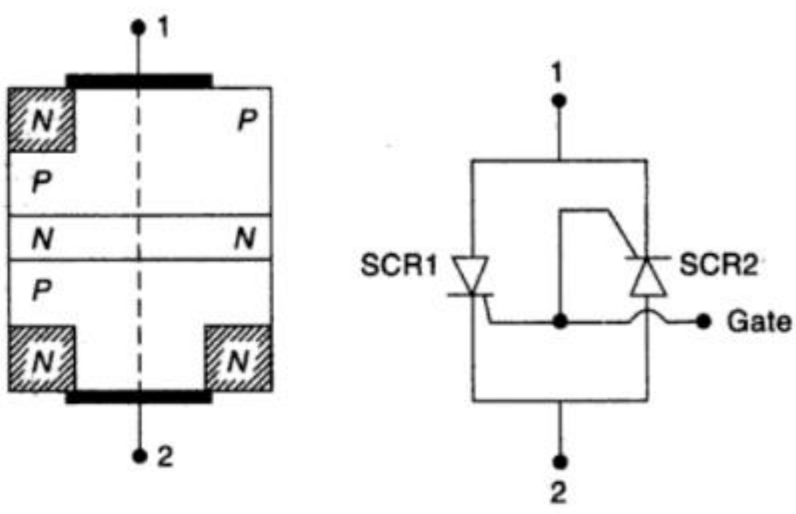
Triac is a three terminal semiconductor switching device which can control alternating current in a load. Its three terminals are MT_1, MT_2 and the gate (*G*). The basic structure and circuit symbol of a Triac are shown in Fig. 8.10. Triac is equivalent to two SCRs connected in parallel but in the reverse direction as shown in Fig. 8.11. So, a Triac will act as a switch for both directions. The characteristics of a Triac are shown in Fig. 8.12.

Like an SCR, a Triac also starts conducting only when the breakover voltage is reached. Earlier to that the leakage current which is very small in magnitude flows



(a) (b)

Fig. 8.10 Triac: (a) Basic structure and (b) Circuit symbol



(a) (b)

Fig. 8.11 Two SCR version of Triac: (a) Basic structure and (b) Equivalent circuit through the device and therefore remains in the OFF state. The device, when starts conducting, allows very heavy amount of current to flow through it. The high inrush of current must be limited using external resistance, or it may otherwise damage the device.

During the positive half cycle, MT_1 is positive with respect to MT_2, whereas MT_2 is positive with respect to MT_1 during negative half cycle. A Triac is a bidirectional device and can be triggered either by a positive or by a negative gate signal. By applying proper signal at the gate, the breakover voltage, i.e. firing angle of the device can be changed; thus phase control process can be achieved.

