

# Electrical Engineering

## Power Electronics



Lecture No - 1

Power Semi conductor devices

By- Ajay Gupta Sir

- ✓ 1. Switching loss
- ✓ 2. PSD Basics



**Topic is  
To be  
covered**

- ✓ 1. P-N Junction
- ✓ 2. Construction of Power Diode
- ✓ 3. Characteristic of Diode

# Doping

Doping  $\uparrow \Rightarrow$  charge carrier  $\uparrow \Rightarrow$  conductivity  $\uparrow$   
 $\Rightarrow R \downarrow$



- Adding of external atom in the semiconductor is called Doping.

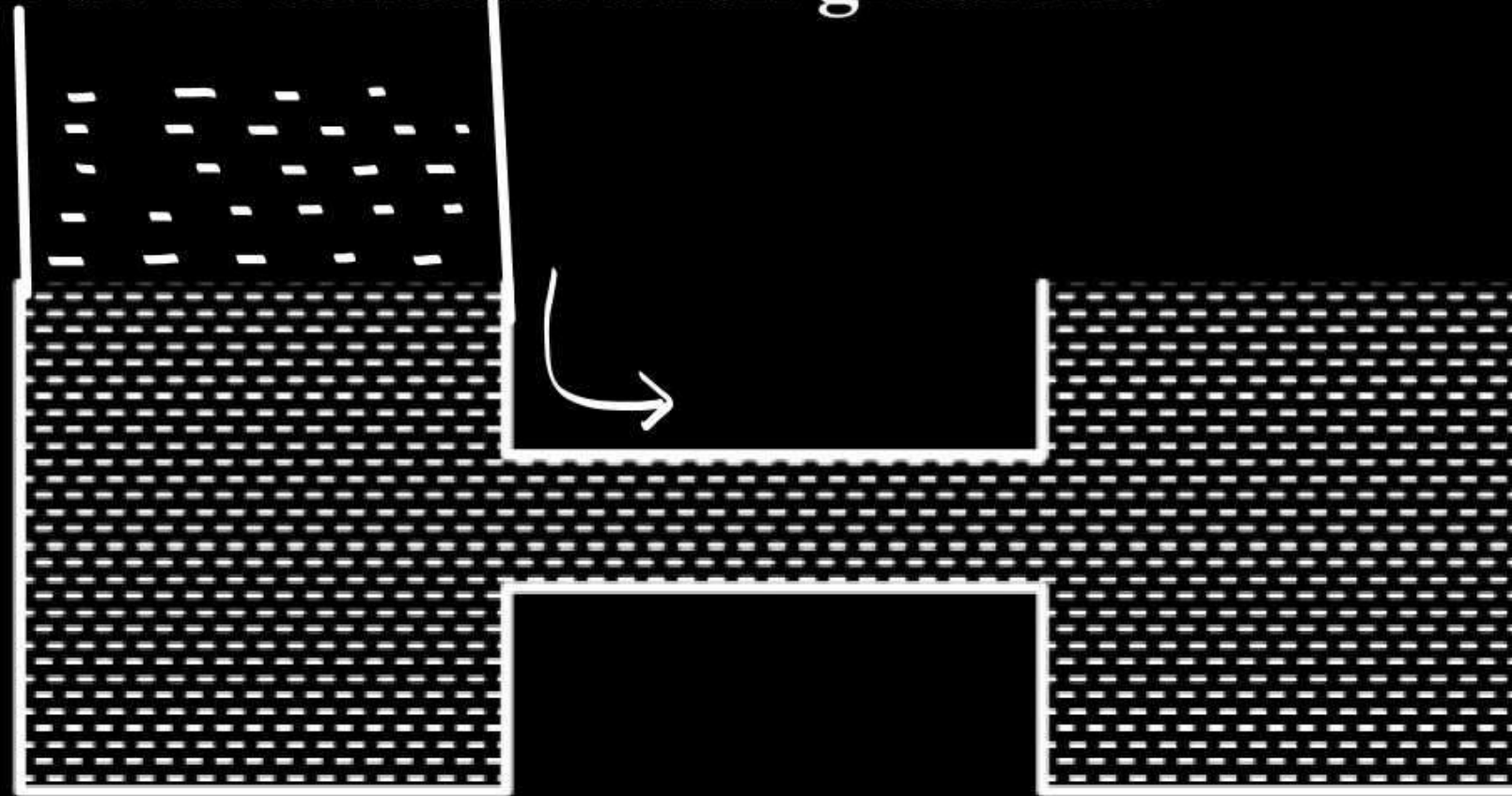
|             |               |                            |                                           |
|-------------|---------------|----------------------------|-------------------------------------------|
| ✓ $P^+/n^+$ | $\rightarrow$ | Highly doped semiconductor | <u><math>(10^{19}/\text{cm}^3)</math></u> |
| ✓ $P/n$     | $\rightarrow$ | Moderately doped           | $(10^{16}/\text{cm}^3)$                   |
| ✓ $P^-/n^-$ | $\rightarrow$ | Lightly doped              | $(10^{13}/\text{cm}^3)$                   |

- **Minority carrier depends upon the temp.**
- **Temp  $\uparrow \rightarrow$  Covalent bond breaks  $\rightarrow$  Minority carrier**

$\rightarrow$  Minority charge depend on temp

$\rightarrow$  Doping density  $\uparrow \Rightarrow$  Resistance  $\downarrow$

- The Movement of charges occur due to
  1. **Diffusion** : Due to concentration gradient.

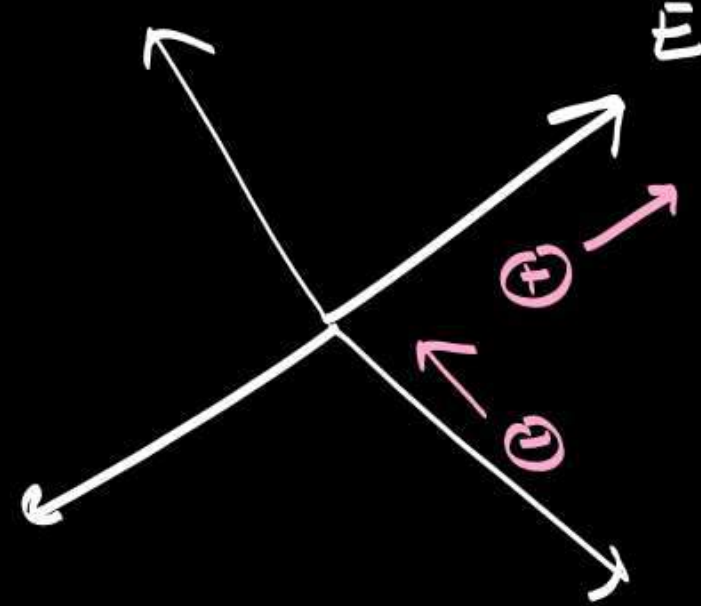


## 2. **Drift : Due to Electric Field**

$$\underline{F = qE}$$

$$\underline{F = \oplus E} \rightarrow \text{In direction of } \underline{E}$$

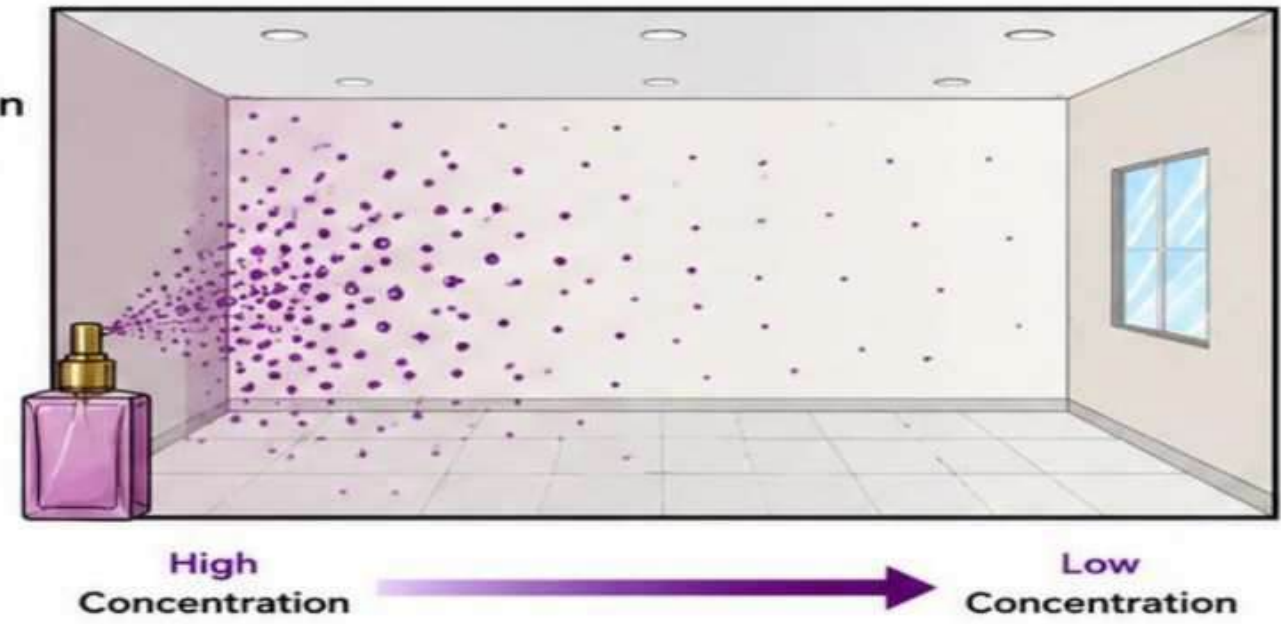
$$\underline{F = \ominus E} \rightarrow \text{Opposite to } \underline{E}$$



