Silicon Controlled Rectifier (SCR)

Lecture – 2

TDC PART – I
Paper - II (Group - B)
Chapter - 5

by:

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Structure of Silicon Controlled Rectifier (SCR)

- A Silicon Controlled Rectifier (SCR) is a four layer avalanche breakdown device. SCR is solid-state semiconductor devices whose working depends on the phenomenon of **avalanche breakdown.** SCR sometimes referred to by the generic name of **thyristor** which is a high power solid-state semiconductor switch whose bistable action depends on P-N-P-N **regenerative feedback.** SCR is a four-layer (P-N-P-N), three junctions and three terminal devices. It can be switched ON or OFF at an extremely fast rate. They are also referred to as **Latching Devices**. A latch is a kind of switch which initially once closed, remains closed until someone opens it.

- A Silicon Controlled Rectifier or Semiconductor Controlled Rectifier (SCR) is a four-layer (P-N-P-N), three terminal solid state semiconductor current-controlling devices. As the terminology indicates, the SCR is a controlled rectifier constructed of a silicon semiconductor material with a third terminal for control purposes. Silicon was chosen because of its high temperature and power capabilities. SCR is a unidirectional device that allows the current in one direction and opposes in another direction.

- Basically, it is a rectifier with a control element. The basic operation of the SCR is different from that of an ordinary two-layer semiconductor diode. **Like** the two terminal diode rectifier, thyristor or SCR is a unidirectional device that allows the current in one direction and opposes in another direction. **Like** the diode, SCR is a unidirectional device that blocks the current flow from cathode to anode, **which means** it will only conduct current in one direction only. But **Unlike** the two terminal uncontrolled rectifier diode, as they conduct current during forward bias condition from Anode (A) to Cathode (K) without any control, a thyristor (SCR) also blocks the current flow from **Anode (A) to Cathode (K)** until it is triggered into conduction by a proper Gate (G) signal between Gate (G) and Cathode (K) terminals. In the conduction state the dynamic resistance of the SCR is typically 0.01 to 0.1 ohm and reverse resistance is typically 100 kilo ohm or more.

- It is a one way (unidirectional) device and conduction takes place from Anode to Cathode under proper forward biasing with Positive Gate trigger pulse. In fact, it consists of two P-N diodes connected back-to-back with a Gate connection. Within the family of P-N-P-N devices, the silicon controlled rectifier (SCR) is unquestionably of the greatest interest today. Silicon Controlled Rectifier (SCR) is one of the oldest members of thyristor family. It is the most widely used as a High Power Switching Device for power control in DC and AC applications today. Hence SCRs are also called Thyristor.

- It is widely used as a Switching Device in power control applications. It is a three-terminal device, consisting of three PN junctions which can be switched "ON" and "OFF" at an extremely fast rate. It can control loads by switching current OFF and ON up to many thousand times a second. It can switch ON for variable length of time duration during half cycles, thereby delivering selected amount of power to the load. Thus, it possesses the advantages of a RHEOSTATE as well as a SWITCH with none of their disadvantages. A schematic diagram and circuit symbol of an SCR are shown in **Fig (7) & (8)** respectively. **Fig (8)** shows the Silicon Controlled Rectifier (SCR) or thyristor circuit symbol used for circuit diagrams to emphasis its rectifier characteristics while also showing the control gate. As a result the thyristor circuit symbol shows the traditional diode symbol with a control gate entering near the junction.

