Silicon Controlled Rectifier (SCR)

Lecture – 7

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

by:

Dr. Niraj Kumar,

Assistant Professor (Guest Faculty)

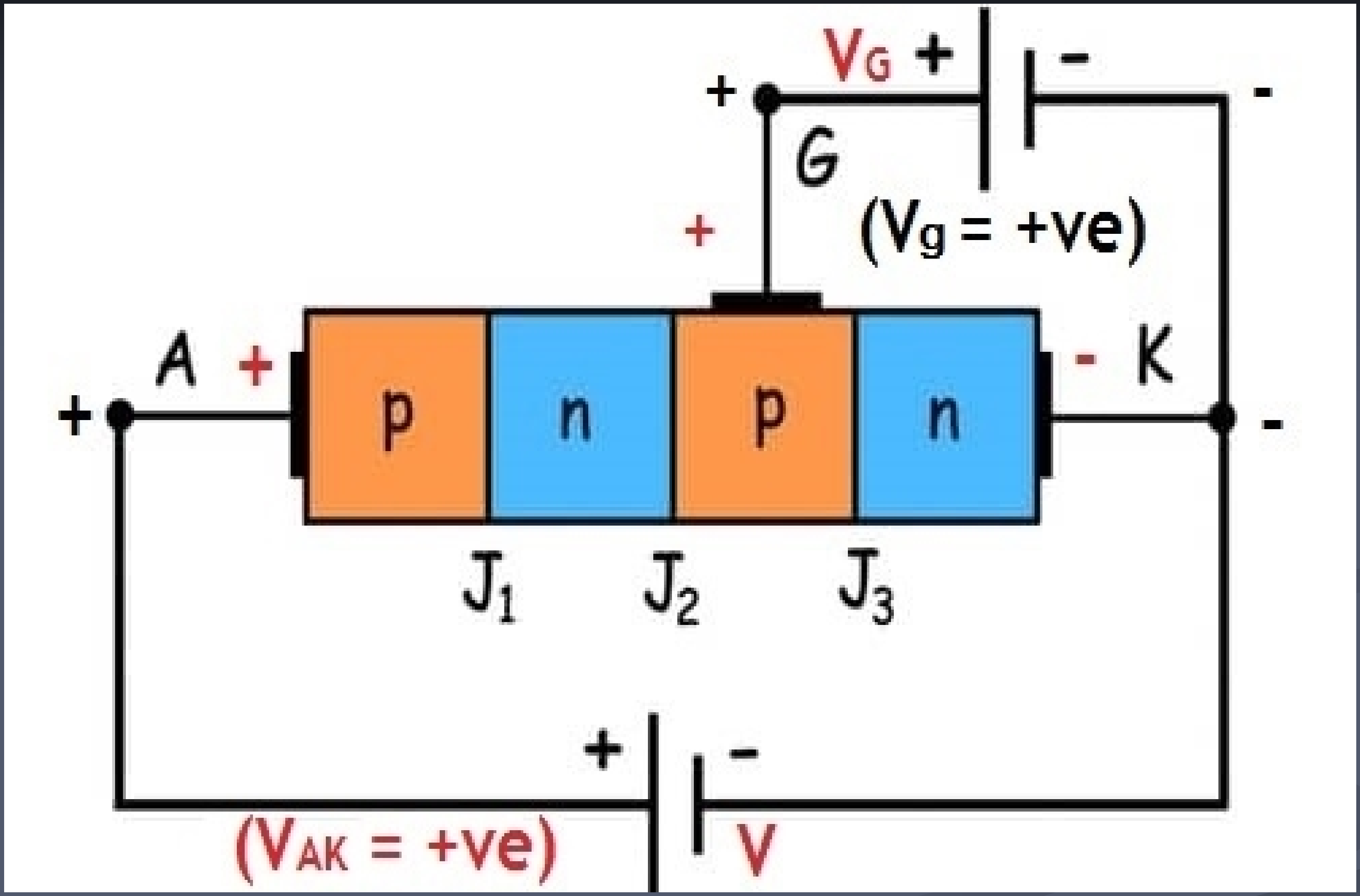
Department of Electronics

L.S. College, BRA Bihar University, Muzaffarpur.

(3) Forward Conduction Mode (ON-State) [V_{AK} = + ve & V_g = + ve]

- Preceding further the actual operating mode of SCR (thyristor) arises when an external Positive (+) Gate Pulse is provided to it. When the Anode (A) Terminal of the SCR is connected to the Positive (+) Terminal of the Battery and Cathode (K) Terminal of the SCR is connected to the Negative (-) Terminal of the Battery, then this condition is known as a **Forward Bias Condition.** There will be a Positive (+) Pulse applied to the Gate (G) Terminal of SCR. Gate (G) terminal is controlling terminal of SCR; it will be kept in the Closed State **(V_g = +ve)** in this mode.