# DIFFUSION (Due to Concentration Gradient)

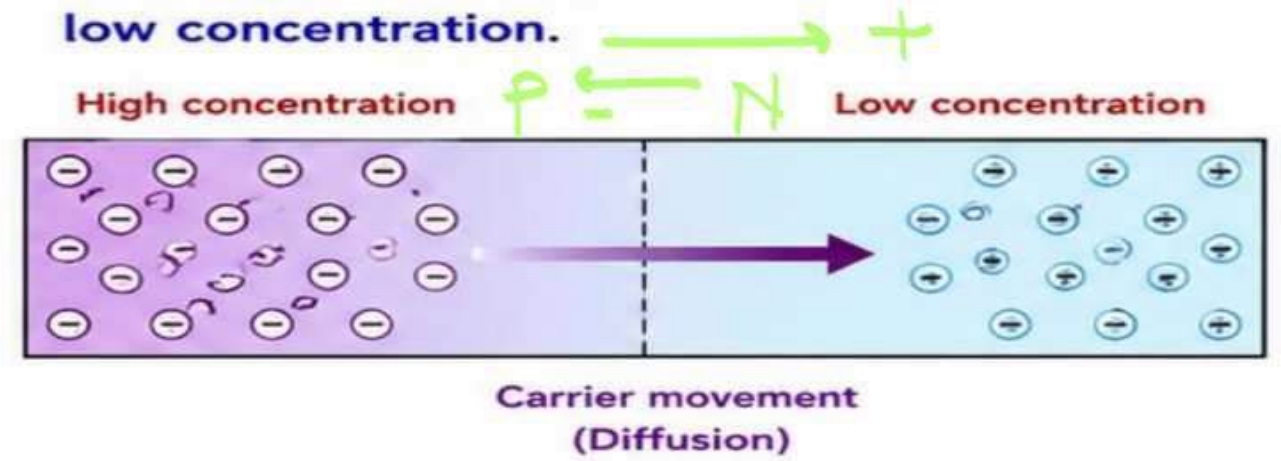
## Everyday Example:

When perfume is sprayed in one corner of a room, its molecules move from high concentration to low concentration and spread throughout the room.



## In Semiconductors:

When carrier concentration is high in one region and low in another, carriers (electrons or holes) diffuse from high concentration to low concentration.

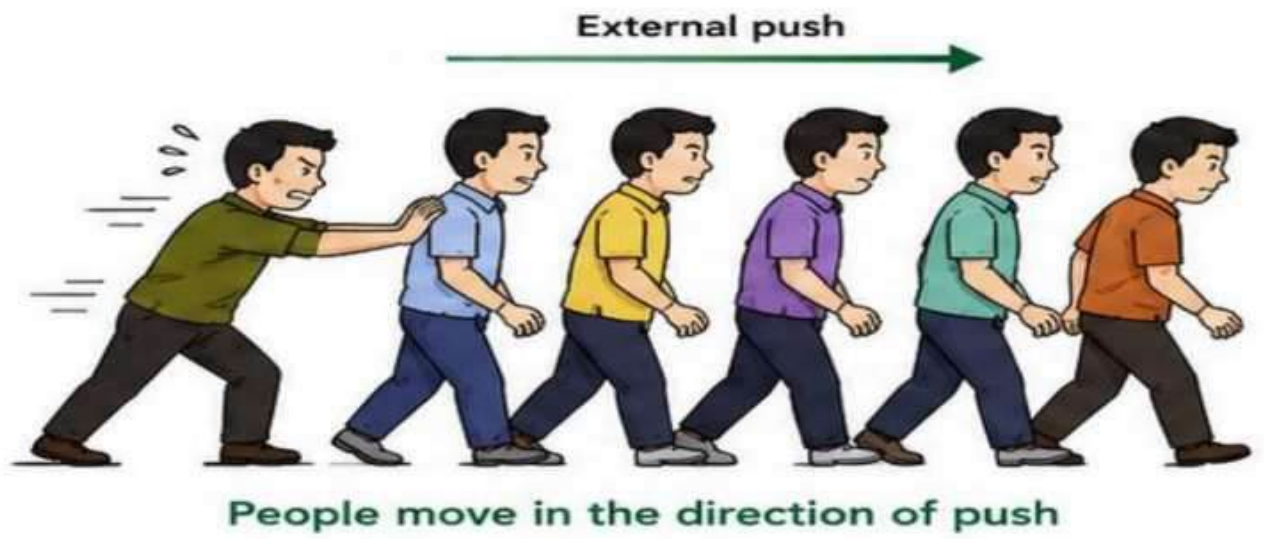


**Diffusion** = Movement of carriers due to concentration difference

# DRIFT (Due to Electric Field)

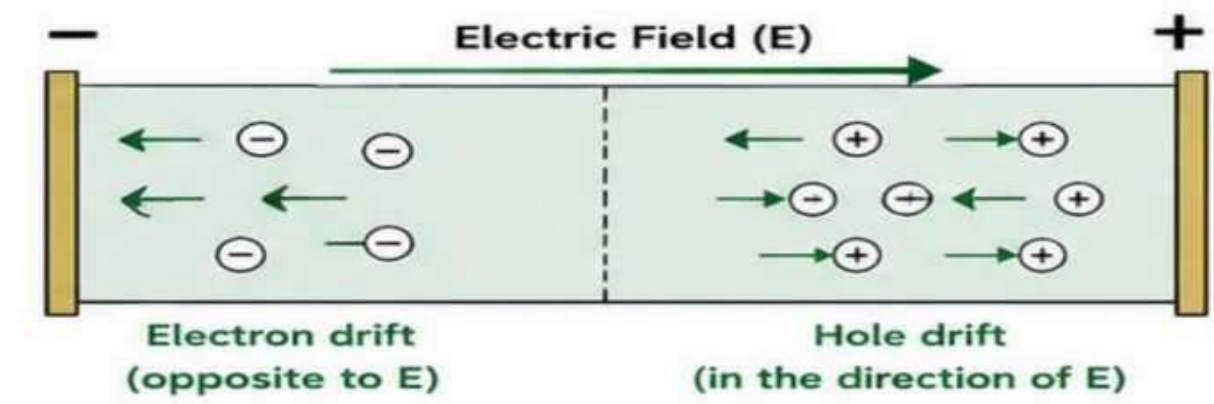
## Everyday Example:

In a crowded corridor, people are pushed from behind, they start moving in a particular direction (even if the crowd is uniform).



## In Semiconductors:

An external electric field exerts force on carriers, due to which they drift in a specific direction.