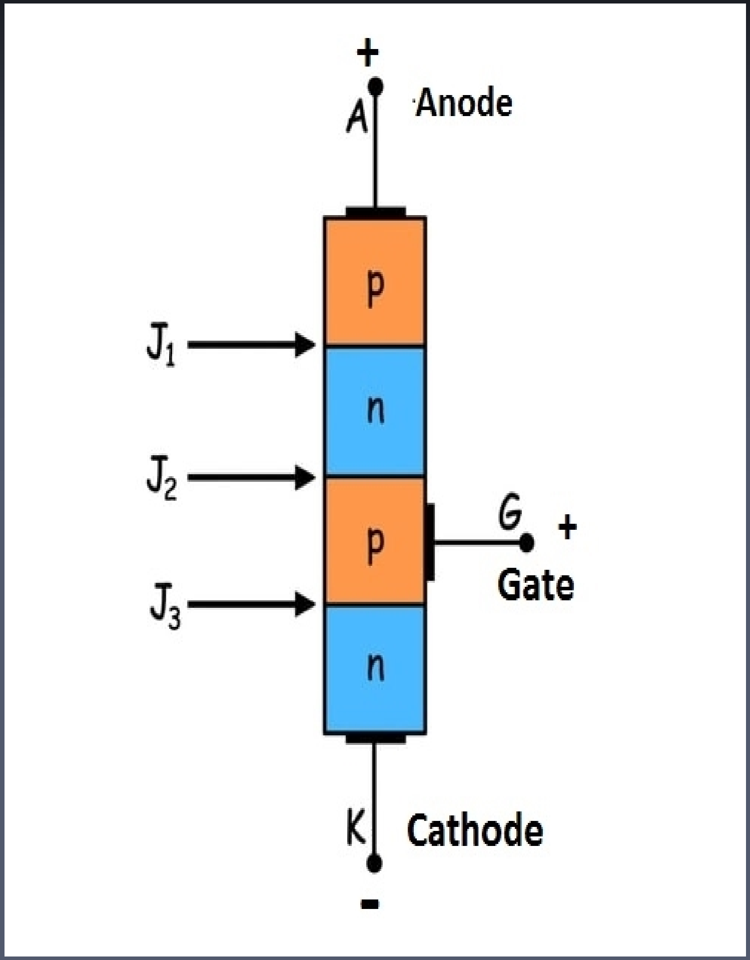


Fig (1)

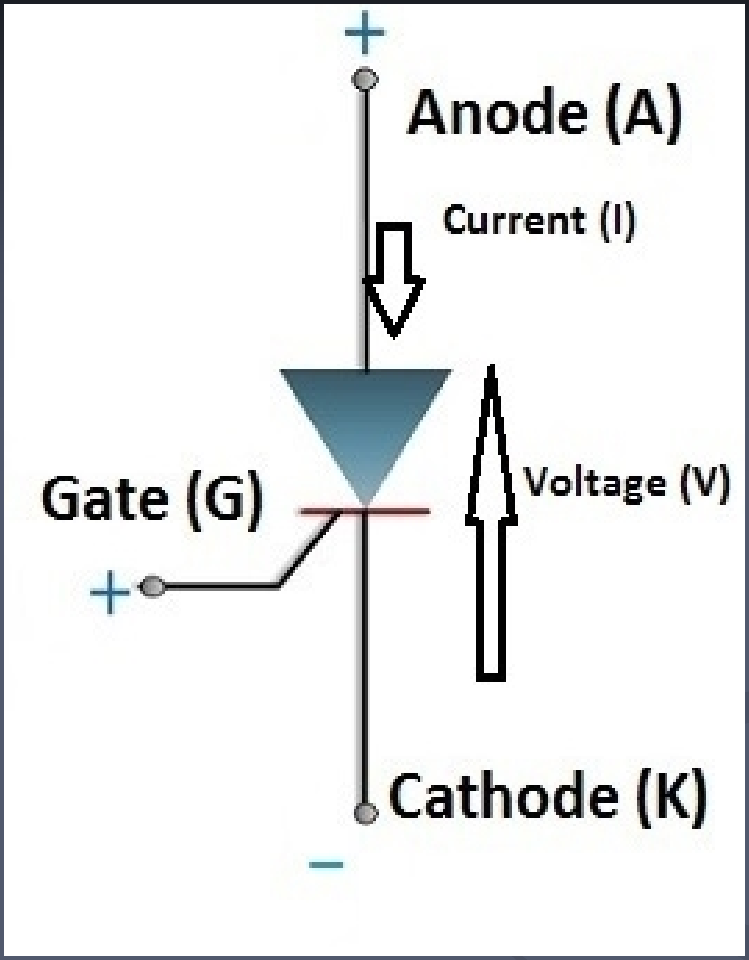


Fig (2)