- **Here sufficient** Positive (+) Voltage is provided to Anode (A) and Gate (G) with reference to the Cathode (K). **The circuit diagram of Forward Conduction Mode (ON-State) is shown by Fig (28) below.** From **Fig (28)**, we can clearly see that a Positive (+) Forward Voltage is provided to the Gate (G) terminal with respect to Cathode (K) terminal. Under Forward Bias Condition once the Forward Bias Voltage is applied, the junction J1 and J3 become forward biased but at the same time, this Forward Bias Voltage makes the junction J2 reverse biased. The **Fig (28)** below represents this forward bias connection clearly.

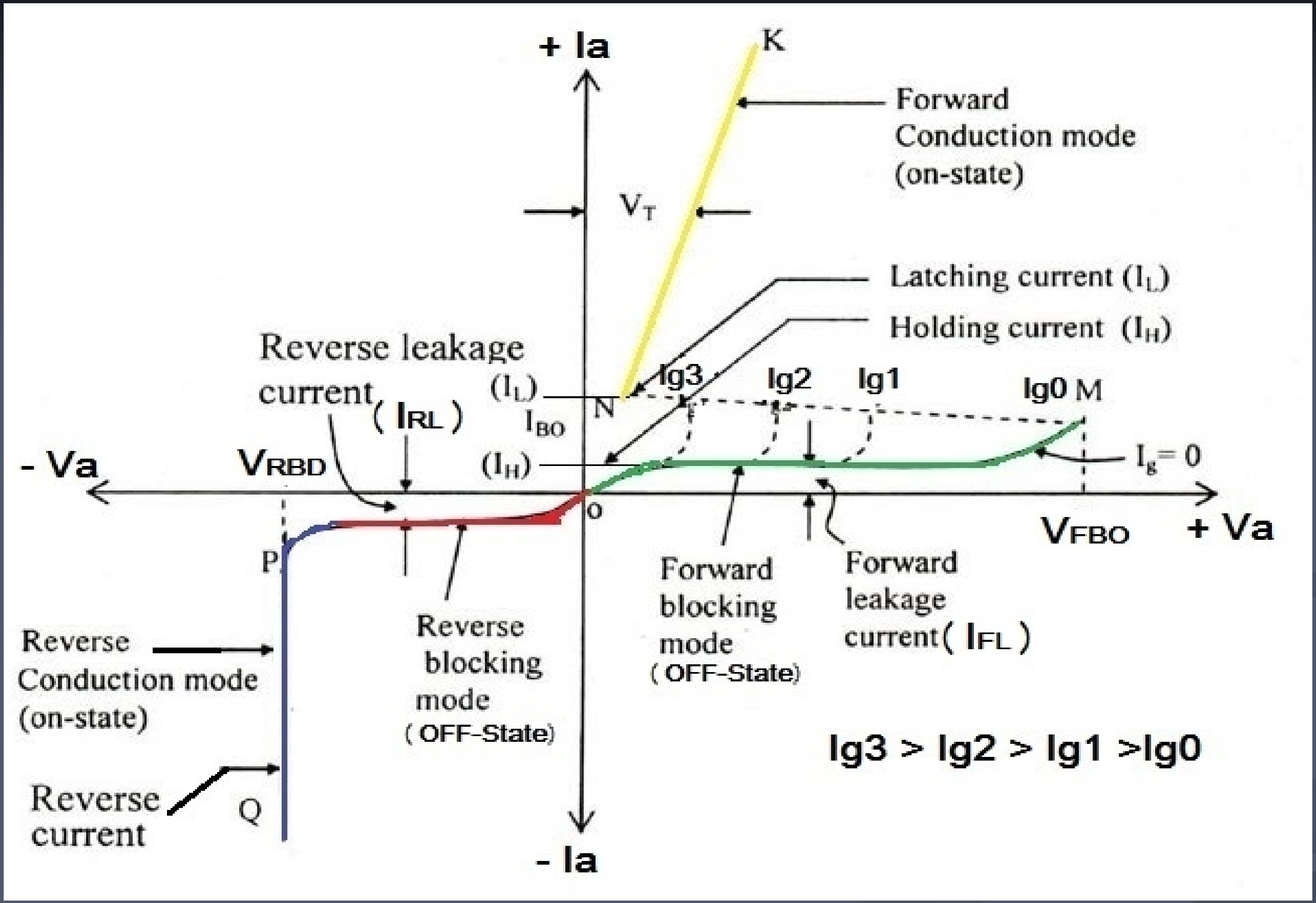


- **Fig (28)** Shown Forward Conduction Mode of SCR under **Forward Bias Condition (V_{AK} = + ve) with Positive Gate Voltage (Vg = + ve).**

- The Forward Conduction Mode is the only mode at which the SCR will be in the ON-state and will be conducting. In this mode, the applied Positive (+) Gate (G) Voltage (V_g = + ve) will help the SCR (thyristor) comes into the Forward Conduction Mode from Forward Blocking Mode. During this mode of operation, the SCR will be operating in Forward Bias Voltage (+Va) with Positive (+) Gate (G) Voltage (Vg = + ve) and Forward Current will be flowing through it.