**Drift** = Movement of carriers due to electric field

## Key Point:

Total Current = Drift Current + Diffusion Current

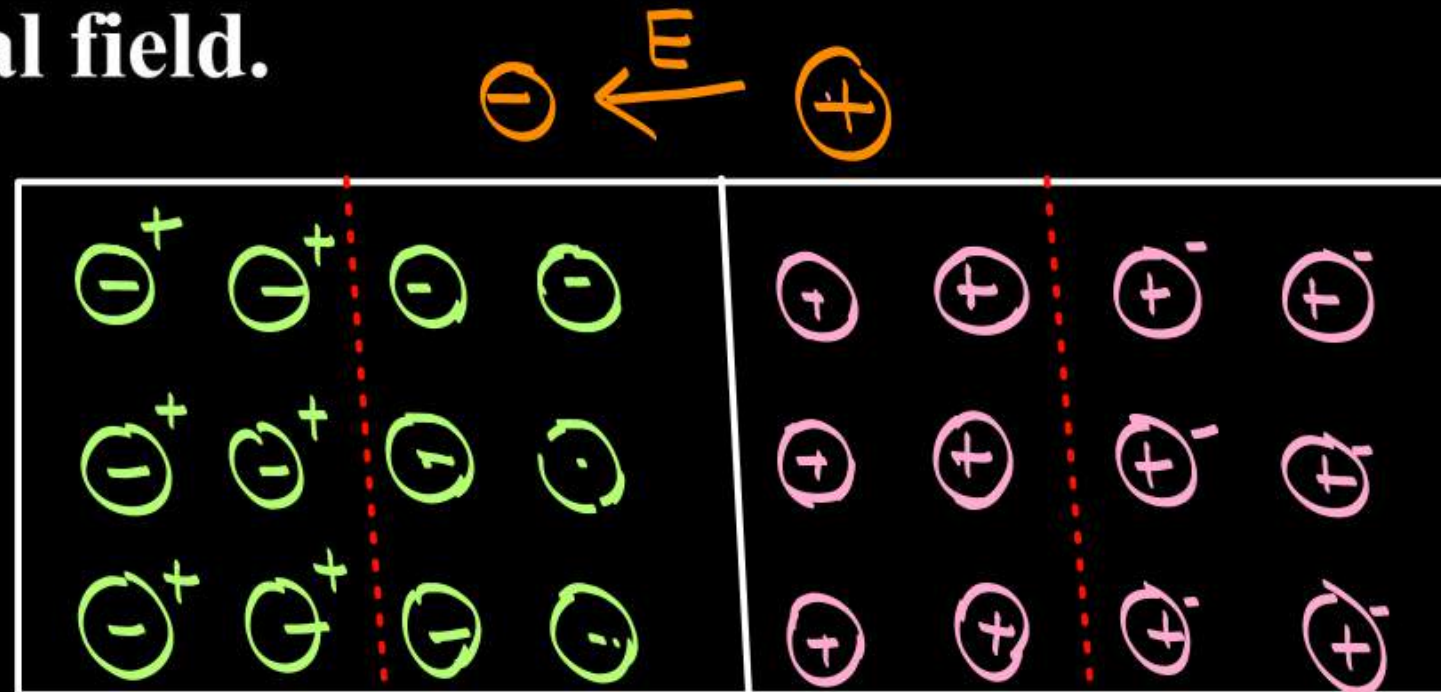
→ Both drift and diffusion are responsible for the flow of current.

# P-n Junction

1. When P-type and n-type semiconductor come in physical contact with each other, a P-n Junction is formed.
2. Due to Diffusion phenomena, the electrons and holes start moving & they recombine with each other.
3. So area near the junction is depleted from free charge carrier, which create electrical field.

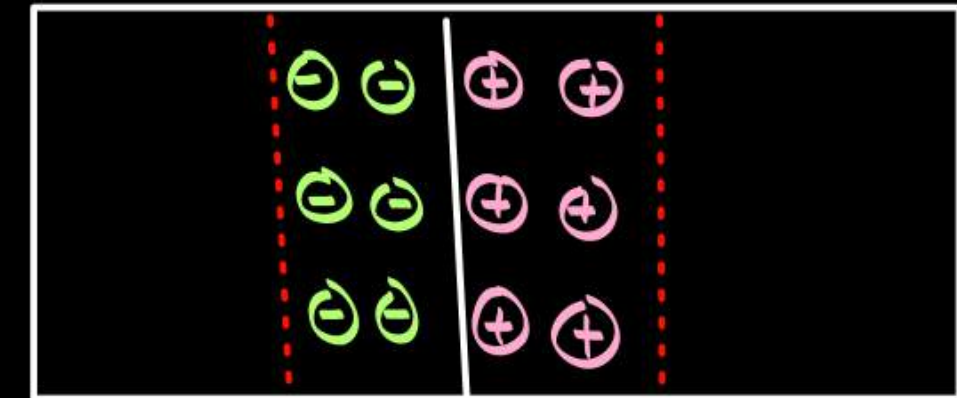
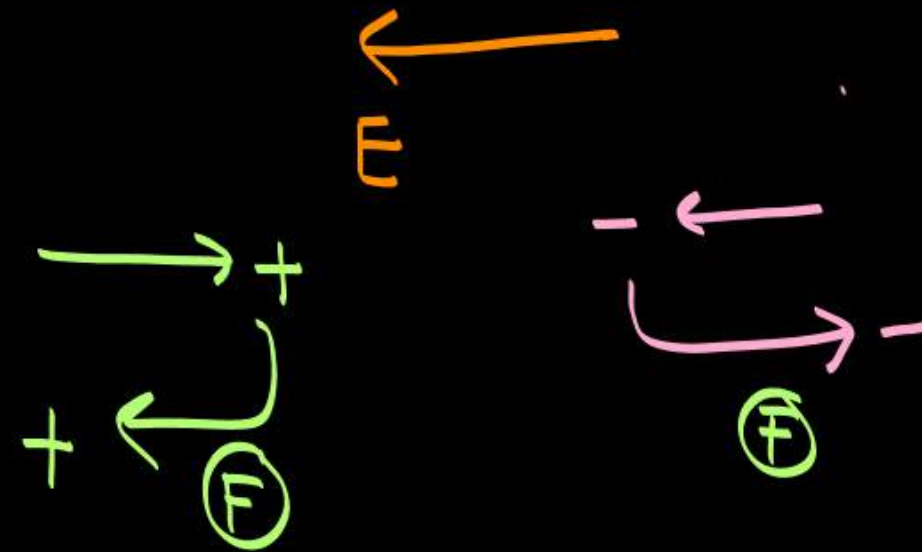
$$\bigcirc + \bullet = NL$$