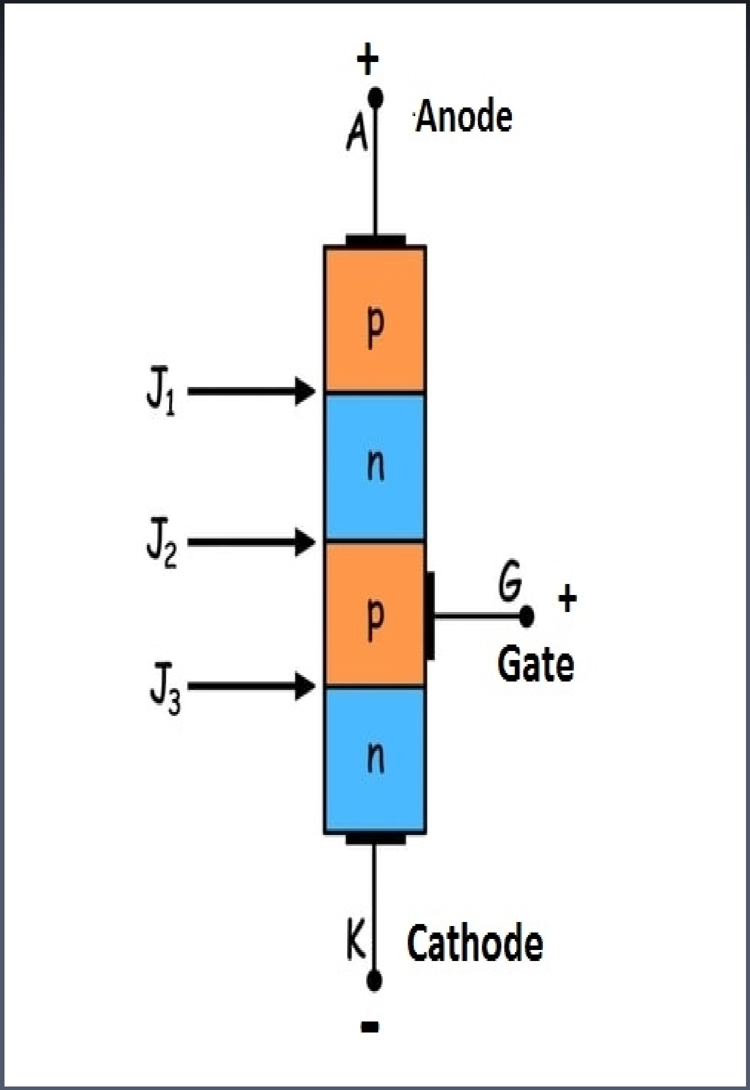
- **Fig (7)** Shown Schematic diagram of a Typical SCR (thyristor).
- **Fig (8)** Shown Circuit Symbol of a Typical SCR (thyristor).