- Hence we can make the SCR conduct in two different ways, either :-
- **(1)** we can Increasing the **Forward Bias Voltage (+Va)** applied between the Anode (A) and Cathode (K) terminals of the SCR beyond the Breakdown Voltage also called **Forward Break-Over Voltage (V_{FBO})** or else
- **(2)** we can applying Positive (+) Gate (G) Voltage (Vg = + ve) to the Gate (G) terminal of SCR as shown in above **Fig (28).**
- **Carefully Noted here that** Once any one of these methods is applied, the avalanche breakdown must be occurs at junction J2. Therefore the SCR turns into conduction mode and acts as a Closed Switch (ON-State) thereby Forward Current starts flowing through SCR.

- **(1) In the First Case :-** If we increase in the applied Forward Bias Voltage (V_{AK} or Va) between the Anode (A) and Cathode (K), higher then **Forward Break-Over Voltage (V_{FBO}),** causes the initially reverse biased junction J2 will be depleted (reduced) due to the avalanche breakdown at the voltage point corresponding to **Forward Break-Over Voltage (V_{FBO}).** This results in the sudden increase in the forward current flowing through the SCR therefore the SCR turns into Forward Conduction Mode (ON-State) and acts as a closed switch (ON-State), hence SCR device conduct. This mode is known as Forward Conduction Mode (ON- State). When Forward voltage is higher then **Forward Break-Over Voltage (V_{FBO}),** SCR offers Very Low Impedance due to Maximum Forward Current though SCR. Maximum Forward Current flow is shown by the Yellow line in V-I Characteristics of SCR in **Figure (29)** below, although the Gate (G) terminal of the SCR is Positive (+) Biased.