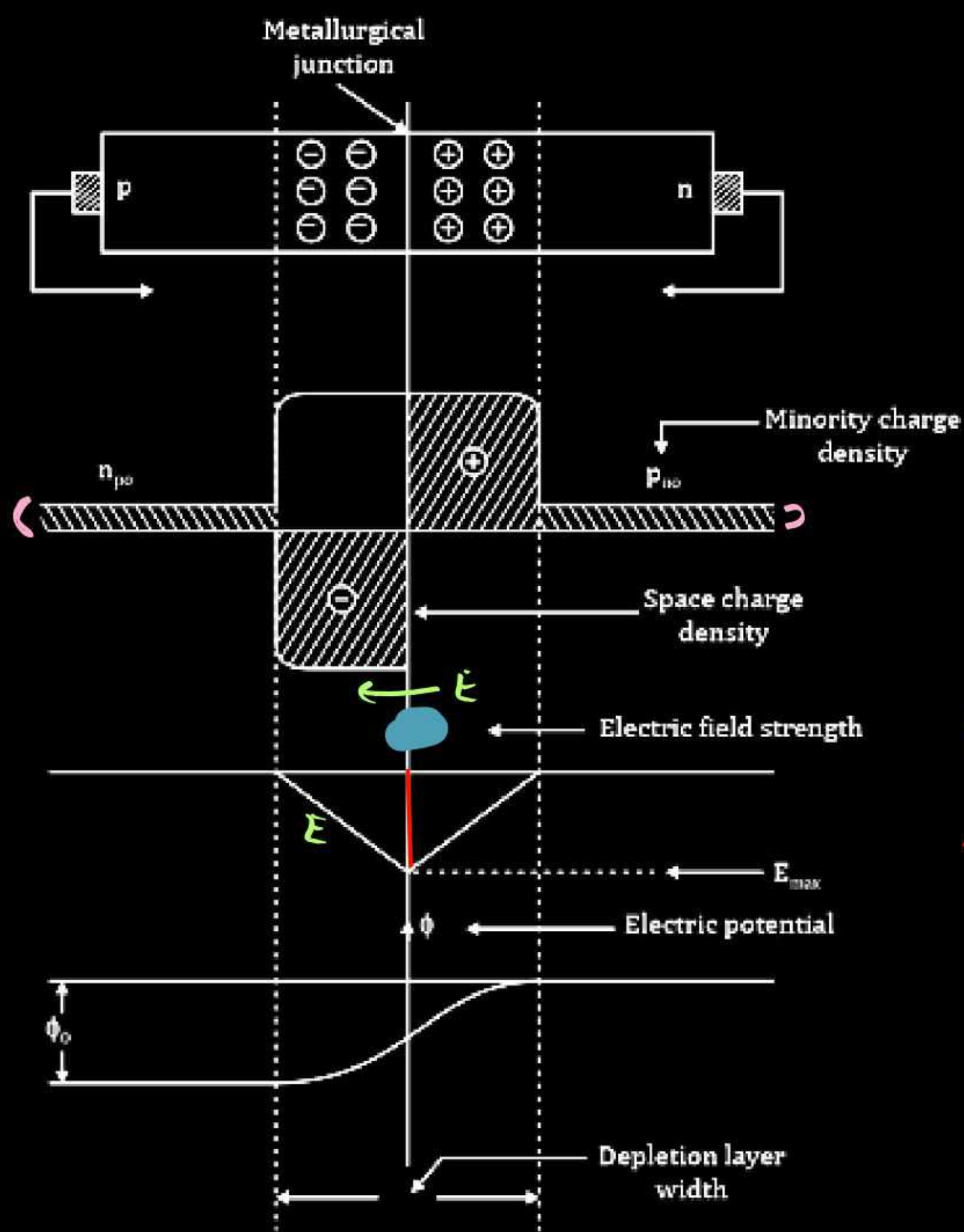
$$+ - =$$



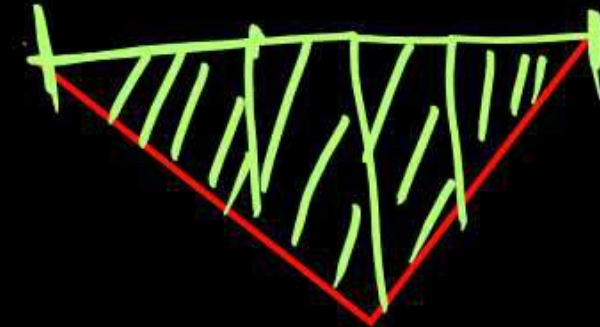
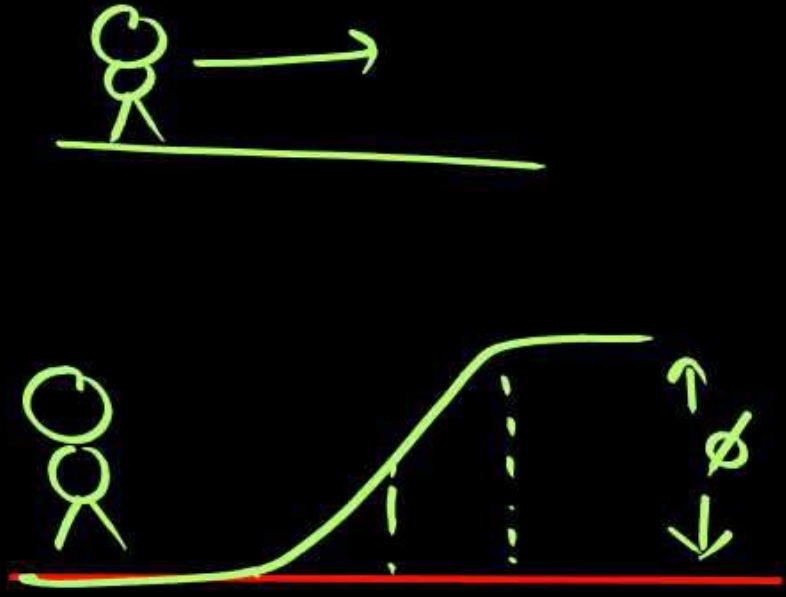
# P-n Junction

4. Due to this, electrical field creates potential barrier which stops the further diffusion of electrons & holes. At this time P-n junction are in thermal equilibrium condition.