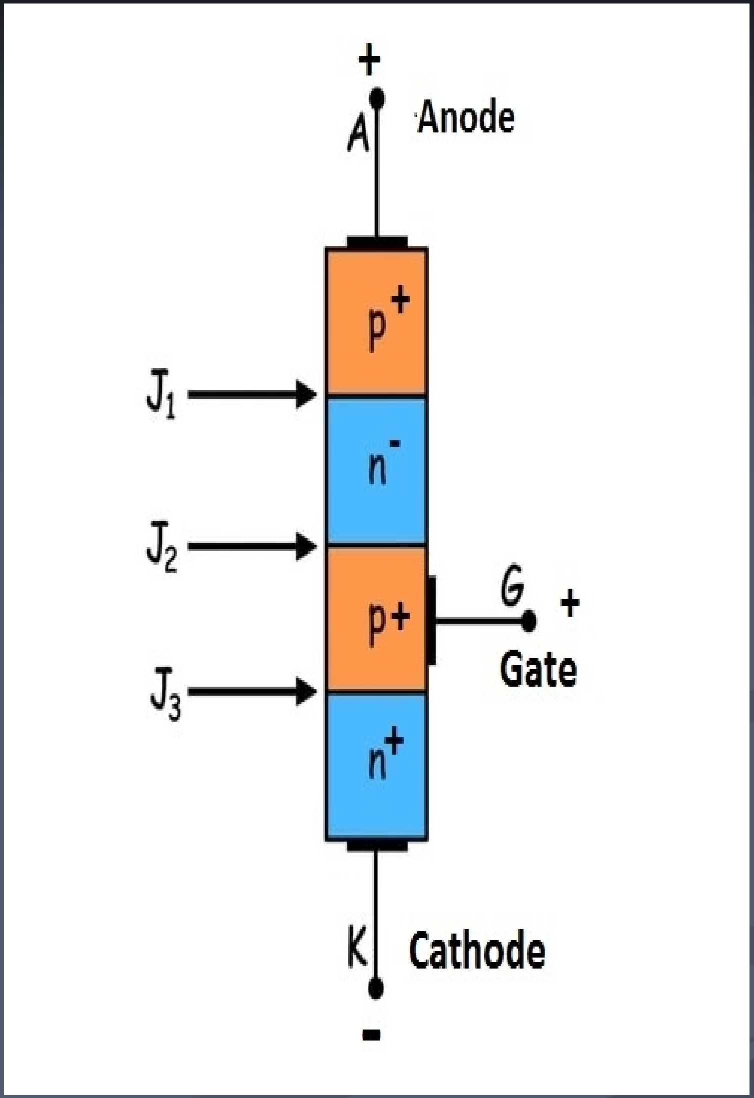
- As illustrated in **Fig (7),** SCR is a four layer (P-N-P-N), three terminals, three-junction, P-N-P-N semiconductor switching device. SCR is one of the prominent members of the thyristor family. This is a semiconductor equivalent of **"Thyratron tube".** Basically, it is a rectifier with a control element. In fact, it consists of three diodes connected back-to-back with a gate connection. A SCR (thyristor) consists of four layers of alternate **P- type** and **N- type (P-N-P-N)** silicon semiconductors layers, forming three junctions J1, J2, and J3, (J1 and J3 operate in forward direction while middle J2 operates in reverse direction) and three terminals known as Anode (A), Cathode (K), and Gate (G) as shown in **Fig (7).**

- As shown in **Fig (7) and Fig (9),** the terminal connected to outer P-region is called Anode (A), the terminal connected to the outer N-region is called Cathode (K) and the terminal connected to inner P-region near to the Cathode (K) is called the Gate (G). Gate terminal is usually kept near the Cathode (K) terminal as shown in **Fig (7).** The function of the Gate (G) is to control the firing of SCR. In normal operating conditions, Anode (A) is positive with respect to Cathode (K).

- As we know that, a SCR (thyristor) is a four-layered, three-junction and three terminals device. The four layers being P-N-P-N, i.e. two P- types and two N- types arranged in alternate P and N layers. Generally the level of doping concentrations varies between the different layers of the SCR (thyristor). Practically, doping concentrations of the layers are P+ N– P+ N+, i.e. the doping concentrations of the two N- type layers are different while it is the same for both P- type layers. Out of these four layers, the first layer (P+) and Last layer (N+) are heavily doped layers. The second layer (N-) is a lightly doped layer and the third layer (P+) is a moderately doped layer. The junction J1 is formed by the P+ layer and N- layer. Junction J2 is formed by the N- layer and P+ layer Junction J3 is formed by P+ layer and N+ layer.

- In term of SCR Terminals doping concentration, the Cathode (K) is the most heavily doped. The Gate (G) and Anode (A) are the next heavily doped. The lowest doping level is within the central N- type layer. The N-type layer is also thicker than the other layers and these two factors enable a large Blocking Voltage to be supported. Thinner layers would mean that the device would break down at lower voltages. But for simplicity we will use P-N-P-N construction. Doping Concentrations in SCR (P-N-P-N) device is shown in **Fig (9)** below.



