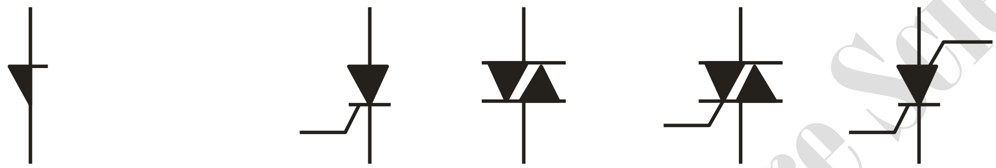
Chapter 9: Thyristors

Thyristors

Thyristors are a class of semiconductor devices characterized by 4-layers of alternating p- and n-material. Four-layer devices act as either open or closed switches; for this reason, they are most frequently used in control applications such as lamp dimmers, motor speed controls, ignition systems, charging circuits, etc. Thyristors include Shockley diode, silicon-controlled rectifier (SCR), diac and triac. They stay on once they are triggered, and will go off only if current is too low or when triggered off. Some thyristors and their symbols are in figure 1.



(a) 4-layer diode (b) SCR (c) Diac (d) Triac (e) SCS

Figure 1

Shockley Diode

The 4-layer diode (or ***Shockley diode***) is a type of thyristor that acts something like an ordinary diode but conducts in the forward direction only after a certain anode to cathode voltage called the forward-breakover voltage is reached. The basic construction of a 4-layer diode and its schematic symbol are shown in Figure 2.

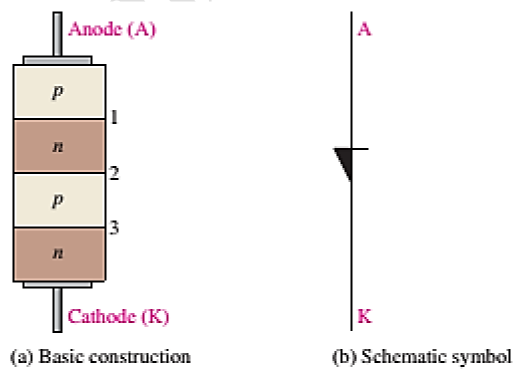


Figure 2: The 4-layer diode.

The 4-layer diode has two leads, labeled the anode (A) and the cathode (K). The symbol reminds you that it acts like a diode. It does not conduct when it is reverse-biased.

The concept of 4-layer devices is usually shown as an equivalent circuit of a pnp and an npn transistor. Ideally, these devices would not conduct, but when forward biased, if there is sufficient leakage current in the upper pnp device, it can act as base current to the lower npn device causing it to conduct and bringing both transistors into saturation

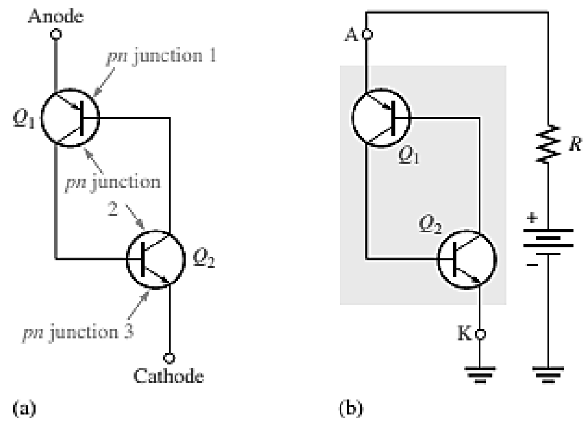


Figure 3: A 4-layer diode equivalent circuit.

Shockley Diode Characteristic Curve

The characteristic curve for a 4-layer diode shows the forward blocking region. When the anode-to-cathode voltage exceeds V_{BR}, conduction occurs. The **switching current** at this point is I_S. Once conduction begins, anode current (I_A) increases rapidly and will continue until I_A is reduced to less than the **holding current** (I_H). This is the only way to stop conduction.

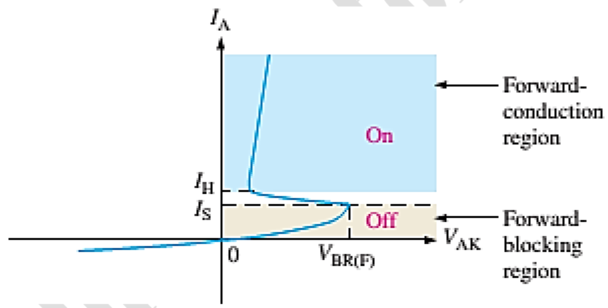


Figure 4: A 4-layer diode characteristic curve.

The Silicon-Controlled Rectifier

An SCR (silicon-controlled rectifier) is a 4-layer pnpn device similar to the 4-layer diode except with three terminals: anode, cathode, and gate. The basic structure and schematic symbol of SCR are shown in Figure 5.

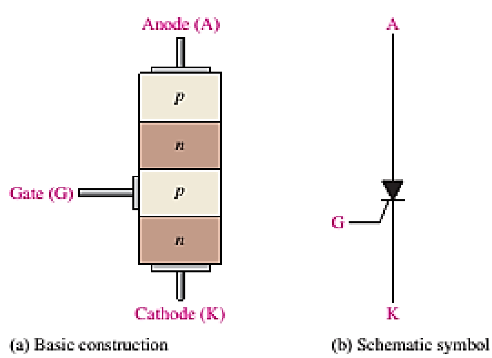


Figure 5: The silicon-controlled rectifier (SCR).