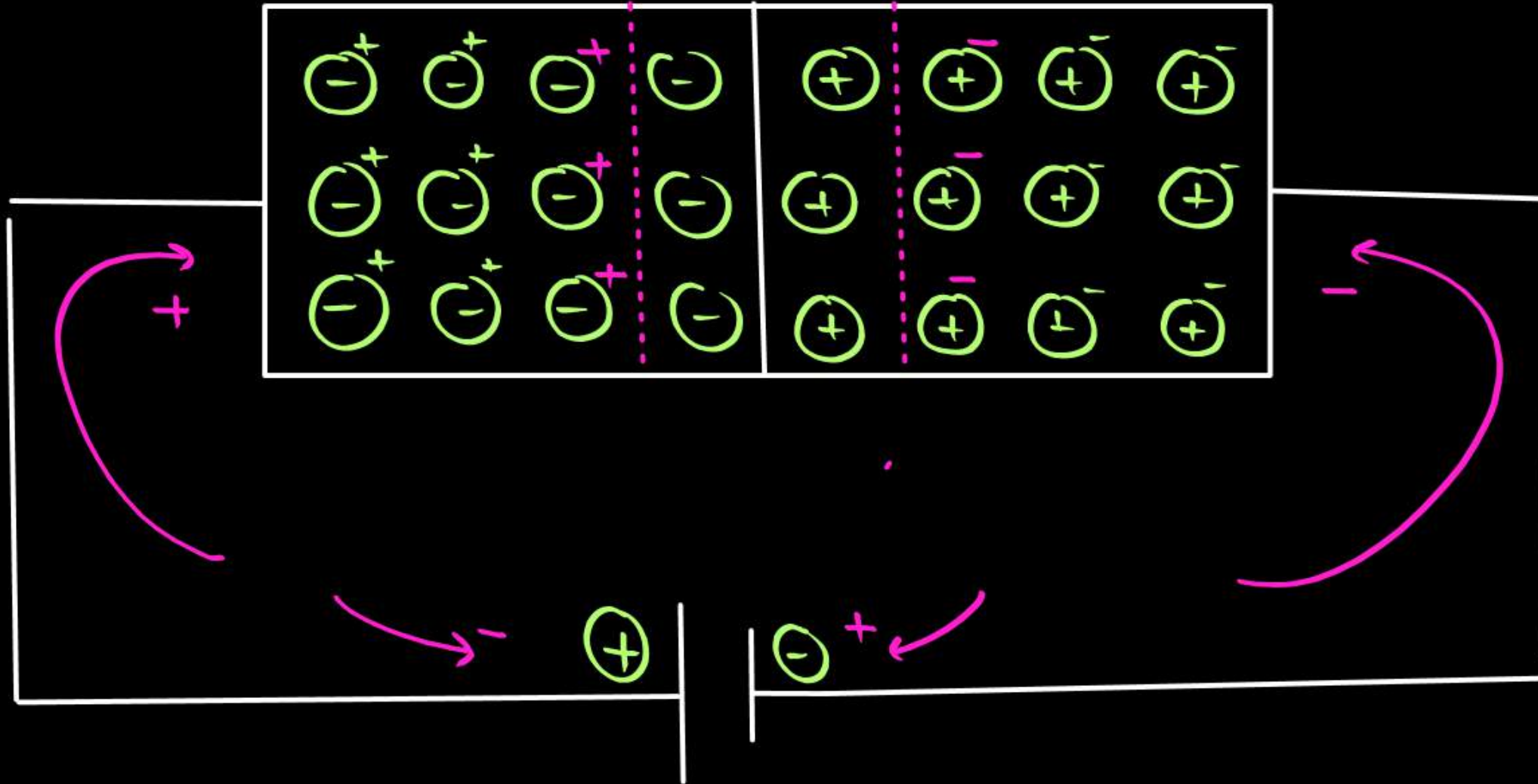
$$V = - \int E dx$$

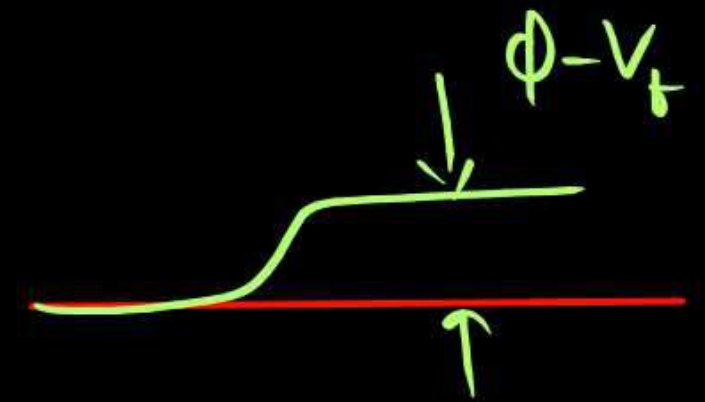
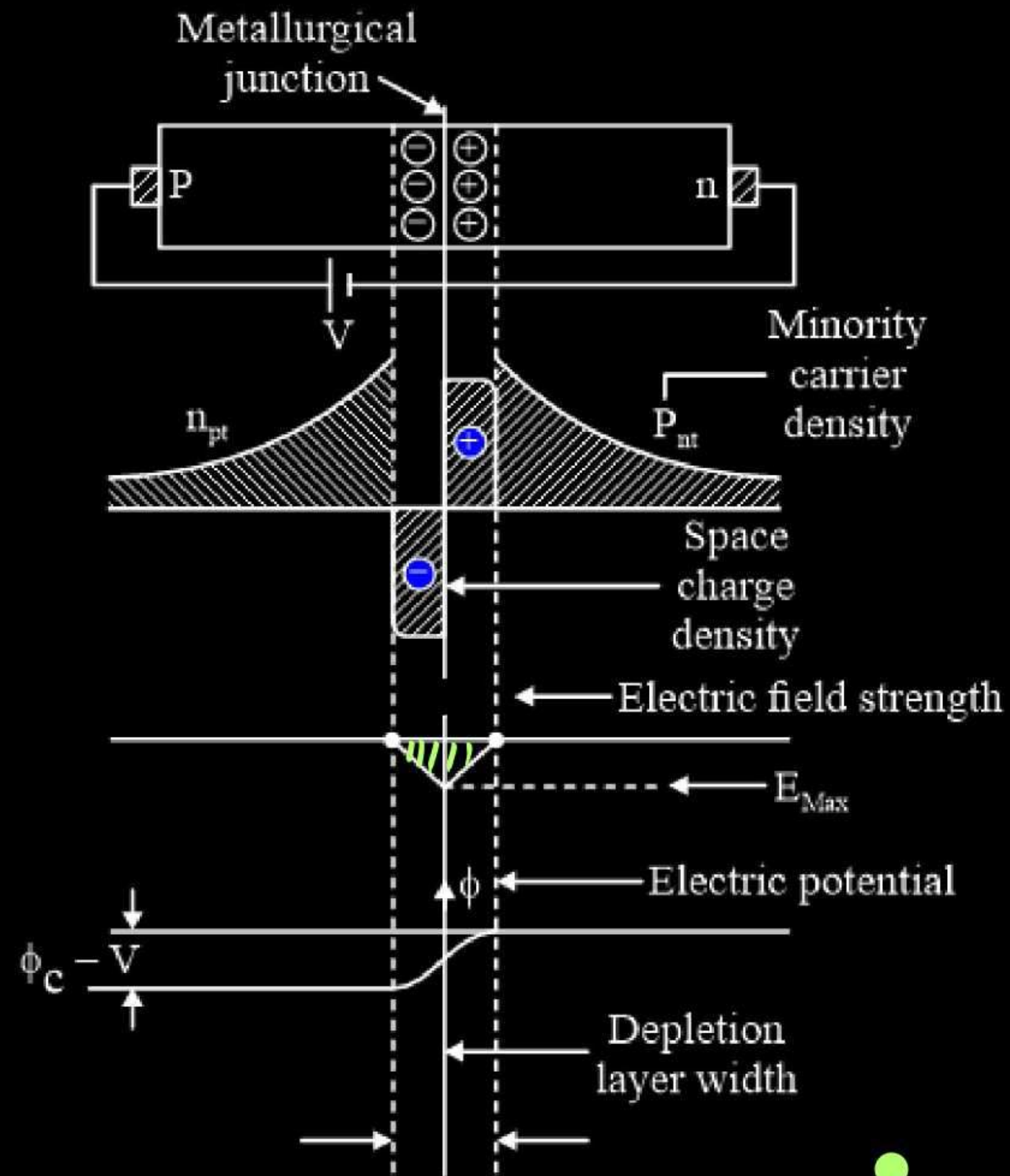


# P-n Junction

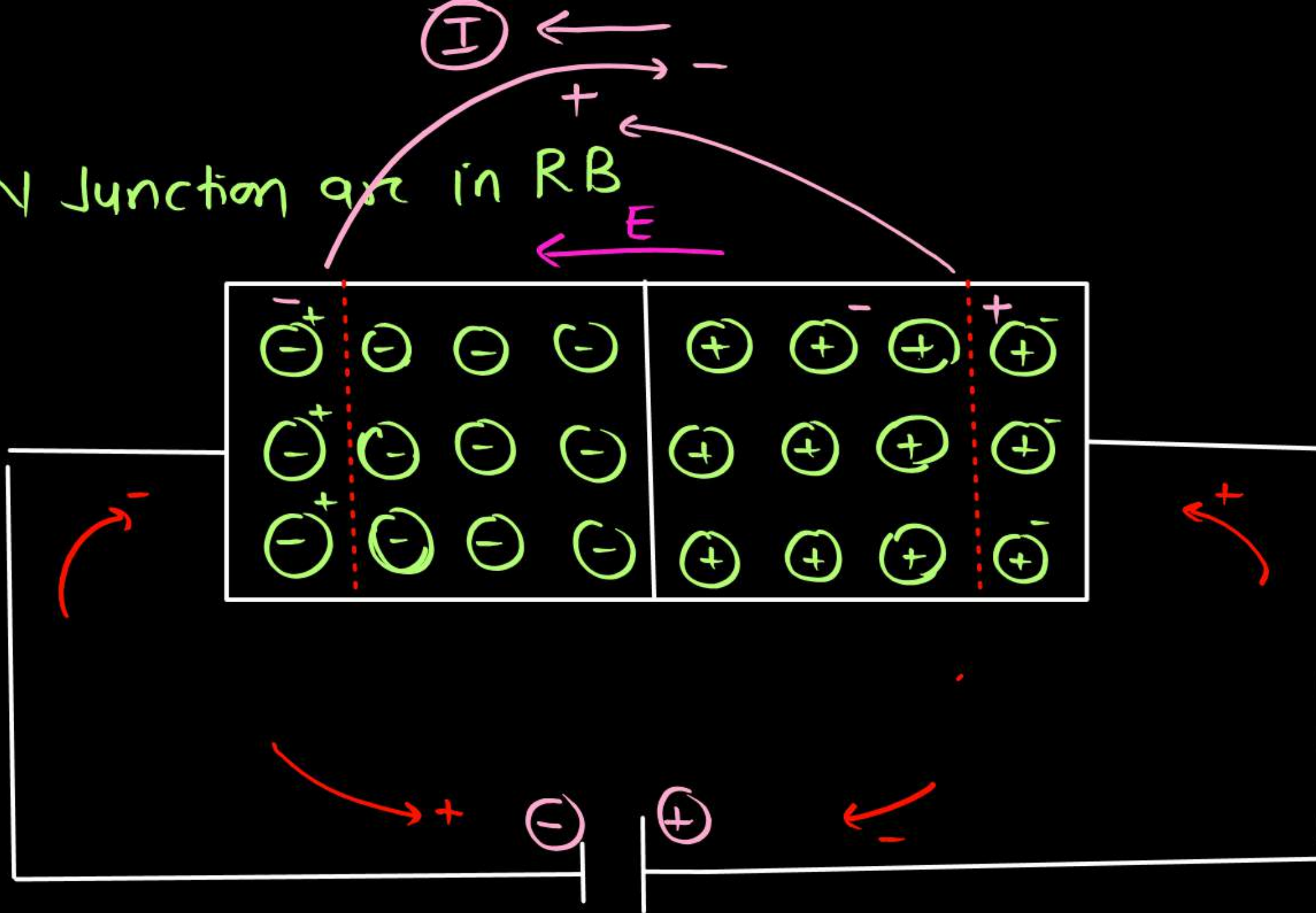
4. Due to this, electrical field creates potential barrier which stops the further diffusion of electrons & holes. At this time P-n junction are in thermal equilibrium condition.
5. When P-n junction is forward biased, the width of depletion layer as well as magnitude of  $E$  will be reduced. So potential barrier starts reducing.
6. Whenever potential barrier becomes zero, current starts flowing in forward direction. In this condition, current flows due to diffusion.