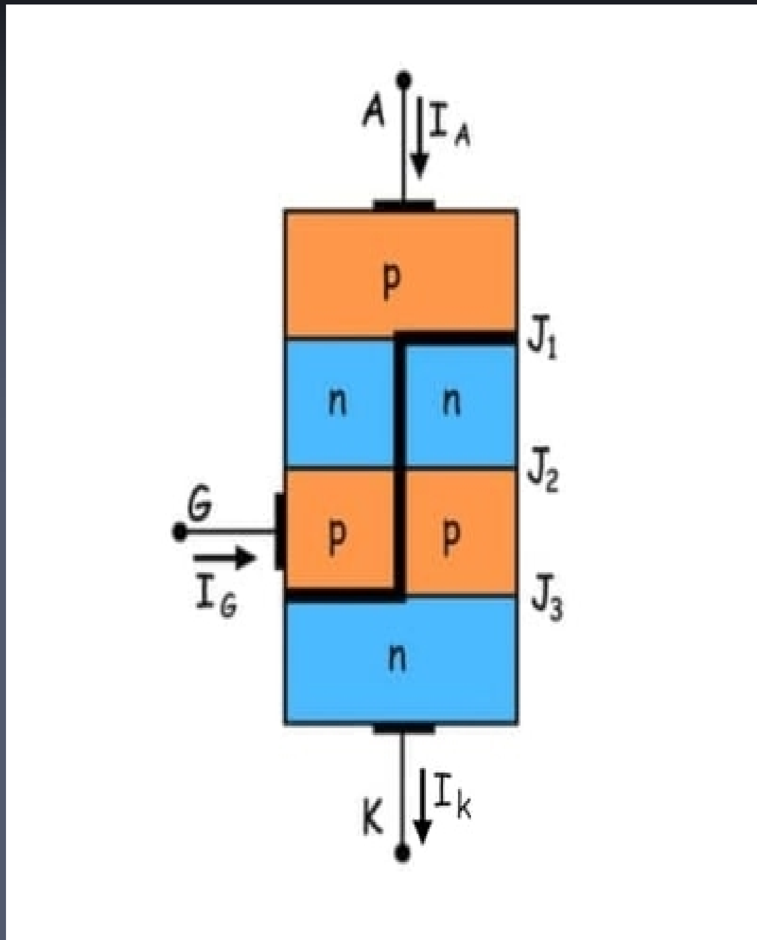


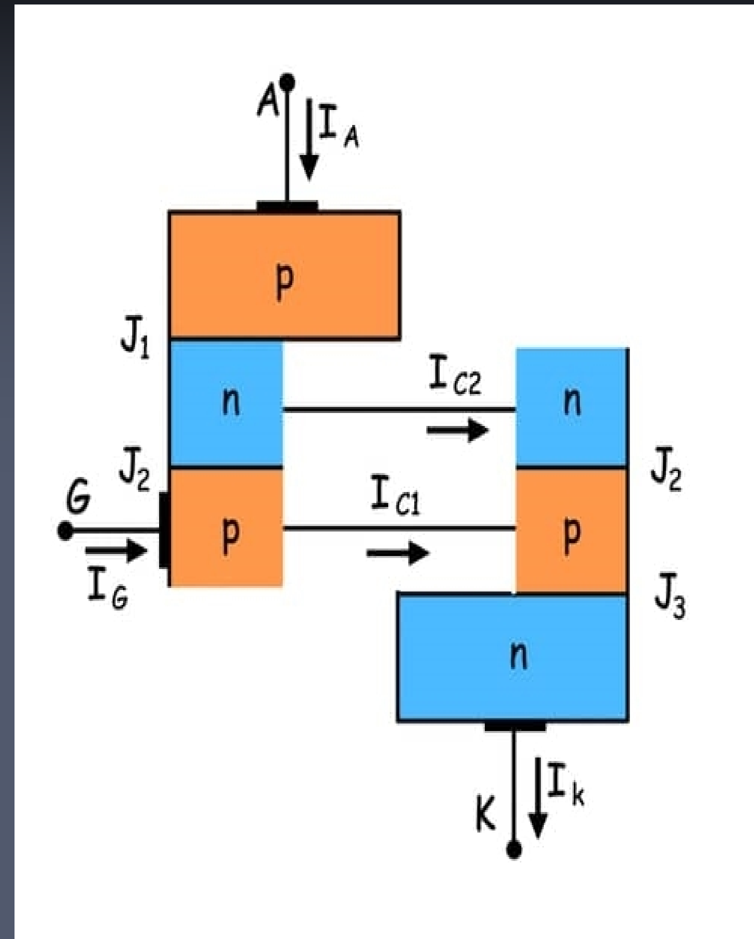
- **Fig (9)** Shown Doping Concentrations in SCR (P-N-P-N) Device.