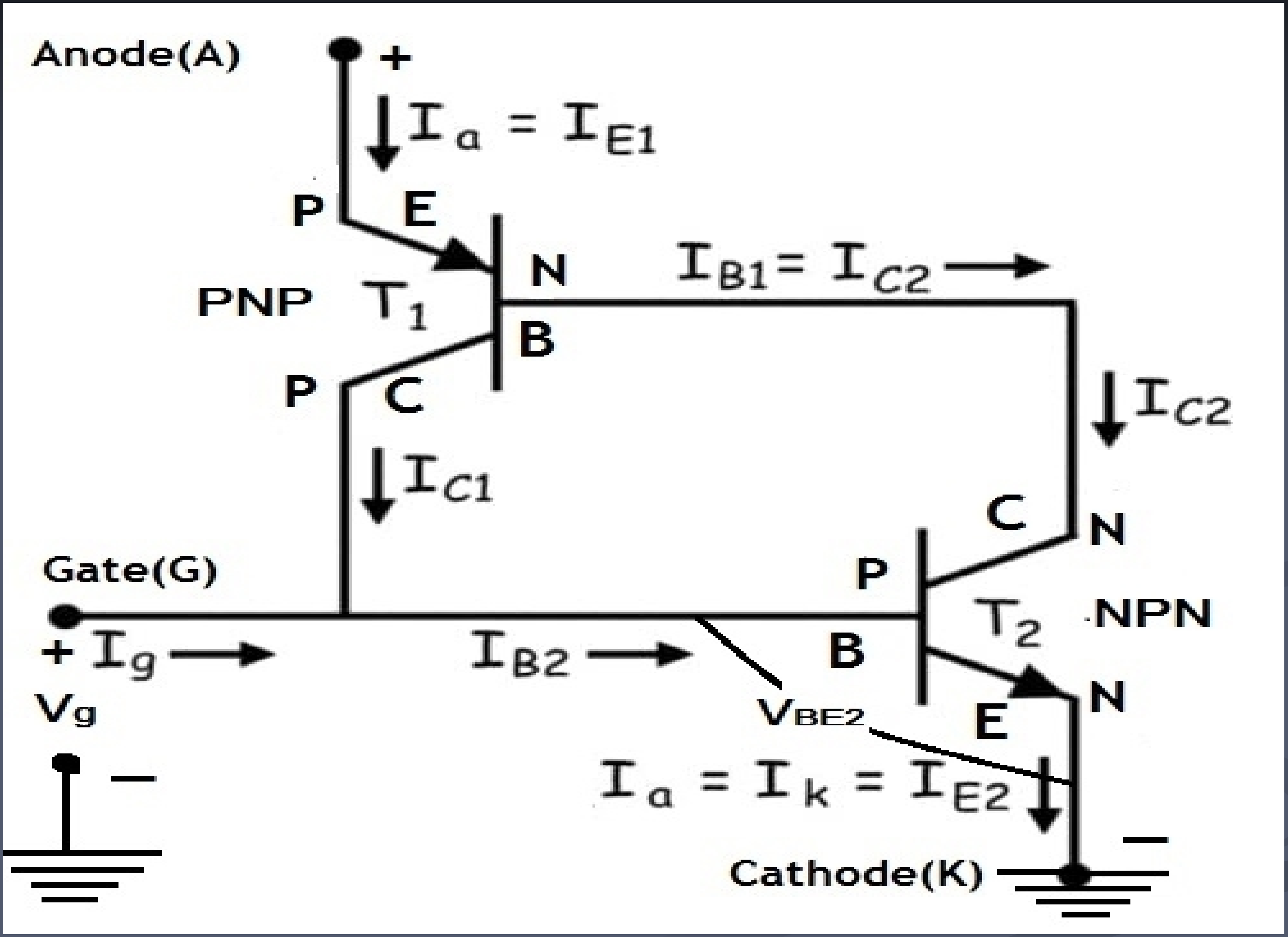


- **Fig (29)** Shown **Maximum Forward Current (Ia)** by the **Yellow line** in **V-I Characteristics of SCR.**

- But we are not able to do this for all the applications and this method of **Activating the SCR** will eventually reduce the lifetime of the SCR.

- **(2) In the Second Case :-** If we want to use the SCR for **Low Forward Bias Voltage (V_{AK} or Va)** applications we can apply a **Positive (+) Voltage to the Gate (G) terminal (Vg = + ve)** of the SCR. However SCRs can be made to Turn -ON at a much smaller Forward Bias Voltage level by providing small Positive (+) Voltage between the Gate (G) and the Cathode (K) terminals as **shown in Fig (28).** From V -I characteristic of SCR shown **in Figure (29),** if the **Gate current (I_g)** value is high, the minimum will be the time to come in Forward Conduction Mode as **Ig3 > Ig2 > Ig1.** It is also noted that if **Gate current (I_g)** is increasing, the Forward Bias Voltage required to turn ON the SCR is less if gate biasing is preferred.

- The applied Positive (+) Gate (G) Voltage ($V_g = +$ ve) will help the SCR move to the **Forward Conduction Mode (ON-State)** from the **Forward Blocking Mode (OFF-State).** Thus the SCR will be operating in **Forward Conduction Mode** with **Forward Biasing Condition** then **Maximum Forward Current** will be flowing through it, hence device conducts. Its value depends on the **external load resistance or impedance. This mode is known as Forward Conduction Mode (ON-State).** The reason behind this can be better understood by considering the **Two Transistor Equivalent Circuit of the SCR** as shown in **Figure (30)** below.



- **Fig (30)** Shown Two Transistor Equivalent Circuit of SCR.

- Here form the above **Fig (30)** it is seen that on applying positive (+) **Gate voltage (+V_g)** of sufficient large magnitude at the Gate (G) terminal, which is connected to the Base (B) terminal of **Transistor T2,** chosen sufficiently large to turn **Transistor T2** switches **ON ($V_{BE2} = V_g$).** As **transistor T2** to **switch ON, collector current (I_{C2}) of transistor T2** will increase, which in turn results in the flow of its **collector current (I_{C2})** into the **Base (B) terminal of transistor T2.** The **Collector current (I_{C2}) of Transistor T2** flows into the Base (B) terminal of **Transistor T1,** will then rise to a value sufficiently large to turn **transistor T1 ON ($I_{B1} = I_{C2}$).** As **transistor T1** to **switch ON, collector current (I_{C1}) of transistor T1** will increase, which in turn results in the flow of its **collector current (I_{C1})** into the **Base (B) terminal of transistor T2.**

- **This results in a** corresponding increases in **base current (I_{B2}) of transistor T2.** Again the increase in **base current (I_{B2}) of transistor T2** will result in a further increase in **Collector current (I_{C2}) of transistor T2.** **The net result is a Regenerative Increase in the Collector current of each transistor.** This causes either transistor to get saturated at a very rapid rate and the action cannot be stopped even by removing the **Positive (+) Gate Voltage (+V_g)** applied at the Gate (G) terminal. This is **provided the** current flow through the SCR is greater than that of the **Latching Current.** The resulting **Anode-to-Cathode Resistance ($R_{SCR} = V / I_a$)** is then small because **Anode Current (Ia)** is large, resulting in the **closed-switch (ON-State)** representation for the SCR.