# PN Junction in F.B.

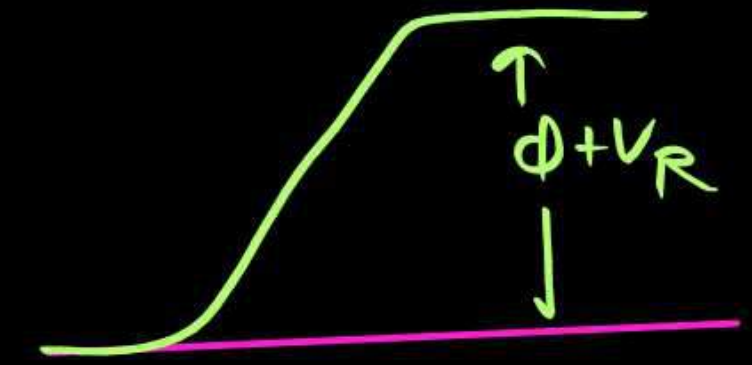
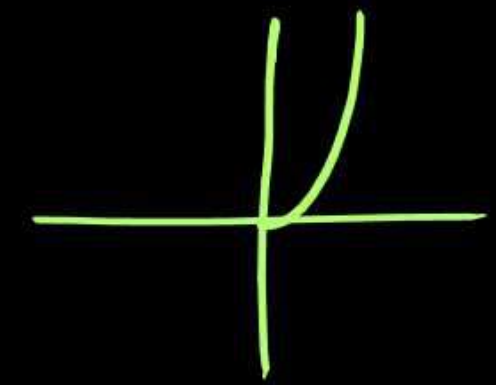
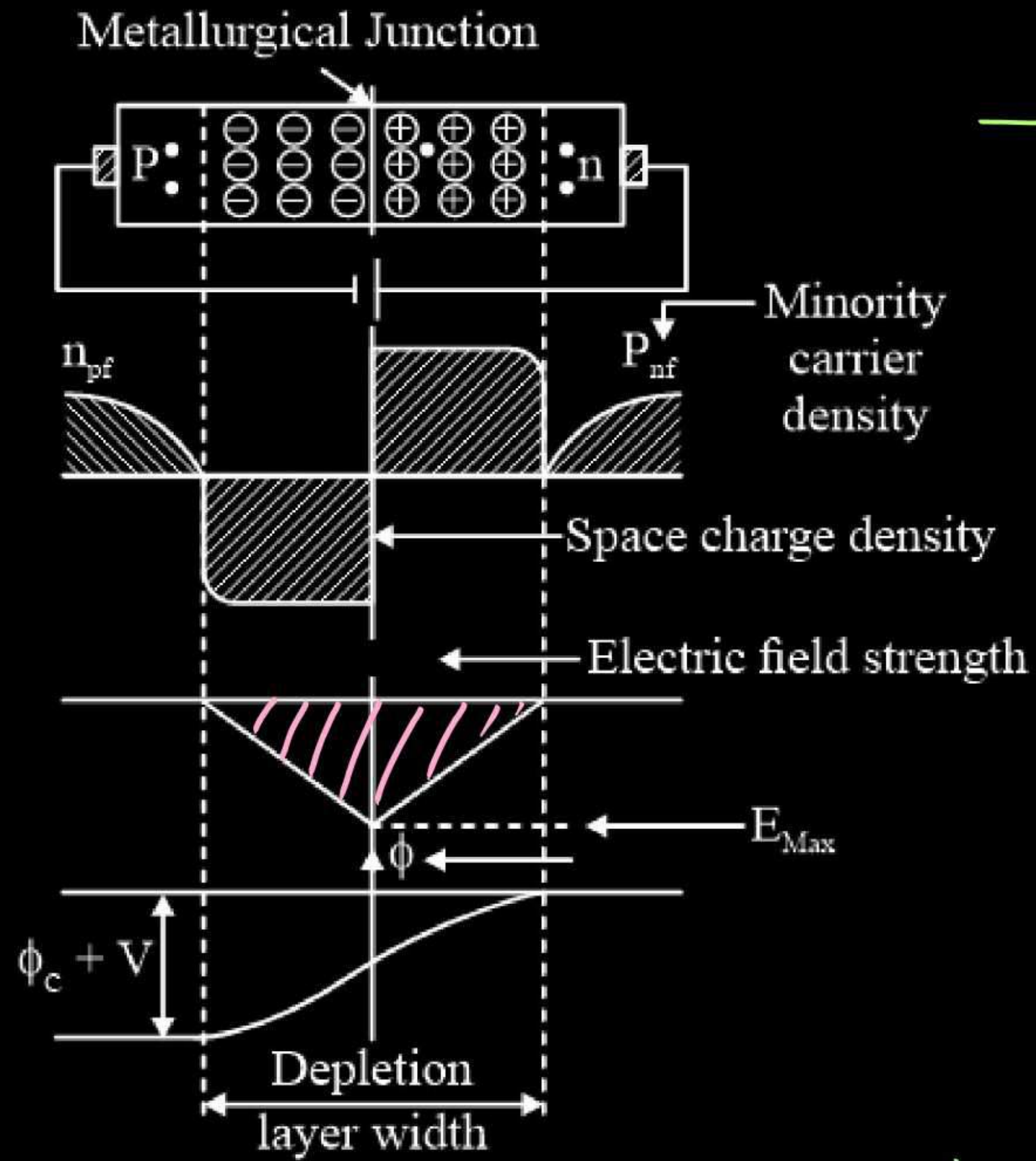


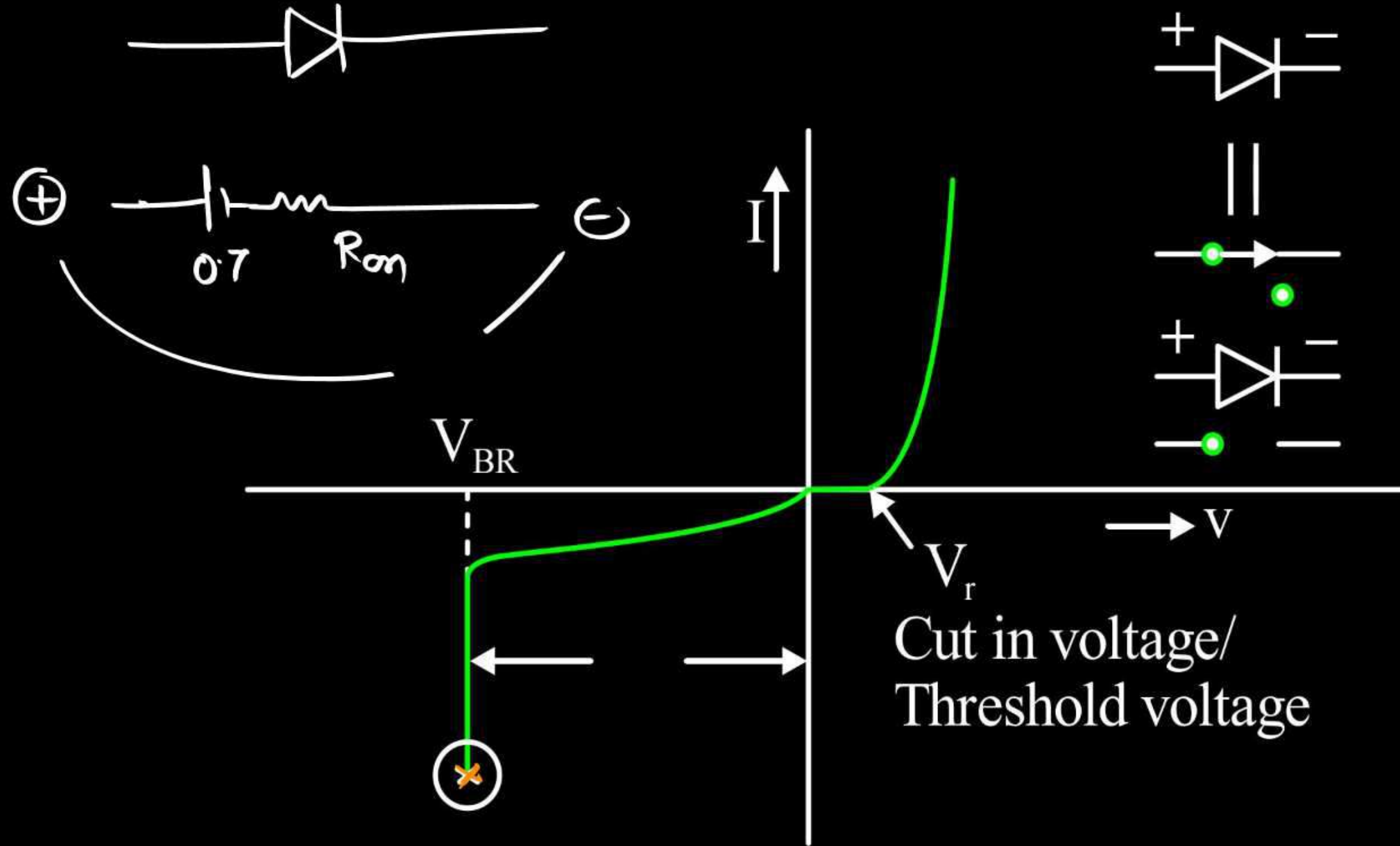


## PN Junction ~~are~~ in RB

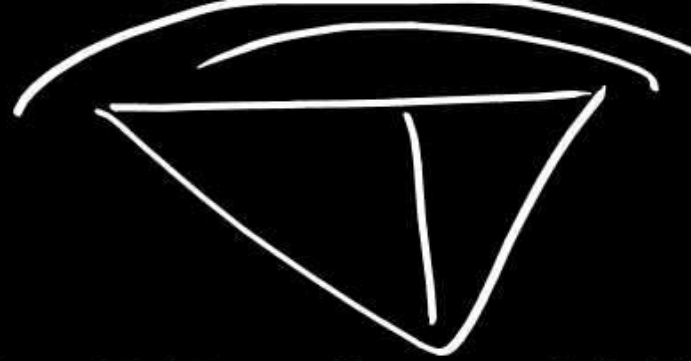


$$\begin{array}{c} V_R \uparrow \\ \downarrow \\ \rightarrow E \uparrow \\ \downarrow \\ \rightarrow F \models q \quad E \uparrow \end{array}$$