- The SCR Anode (A) terminal is taken from the P+ layer. The Cathode (K) terminal is taken from the N+ layer. The Gate (G) terminal is taken from the middle P - layer. Sometimes, the Gate (G) terminal is known as the control terminal. For proper operation of a SCR it is necessary to proper bias the SCR. In term of Biasing of a SCR, when the Anode (A) terminal of SCR is connected with a Positive (+) terminal of battery and Cathode (K) is connected with a Negative (-) terminal of the battery, the condition is known as a Forward Bias Condition. When the Anode (A) terminal is connected with a Negative (-) terminal and Cathode (K) is connected with a Positive (+) terminal of the battery, the SCR is connected in Reverse Bias. This condition is known as a Reverse Bias Condition.

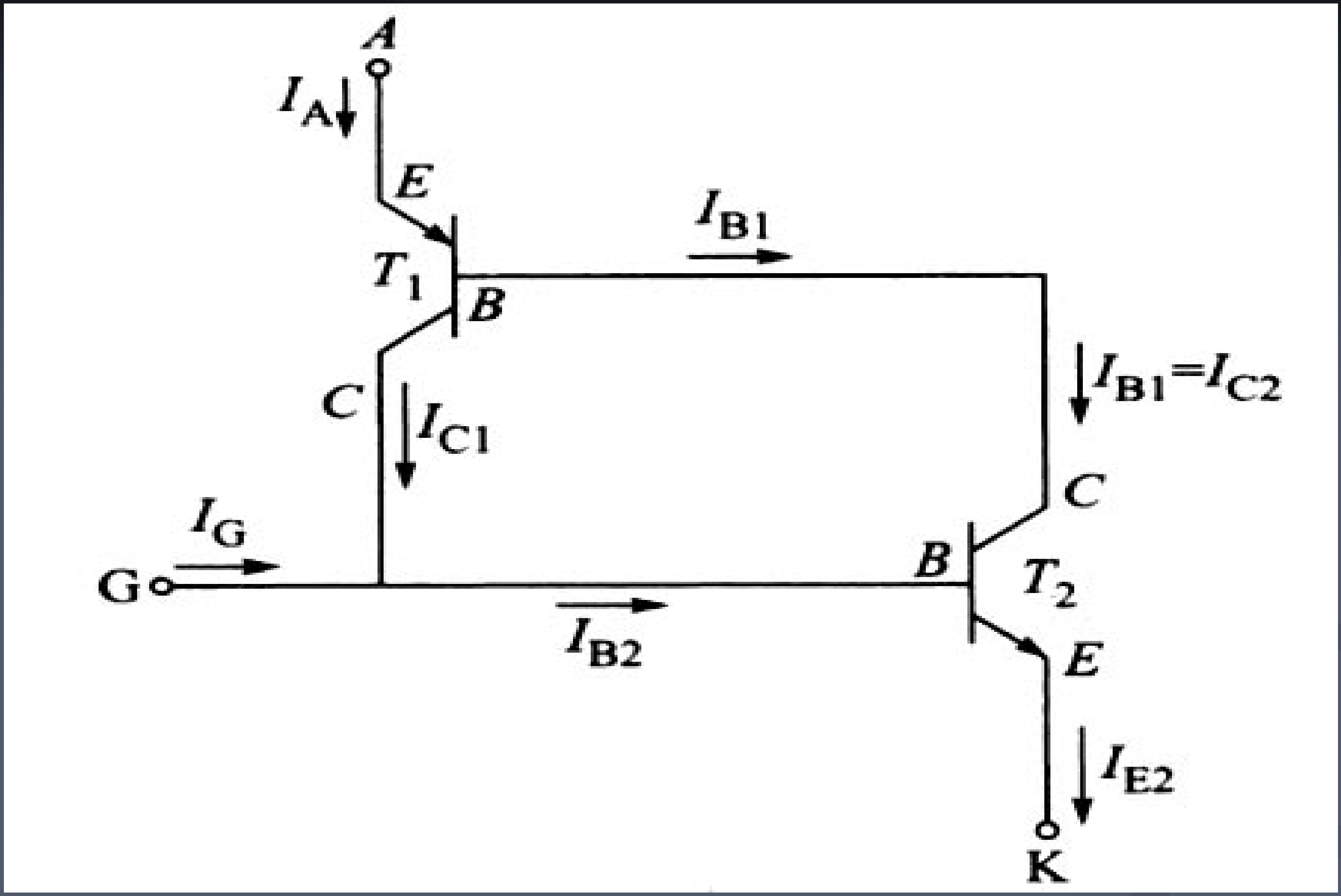
- From **Fig (9),** it is clear that SCR is essentially an ordinary rectifier (PN) and a junction transistor (P-N-P and N-P-N) combined in one unit to form PNPN device. SCR can be best explained by assuming it to be made up of two transistors connected back-to-back as a pair of complementary regenerative switches as shown in **Fig (11).** Interestingly enough, the SCR looks like two PNP and NPN transistor connected in a back to back manner. **It is called two transistor model of SCR.** Two transistor model is obtain by bisecting the two middle layers of four layer P-N-P-N (SCR) device along the dotted line in two separate halves as shown in **Fig (10).**