- Now, even if we **remove the Positive (+) Gate Voltage** then also this **Regenerative Feedback (Cumulative) Action** will take place and the **Maximum Forward Current or Forward Anode Current (+Ia)** flows through the SCR device once it reaches the **minimum current value. This minimum current is known as Latching Current (I_L).** Here the **Latching Current (I_L)** is defined as the minimum current required to maintain the SCR in **Conducting State (ON-State)** even after the **Positive (+) Gate Voltage (Gate Pulse V_g = + ve)** is removed. In such state, the SCR is said to be Latched and there will be no means to limit the Maximum Forward Current flowing through the SCR device, unless by using an external impedance in the circuit.

- **Question :-** Now the question arises then what must be done in order to Turn - OFF the SCR (thyristor) once it gets Turn - ON?

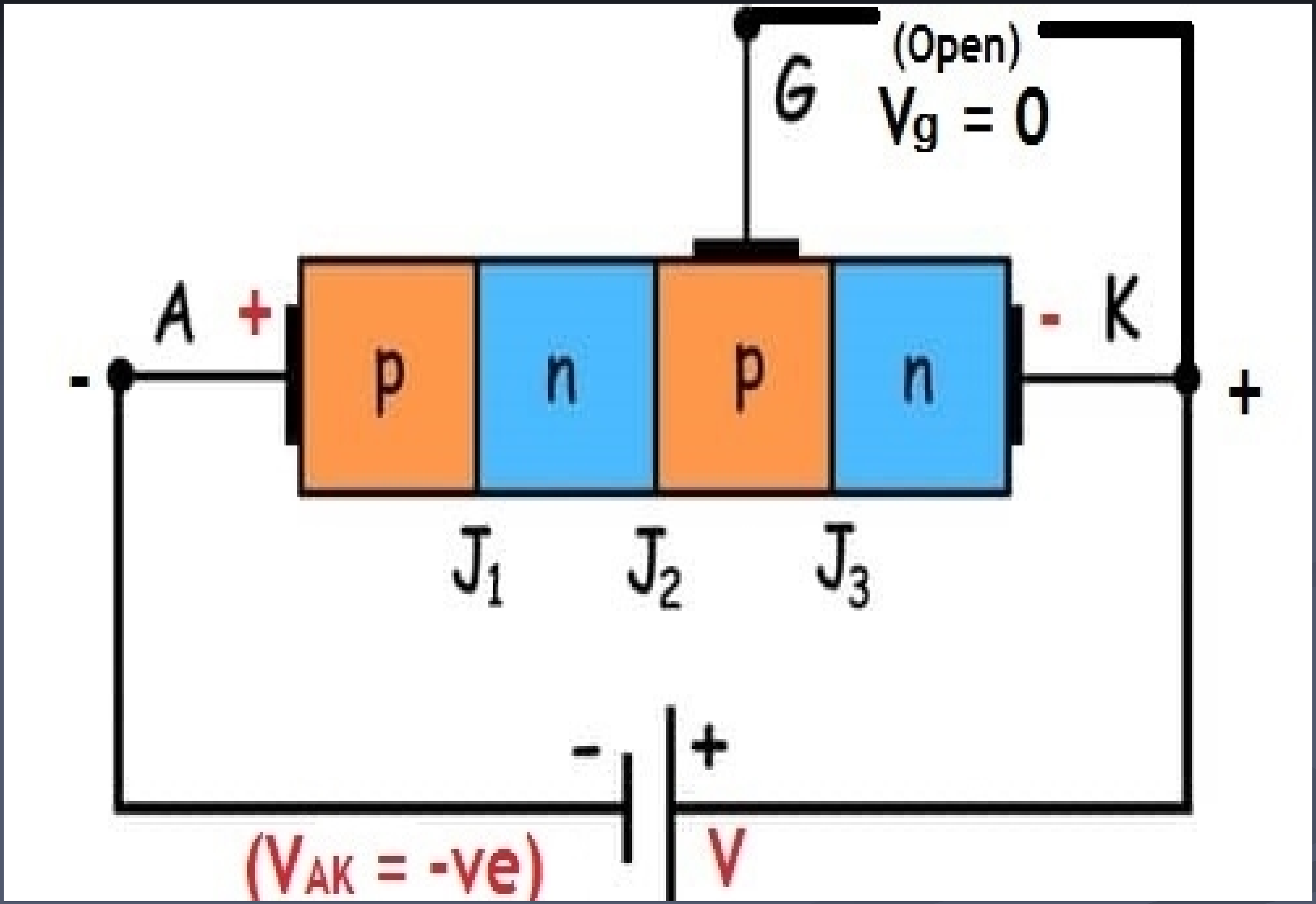
- **Answer :-** So, the answer to the above question is, the SCR will only Turn-OFF by **reducing** the **Maximum Forward Current or Forward Anode Current (Ia)** up to its lowest current value which is called **Holding Current (I_H).** The **Holding Current (I_H) is defined** as the minimum current required to hold the SCR in the **Forward Conduction Mode (ON-State).** Thus, a reduction in **Anode Voltage (Va)** will bring back the SCR (thyristor) again to its **Forward Blocking Mode (OFF-State).**