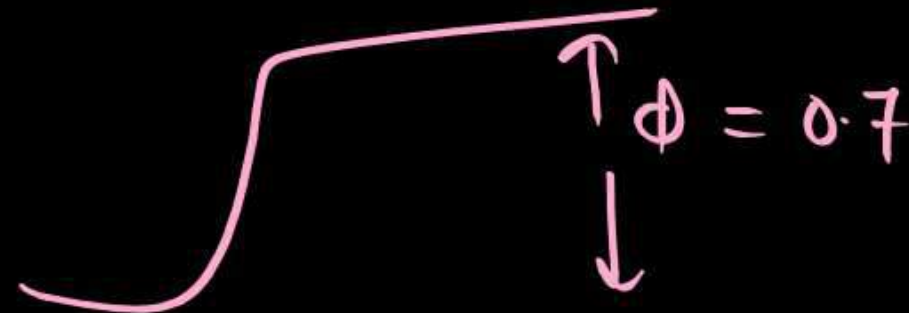


# P-n Junction

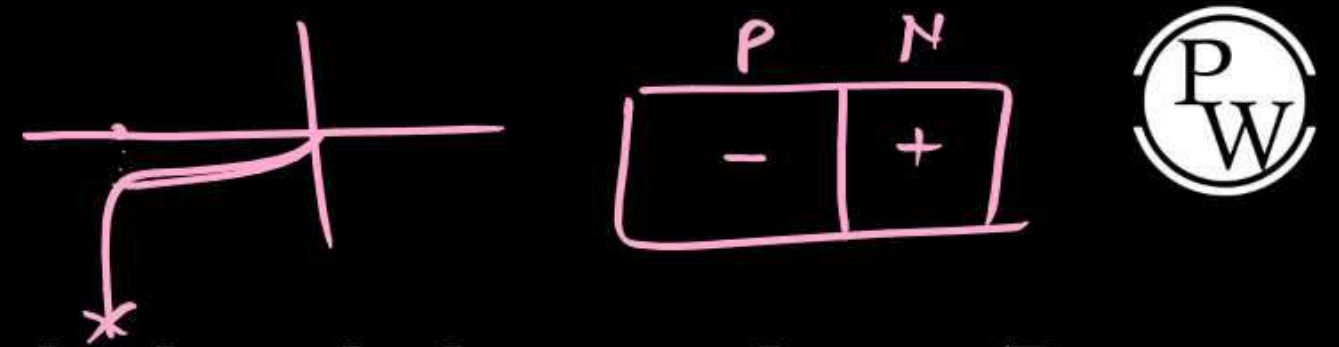


7. When P-n junction is RB, the width of depletion layer as well as magnitude of electric field both increase which increases the barrier potential. Therefore, diffusion is not possible.
8. But still small amount of current is flowing due to minority charge carrier, which is called Reverse Saturation Current.
9. The magnitude of reverse saturation current depends on temperature.

$$0.7 - 0.5 = 0.2$$



# P-n Junction



- 10.** If we go on increasing reverse voltage, at the break down voltage (Due to impact Ionisation), the number of free charge carrier increases rapidly.
- 11.** In Break-down region, the magnitude of voltage & current is very high. So, power loss will be high which may damage the diode.
- 12.** Therefore, the applied reverse voltage should be less than break down voltage.

$V_R \uparrow \rightarrow \text{width of depletion layer} \uparrow \rightarrow \text{Electrical field} \uparrow$

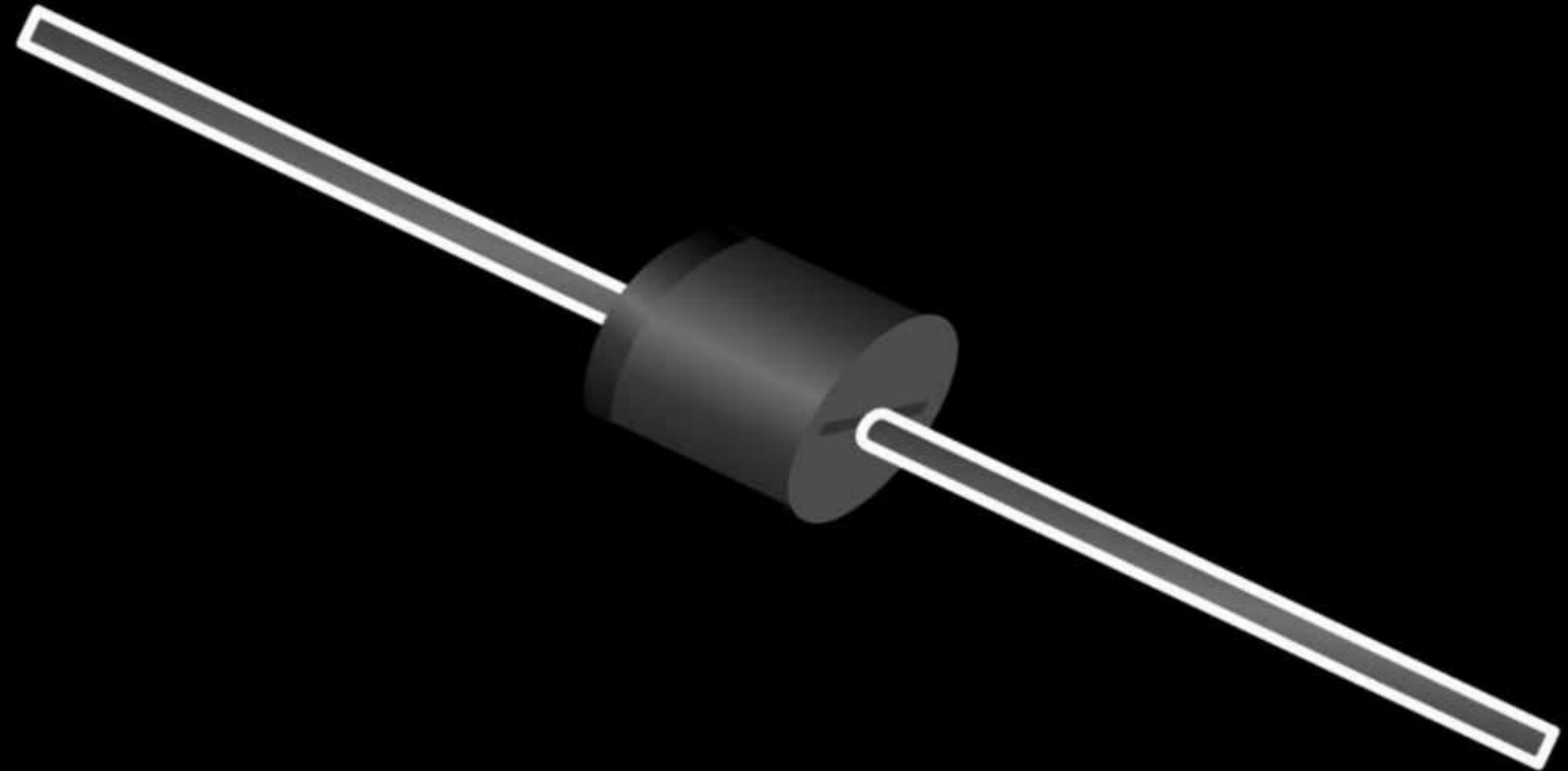
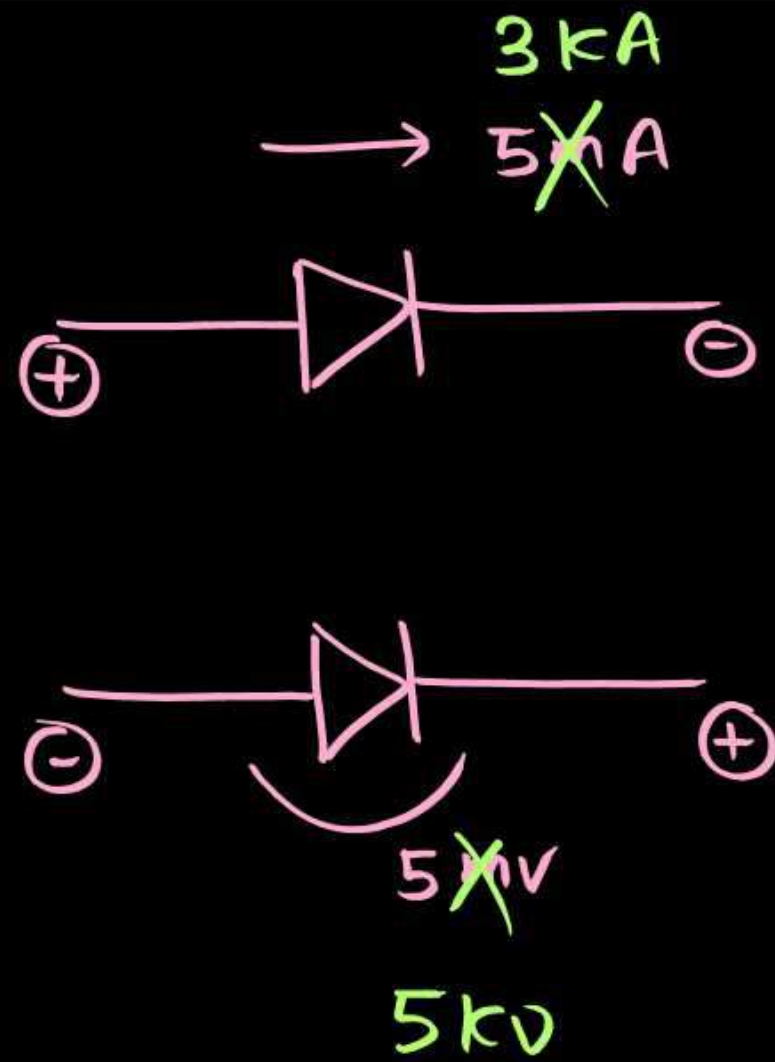
$\rightarrow F \uparrow \rightarrow qE \uparrow \rightarrow$

