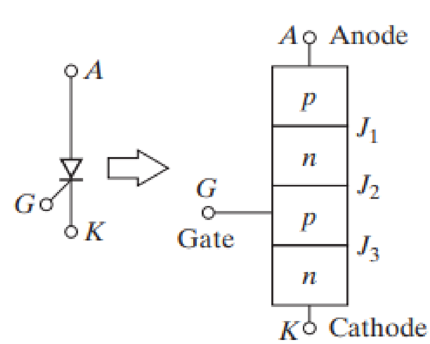
1. Thyristors and Thyristorized Converters

Thyristors are a family of power semiconductor devices. Thyristors are used extensively in power electronic circuits. They are operated as bistable switches, operating from non-conducting state to conducting state. Thyristors can be assumed as ideal switches for many applications.

Conventional thyristors are designed without gate-controlled turn-off capability, in which case the thyristor can recover from its conducting state to a non-conducting state only when the current is brought to zero by other means. Gate turn-off thyristors (GTOs) are designed to have both controlled turn-on and turn-off capability.

2. Thyristor Characteristics

A thyristor is a four-layer semiconductor device of PNPN structure with three pnjunctions. It has three terminals: anode, cathode, and gate. Figure shows the thyristor symbol and the sectional view of three pn-junctions. Thyristors are manufactured by diffusion.



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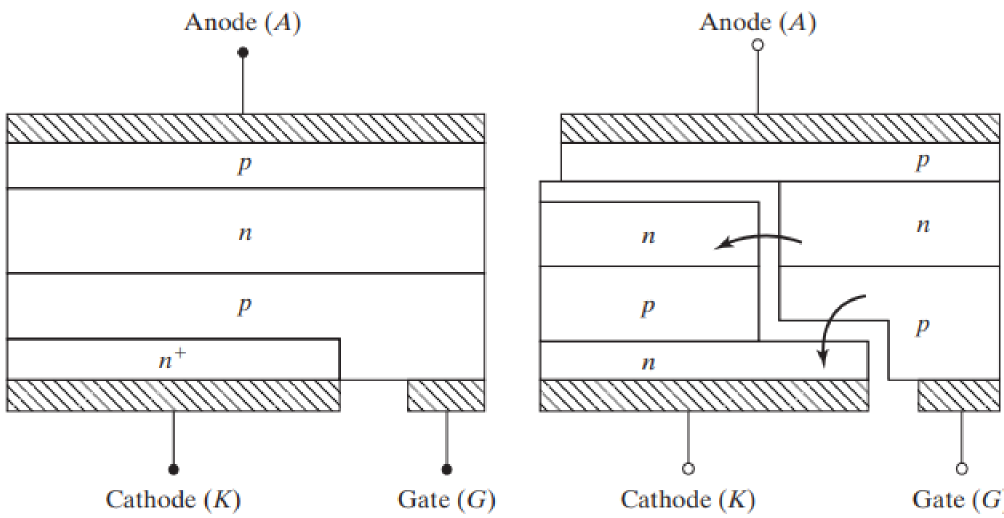
The cross section of a thyristor is shown in Figure a, which can be split into two sections of NPN and PNP as shown in Figure b.



(a) Cross section of *PNPN* structure (b) Split sections of *NPN* and *PNP*

When the anode voltage is made positive with respect to the cathode, the junctions J1 and J3 are forward biased. The junction J2 is reverse biased, and only a small leakage current flows from anode to cathode. The thyristor is then said to be in the forward blocking, or off-state, condition and the leakage current is known as off-state current ID. If the anode-to-cathode voltage VAK is increased to a sufficiently large value, the reverse-biased junction J2 breaks. This is known as avalanche breakdown and the corresponding voltage is called forward breakdown voltage VBO.

Because the other junctions J1 and J3 are already forward biased, there is free movement of carriers across all three junctions, resulting in a large forward anode current. The device is then in a conducting state, or on-state.