- It is obvious from the **Fig (11)** that the junction J2 is a Collector Junction common to both transistors while J1 and J3 constitute Emitter Junction of these two transistors. The principle of SCR (thyristor) operation can be best explained with the use of its two transistor model also called two transistor analogy. The two transistor model of SCR and two transistor model circuit diagram of SCR with current components is shown below in **Fig (11) and Fig (12) respectively.**



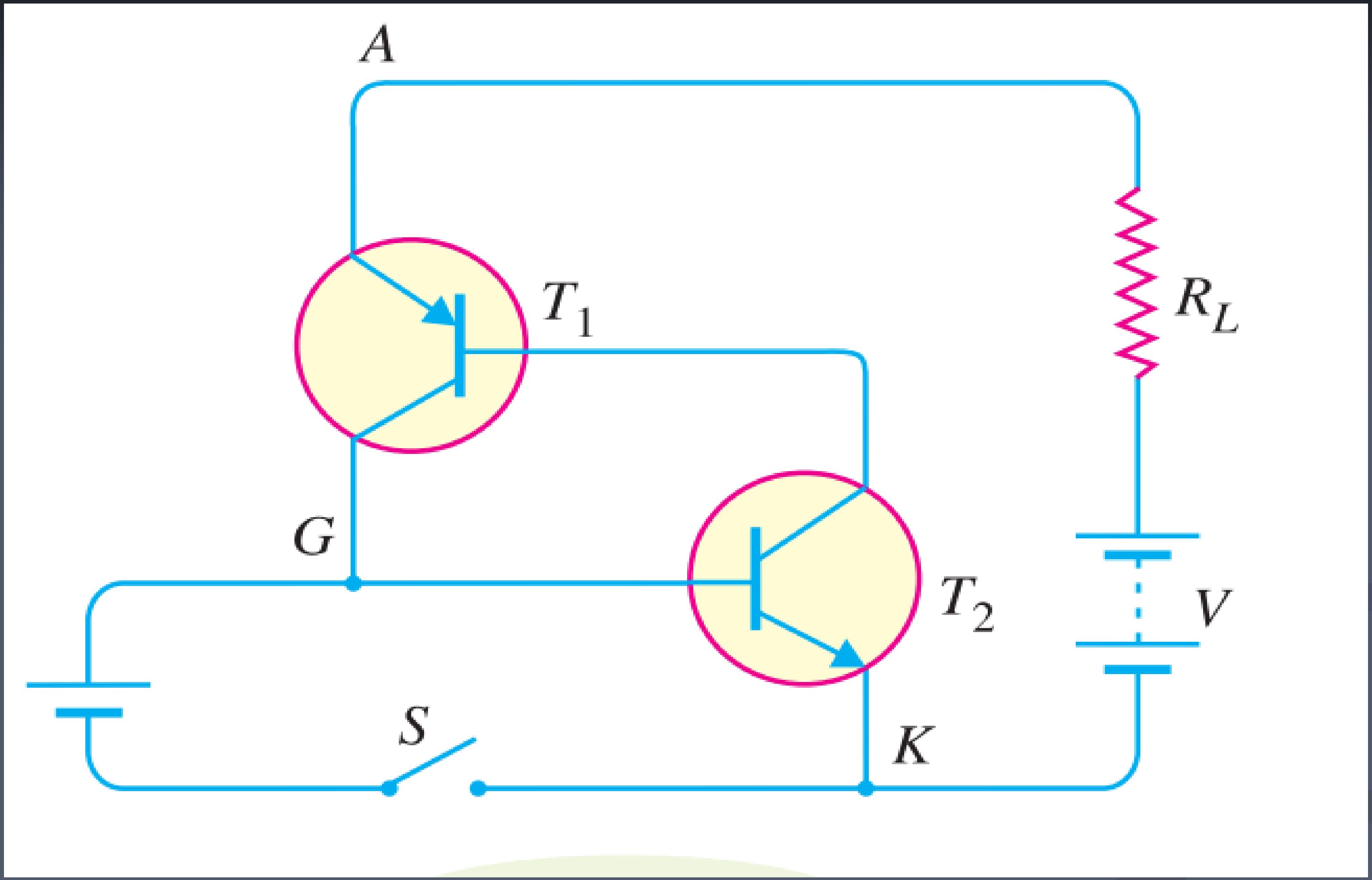


- **Fig (10)** Shows Two transistor model is obtained by bisecting the two middle layers of P-N-P-N (SCR) device along the dotted line in two separate halves.
- **Fig (11)** Shows Two Transistor Model of a SCR.



- **Fig (12)** Shows Two Transistor Model Equivalent Circuit Diagram of a SCR with Current Components.

- The SCR shown in **Fig (10)** can be visualised as separated into two transistors as shown in **Fig (11).** Thus, the equivalent circuit of SCR is composed of PNP transistor and NPN transistor connected as shown in **Fig (12).** Two transistors are named as T1 (PNP) and T2 (NPN). The collector T1 is connected with the base of T2 and the Collector of T2 is connected with the base of T1. The emitter of T1 is anode terminal and the emitter of T2 is the cathode terminal of SCR. It is clear that collector of each transistor is coupled to the base of the other, thereby making a positive feedback loop.



- **Fig (13)** Shows the Two Transistor Model Equivalent Circuit of SCR with supply voltage V and load resistance RL

- The working of SCR can be easily explained from its equivalent circuit. **Fig (13)** shows the Two Transistor Model equivalent circuit of SCR with supply voltage V and load resistance RL. Assume the supply voltage V is less than breakover voltage as is usually the case. With gate open (i.e. switch S open), there is no base current in transistor T2. Therefore, no current flows in the collector of T2 and hence that of T1. Under such conditions, the SCR is open. However, if switch S is closed, a small gate current will flow through the base of T2 which means its collector current will increase. The collector current of T2 is the base current of T1. Therefore, collector current of T1 increases. But collector current of T1 is the base current of T2. This action is accumulative since an increase of current in one transistor causes an increase of current in the other transistor. As a result of this action, both transistors are driven to saturation, and heavy current flows through the load RL. Under such conditions, the SCR closes.

to be continued ....