- **There are various Turn-OFF techniques used for the SCR** like **Natural Commutation, Forced Commutation or Reverse Bias Turn-Off and Gate Turn-Off,** to **Switch-OFF the SCR.** Basically main-aim of all of these techniques are to reducing the Anode Current (Ia) below the **Holding Current (I_H),** the minimum current which is to be maintained through the SCR to keep it in its Forward Conducting Mode. **Similar to Turn-OFF techniques, there are also exist different Turn-ON techniques used for the SCR** like **Triggering by DC Gate Signal, Triggering by AC Gate Signal and Triggering by Pulsed Gate Signal, Forward-Voltage Triggering, Gate Triggering, dv/dt Triggering, Temperature Triggering and Light Triggering.**

- Thus, by applying sufficient Positive (+) Voltage to the Anode (A) with reference to the Cathode (K) and Positive Gate (G) Trigger Pulse, Maximum **Forward Anode Current (Ia)** flows through the SCR (thyristor). **This mode of the SCR device is known as the Forward Conduction Mode (ON State).** In Forward Conduction Mode (ON-State) SCR offers a **Very Low Resistance** to the Forward Current flow. Therefore, the SCR acts as a **Closed Switch (ON-Switch)** in this mode by conducting forward current flowing through the SCR. **Hence, the name of this mode is Forward Conduction Mode (ON-State).**

(4) Reverse Conducting Mode (ON-State) [V_{AK} = - ve & V_g = 0]

- The Last condition arises when the Anode (A) terminal of the SCR (thyristor) is connected to the Negative (-) battery terminal and the Cathode (K) terminal of the SCR (thyristor) is connected with the Positive (+) terminal of the battery. Hence, the SCR is connected in reverse bias condition. This condition is known as a **Reversed Bias Condition.** In this mode, there will not be any pulse given to the Gate (G) Terminal of SCR. Gate (G) terminal is controlling terminal of SCR; it will be kept as an open circuit **(Vg = 0) in this mode. The circuit diagram of Reverse Conducting Mode (ON-State) is shown by Fig (31) below.** Under Reversed Bias Condition once the Reverse Bias Voltage is applied, this causes the junction J1 and J3 to get reverse biased but at the same time due to same Reversed Bias Voltage, the junction J2 comes to forward biased condition. The **Fig (31)** below represents this Reverse bias connection clearly.



- **Fig (31)** Shown Reverse Conducting Mode of SCR under **Reverse Bias Condition (VAK = - ve) with No Gate Voltage (Vg = 0).**

- Due to forward biased junction J2 allows the movement of majority carriers as well as minority carriers. But at the both end junction J1 and J3, because of reverse biased voltage applied, due to this potential, generates a wide depletion region at the junction J1 and J3. **Due to the** reverse bias voltage at junction J1 and J3, the width of depletion region increases at junction J1 and J3. This increased depletion region at the junction J1 and J3 acts as a wall or obstacle for junction J2 through which majority carriers as well as minority carriers flow. Junction J1 and J3 blocks the majority current carriers flowing through junction J2. Therefore, the majority of the current carrier does not flow through junction J1 and junction J3.

- Hence, current cannot flow through the SCR because of the reverse bias of junction J1 and J3. However, a very small leakage current (minute amount of current) due to the movement of minority carriers, called **Reverse Leakage Current (I_{RL}) also named reverse saturation current** flows through junction J1 and J3 to the device until the applied **Reverse Biased Voltage (-Va)** reached to **Reverse Breakdown Voltage (V_{RBD}). Hence, this very** small amount of **Reverse Current i.e., Reverse Leakage Current (I_{RL})** flows through the SCR device due to the drift minority charge carriers in the forward-biased Junction J2 but it is not enough to Turn - ON the SCR, although the Gate (G) terminal of the SCR remains unbiased **(Open state Vg = 0).**