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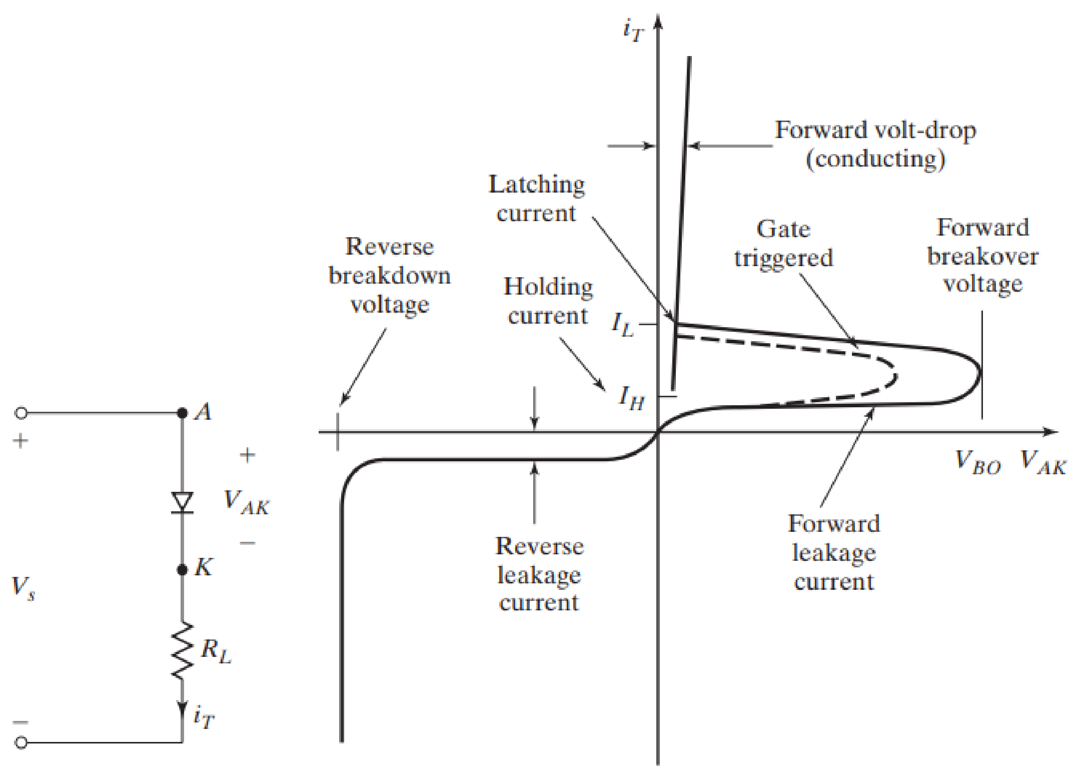
In the on-state, the anode current is limited by an external impedance or a resistance, RL, as shown in Figure a. The anode current must be more than a value known as latching current IL to maintain the required amount of carrier flow across the junction; otherwise, the device reverts to the blocking condition as the anode-to-cathode voltage is reduced. Latching current IL is the minimum anode current required to maintain the thyristor in the on-state immediately after a thyristor has been turned on and the gate signal has been removed. A typical v-i characteristic of a thyristor is shown in Figure b.



(a) Circuit (b) v–i Characteristics

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Once a thyristor conducts, it behaves like a conducting diode and there is no control over the device. The device continues to conduct because there is no depletion layer on the junction J2 due to free movements of carriers. However, if the forward anode current is reduced below a level known as the holding current IH, a depletion region develops around junction J2 due to the reduced number of carriers and the thyristor is in the blocking state. The holding current is on the order of milliamperes and is less than the latching current IL. That is, IL > IH. Holding current IH is the minimum anode current to maintain the thyristor in the on-state. The holding current is less than the latching current.

When the cathode voltage is positive with respect to the anode, the junction J2 is forward biased but junctions J1 and J3 are reverse biased. This is like two series-connected diodes with reverse voltage across them. The thyristor is in the reverse blocking state and a reverse leakage current, known as reverse current IR, flows through the device

3. Thyristor Turn-On

A thyristor is turned on by increasing the anode current. This can be accomplished in one of the following ways.