The SCR has two possible states of operation. In the off state, it has a very high resistance. In the on state, the SCR acts ideally as a short from the anode to the cathode; actually, there is a small on (forward) resistance.

The SCR operation can best be understood by thinking of its internal pnpn structure as a two-transistor arrangement, as shown in Figure 6. This structure is like that of the 4-layer diode except for the gate connection. The upper pnp layers act as a transistor, Q_1, and the lower npn layers act as a transistor, Q_2. Again, notice that the two middle layers are shared.

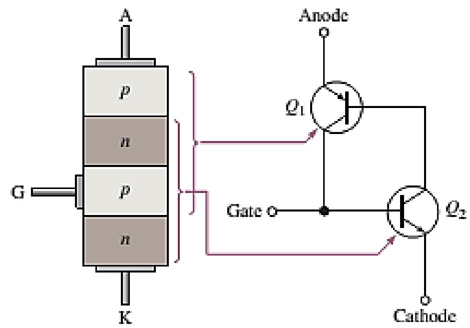


Figure 6: SCR equivalent circuit.

Turning the SCR On

The **SCR** had its roots in the 4-layer diode. By adding a gate connection, the SCR could be triggered into conduction. This improvement made a much more useful device than the 4-layer diode. The SCR can be turned on by exceeding the forward breakover voltage ($V_{BR(F)}$) or by gate current, as shown in Figure 7.. Notice that the gate current controls the amount of forward breakover voltage required for turning it on. $V_{BR(F)}$ decreases as I_G is increased above 0 V.

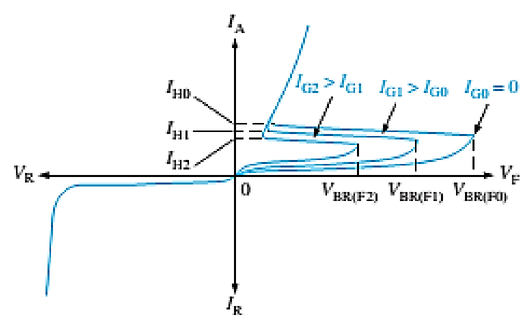


Figure 7: SCR characteristic curves.

Turning the SCR Off

Like the 4-layer diode, the SCR will conduct as long as forward current exceeds I_H. There are two ways to drop the SCR out of conduction: 1) **anode current interruption** and 2) **forced commutation**. Anode current can be interrupted by breaking the anode current path (shown here), providing a path around the SCR, or dropping the anode voltage to the point that $I_A < I_H$.

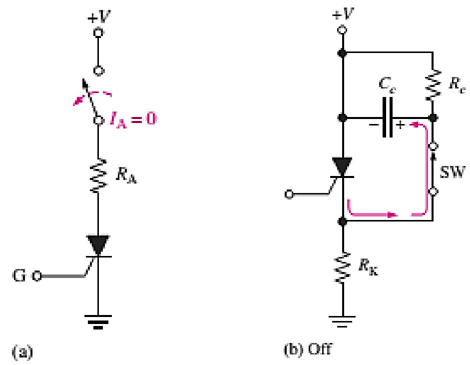


Figure 8: SCR turn-off by: (a) anode current interruption, and (b) forced commutation.

Force commutation uses an external circuit to momentarily force current in the opposite direction to forward conduction. SCRs are commonly used in ac circuits, which forces the SCR out of conduction when the ac reverses.

SCR Characteristics and Ratings

Several of the most important SCR characteristics and ratings are defined as follows.

- **Forward-breakover voltage**, $V_{BR(F)}$: voltage at which the SCR enters the forward conduction region.
- **Holding current, I_H:** This is the value of anode current below which the SCR switches from the forward-conduction region to the forward-blocking region.
- **Gate trigger current, I_{GT}:** This is the value of gate current necessary to switch the SCR from the forward-blocking region to the forward-conduction region under specified conditions.
- **Average forward current**, $I_{F(avg)}$: This is the maximum continuous anode current (dc) that the device can withstand in the conduction state under specified conditions.
- **Reverse-breakdown voltage**, $V_{BR(R)}$: maximum reverse voltage before SCR breaks into avalanche.

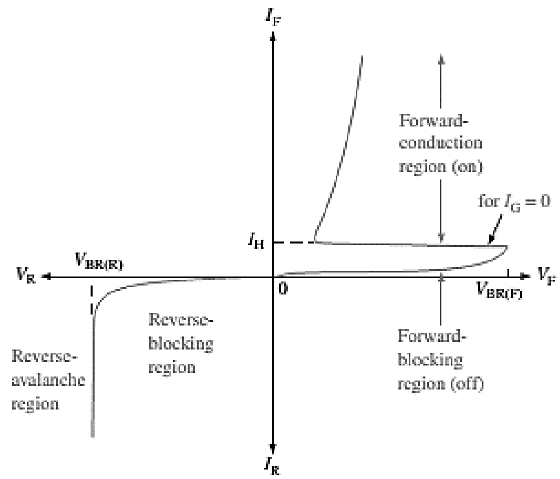


Figure 9: SCR characteristic curves For $I_G = 0$.