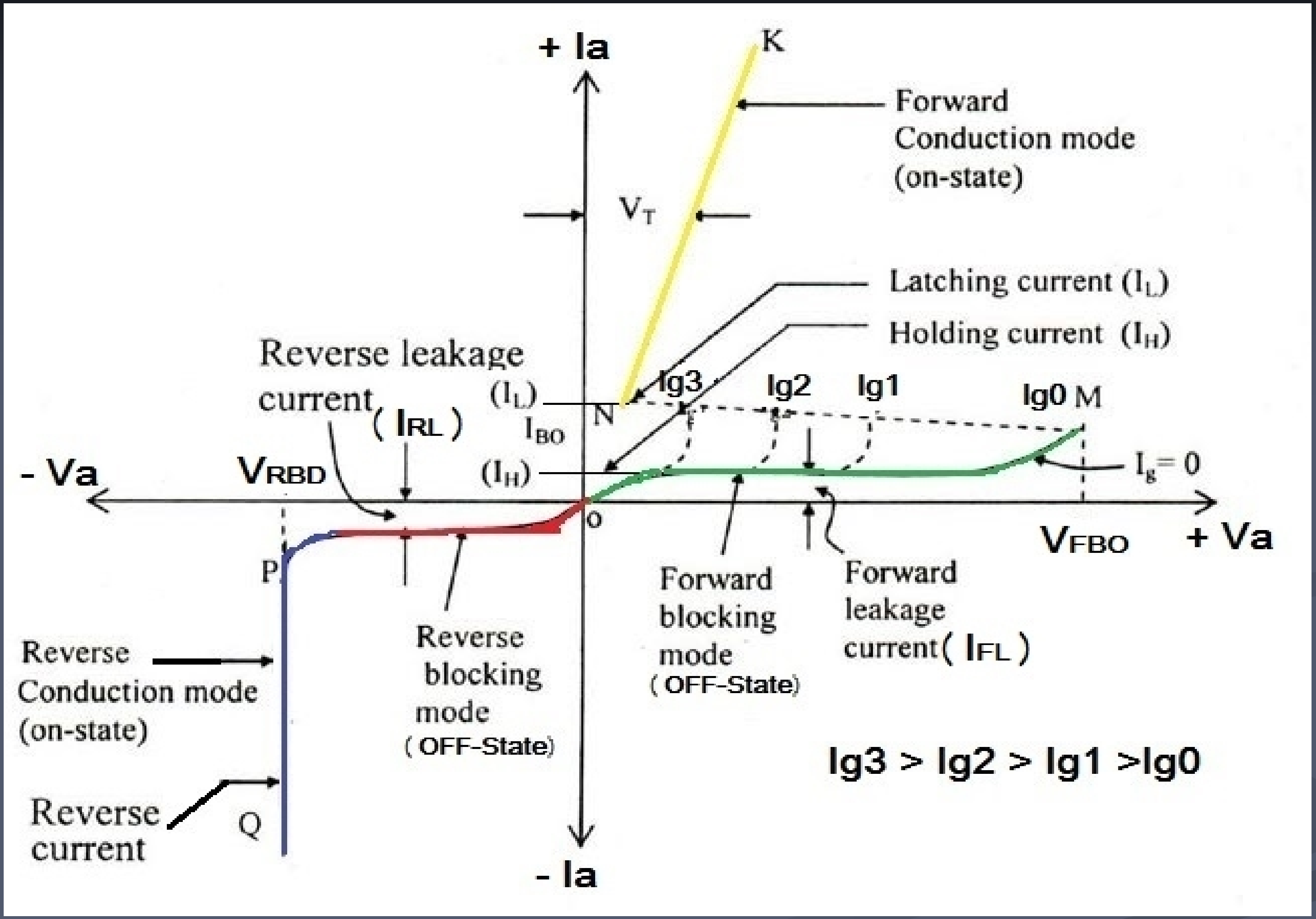
- **Reverse Leakage Current (I_{RL}) is shown by the Red line in V-I Characteristics of SCR in Figure (32) below.** This **Reverse Leakage Current (I_{RL})** is not enough to drive the SCR. So the SCR providing Reverse Biased Voltage (-Va), but, there will not be any enough Reverse Current (-Ia) except **Reverse Leakage Current (I_{RL})** flow through SCR hence SCR does not conduct. Further, in this state, the SCR behaviour will be identical to that of a typical diode as it exhibits both the flow of **Reverse Leakage Current (I_{RL}) also named reverse saturation current** as well as the **Reverse Break-Down phenomenon.**