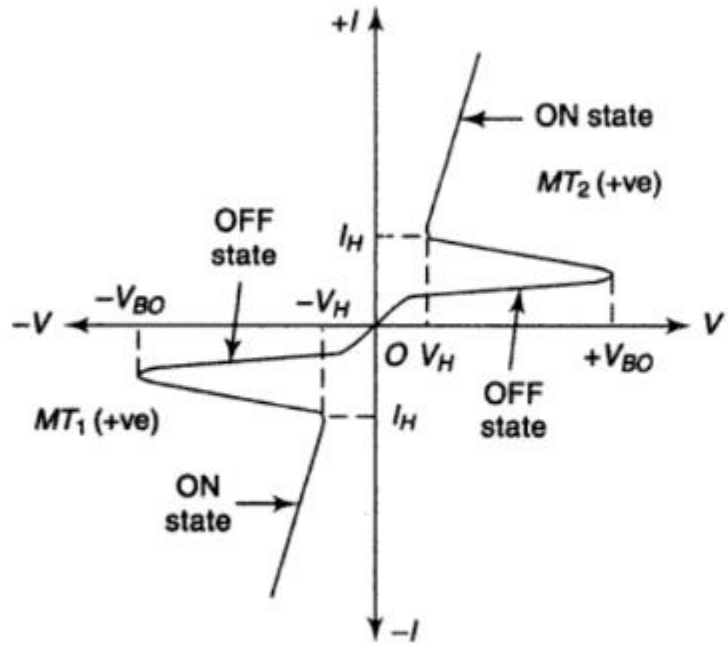


Fig. 8.12 Characteristics of Triac

Triac is used for illumination control, temperature control, liquid level control, motor speed control and as static switch to turn a.c. power ON and OFF. Nowadays, the diac–triac pairs are increasingly being replaced by a single component unit known as quadrac. Its main limitation in comparison to SCR is its low power handling capacity.

8.8 DIAC (DIODE A.C. SWITCH)

The construction and symbol of diac are shown in Fig. 8.13. Diac is a three layer, two terminal semiconductor device. MT_1 and MT_2 are the two main terminals which are interchangeable. It acts as a bidirectional Avalanche diode. It does not have any control terminal. It has two junctions J_1 and J_2. Though the Diac resembles a bipolar transistor, the central layer is free from any connection with the terminals.

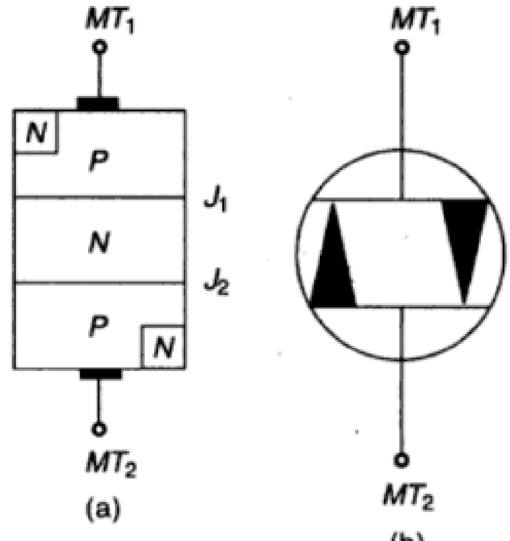


Fig. 8.13 Diac: (a) Basic structure and (b) Circuit symbol.

From the characteristic of a Diac shown in Fig. 8.14, it acts as a switch in both directions. As the doping level at the two ends of the device is the same, the Diac has identical characteristics for both positive and negative half of an a.c. cycle. During the positive half cycle, MT_1 is positive with respect to MT_2 whereas MT_2 is positive with respect to MT_1 in the negative half cycle. At voltage less than the breakover voltage, a very small amount of current called the leakage current flows through the device and the device remains in OFF state. When the voltage level reaches the breakover voltage, the device starts conducting and it exhibits negative resistance characteristics, i.e. the current flowing in the device starts increasing and the voltage across it starts decreasing.

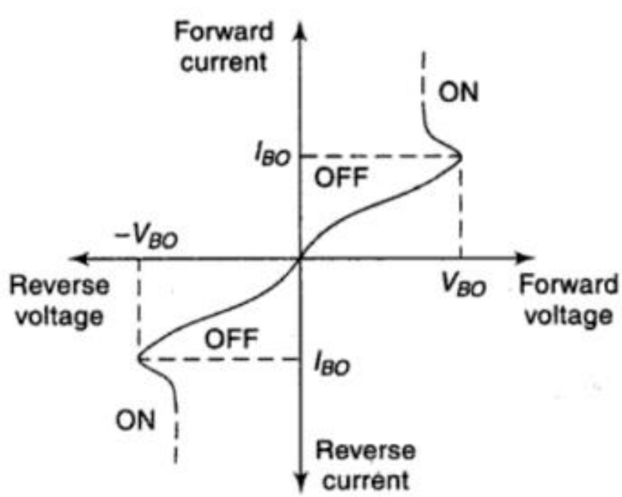


Fig. 8.14 Characteristic of Diac

The Diac is not a control device. It is used as triggering device in Triac phase control circuits used for light dimming, motor speed control and heater control.