Thermals: If the temperature of a thyristor is high, there is an increase in the number of electron–hole pairs, which increases the leakage currents. This increase in currents causes $\alpha 1$ and $\alpha 2$ to increase. Due to the regenerative action, $\alpha 1 + \alpha 2$ may tend to unity and the thyristor may be turned on. This type of turn-on may cause thermal runaway and is normally avoided.

Light: If light is allowed to strike the junctions of a thyristor, the electron–hole pairs increase; and the thyristor may be turned on. The light-activated thyristors are turned on by allowing light to strike the silicon wafers.

High voltage: If the forward anode-to-cathode voltage is greater than the forward breakdown voltage VBO, sufficient leakage current flows to initiate regenerative turn-on. This type of turn-on may be destructive and should be avoided.

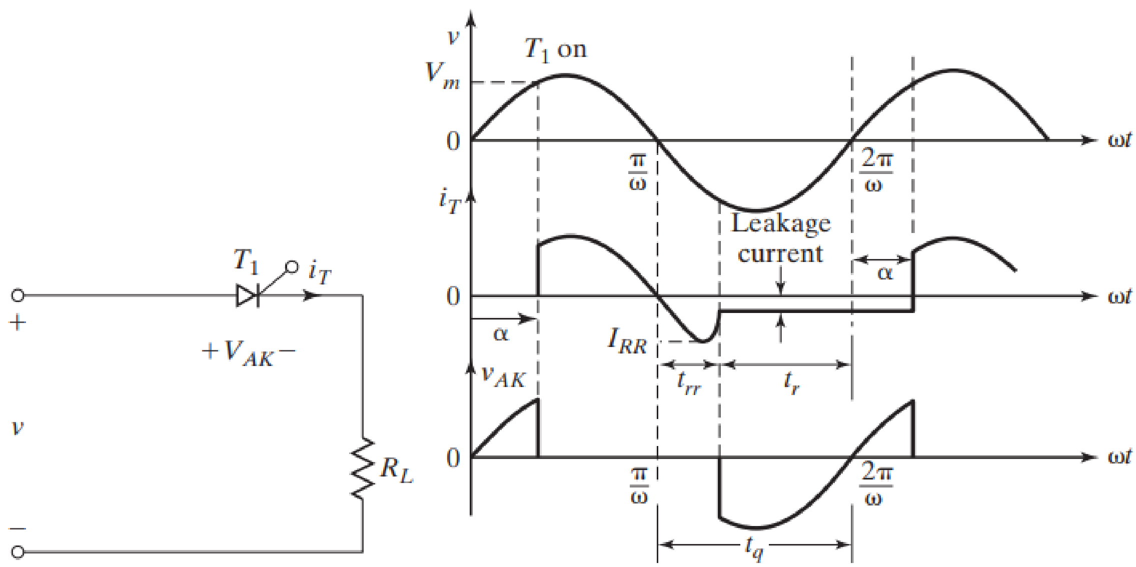
Gate current: If a thyristor is forward biased, the injection of gate current by applying positive gate voltage between the gate and cathode terminals turns on the thyristor. As the gate current is increased, the forward blocking voltage is decreased.

4. Thyristor Turn-Off

A thyristor that is in the on-state can be turned off by reducing the forward current to a level below the holding current IH.

There are various techniques for turning off a thyristor. In all the commutation techniques, the anode current is maintained below the holding current for a sufficiently long time, so that all the excess carriers in the four layers are swept out or recombined.

In Figure, a reverse voltage appears across the thyristor immediately after the forward current goes through the zero value. This reverse voltage accelerates the turnoff process, by sweeping out the excess carriers from pn-junctions J1 and J3



(a) Line-commutated thyristor circuit

The inner pn-junction J2 requires a time known as recombination time trc to recombine the excess carriers. A negative reverse voltage would reduce this recombination time. trc is dependent on the magnitude of the reverse voltage. The turnoff characteristics are shown in Figures for a line-commutated circuit and forced-commutated circuit, respectively.

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