- When the Reverse Biased Voltage (-Va) applied to the SCR is increased and if it reaches to the **Reverse Breakdown Voltage (V_{RBD})** of the SCR **avalanche breakdown occur** at junction J1 and J3. The junction J1 and J3 gets depleted due to avalanche breakdown. Once the Avalanche breakdown occurs the **Reverse Leakage Current (I_{RL}) transform into Maximum Reverse Current (-Ia)** will start flowing through the SCR. But in Reverse Blocking Mode of operation, the SCR is reverse biased and if **Reverse Bias Voltage (-Va)** applied to the SCR is below **Reverse Breakdown Voltage (V_{RBD}) there will not be any current flow through SCR except Reverse Leakage Current (I_{RL}), also known as Reverse Saturation Current,** hence device does not conduct. **This mode is known as Reverse Blocking Mode (OFF State).**

- In Reverse Blocking Mode (OFF State) SCR offers a High Impedance for the **Reverse Leakage Current (I_{RL})** flow until the **Reverse Biased Voltage (-Va)** applied is less than the **Reverse Breakdown Voltage (V_{RBD})** of the SCR. Therefore, the SCR acts as an open switch (OFF-Switch) in this mode by blocking **Maximum Reverse Current (-Ia),** except **Reverse Leakage Current (I_{RL})** also named Reverse Saturation Current flow through the SCR. **Hence, the name of this mode is Reverse Blocking Mode (OFF-State).** Here the device offers a High Impedance in this **Reverse Blocking Mode** until the **Reverse Biased Voltage (-Va)** applied is less than the **Reverse Breakdown Voltage (V_{RBD})** of the SCR. Therefore the SCR act as an Open Switch in this mode by blocking Maximum Reverse Current (-Ia) except Reverse Leakage Current flowing through the SCR. **Hence, the name of this mode is Forward Blocking Mode (OFF State).**

- Again we know from above discussion if the applied **Reverse Biased Voltage (-Va)** is increased and if it reaches to the **Reverse Breakdown Voltage (V_{RBD}) point** then **Avalanche Breakdown occurs** at junctions J1 and J3 which results to increase **Reverse Leakage Current (I_{RL})** Which is flow through the SCR. At the **Reverse Breakdown Voltage (V_{RBD}) point** and **beyond this point**, the **Reverse Leakage Current (I_{RL}) also called Reverse Saturation Current,** which is already flow in SCR due to reverse biasing of SCR, is exponentially increases. This result in the sudden increase in the **Reverse Current (-Ia) i.e. Reverse Leakage Current (I_{RL}) and converted into Maximum Reverse Current which is now** flowing through the SCR. **Then this Maximum Reverse current flowing through SCR**.

- Therefore the SCR turn into Conduction Mode (ON-State) and acts as a closed switch (ON-switch)) in Reverse Biased Condition. In this **Reverse Conducting Mode (ON-State)**, **Maximum Reverse Current** flows through the SCR and its value depends on the external load resistance or impedance. **Hence, the name of this mode is Reverse Conducting Mode (ON-State).** So, the SCR offers a Low Impedance in this **Reverse Conducting Mode (ON-State)** when the **Reverse Bias Voltage (-Va)** applied is more than the **Reverse Breakdown Voltage (V_{RBD})**. **Maximum Reverse Current (-Ia) is shown by the Blue line in V-I Characteristics of SCR in Figure (32) below,** although the Gate (G) terminal of the SCR remains unbiased (Open State **Vg = 0**).



- **Fig (32)** Shown **Maximum Reverse Current (-Ia)** by the **Blue line** in **V-I Characteristics of SCR.**

- If the applied **Reverse Bias Voltage (-Va)** is increased beyond the **Reverse Breakdown Voltage (V_{RBD}),** then **Avalanche Breakdown** occurs at junctions J1 and J3 which results to increase **Maximum Reverse Current (-Ia)** beyond the **Reverse Leakage Current (I_{RL})** flow through the SCR. This large **Maximum Reverse Current** beyond the Reverse **Leakage Current (I_{RL})** causes more losses in the SCR and even to dissipating in the form of heat. So there will be a considerable damaging the SCR when the Reverse Bias Voltage (-Va) applied more than **Reverse Breakdown Voltage (V_{RBD}). Hence final conclusion is that Reverse Conduction Mode (ON-State) condition must be avoided because of dissipating excess heat generation and then considerable damaging the SCR.**

Key Terms Related to SCR (Thyristor)

- **(1) Latching Current (I_L) :-**

- Latching current is that minimum current that flows through the device in forward biased condition. Once the device reaches this particular value then the device completely starts conduction (ON-State) even after the removal of the Gate Pulse.
  This current is associated with the turn-on process of the SCR (thyristor). Its value is somewhat twice or thrice the holding current.

- **(2) Holding Current (I_H) :-**

- Holding current is that minimal current that flows through the device in forward condition but below this particular value the device stops conduction. This current is related to turn off the process of the SCR (thyristor).

to be Continued ....