# Some points about P-N Diode:

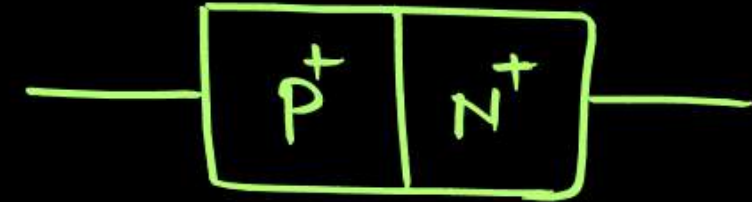


1. In thermal equilibrium condition depletion region( space charge region ) exist. Which create barrier potential  $\phi$
2. Forward bias reduce width of depletion region Forward current flows due to majority charge carrier if forward voltage is more than cut-in(threshold) voltage.
3. Reverse bias increase width of depletion region, Reverse saturation current flows due to minority charge and this current mainly depend on temperature.
4. Above breakdown voltage impact ionisation takes place and reverse current increases with faster rate.
5. We can use diode only up to breakdown voltage. It shown the reverse blocking capacity.

# Power Diode



# Construction of Power Diode



1. In power diode, P & n type semiconductor layers are connected in vertical configuration. In vertical configuration, large cross section area is possible which reduces "on state resistance"  $R_m$ . So more amount of current can be flown without excessive power loss.

$$150^\circ \rightarrow 10,000 \text{ W}$$

$$10,000 = I^2 (150)$$

$$I^2 = 150$$

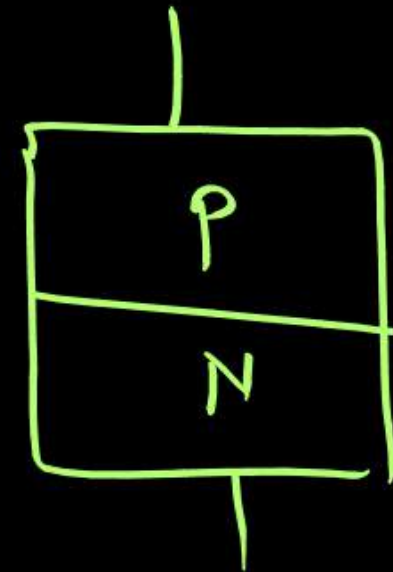
$$I = 10$$

$$R_{on} \downarrow = \frac{\rho l}{A \uparrow}$$

$$P = I^2 \uparrow R_{on} \downarrow$$

$$10,000 = I^2 (1)$$

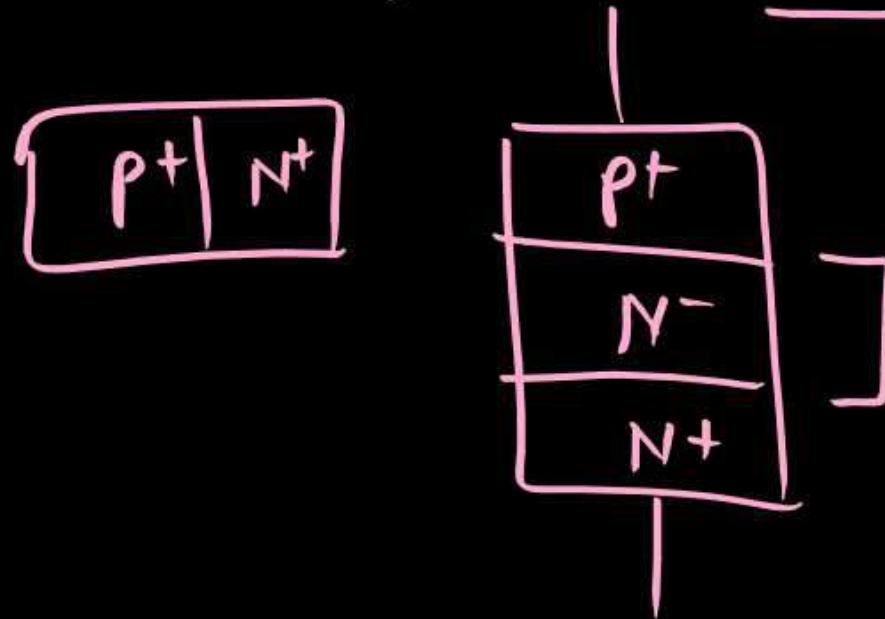
$$I = 100 \text{ A}$$

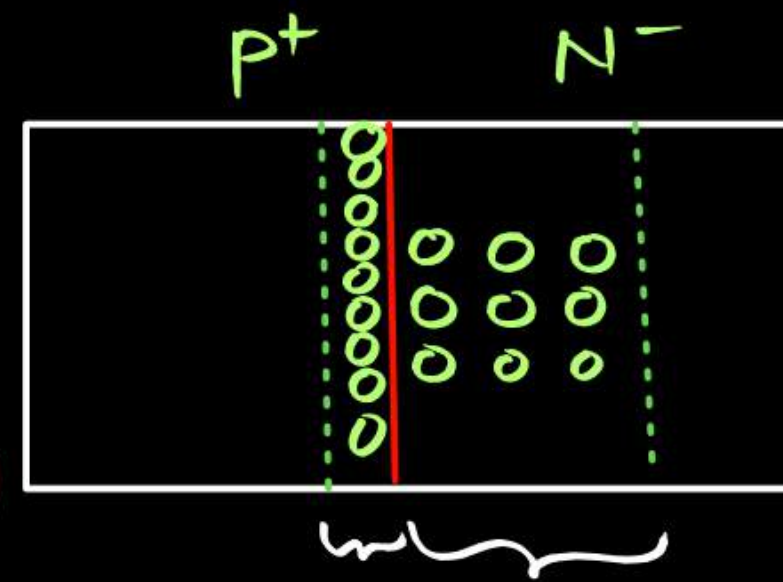
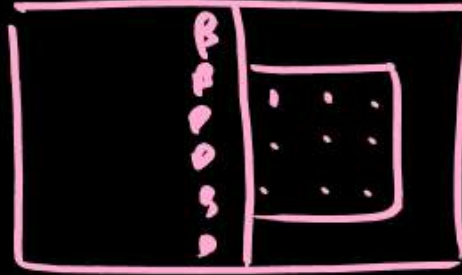
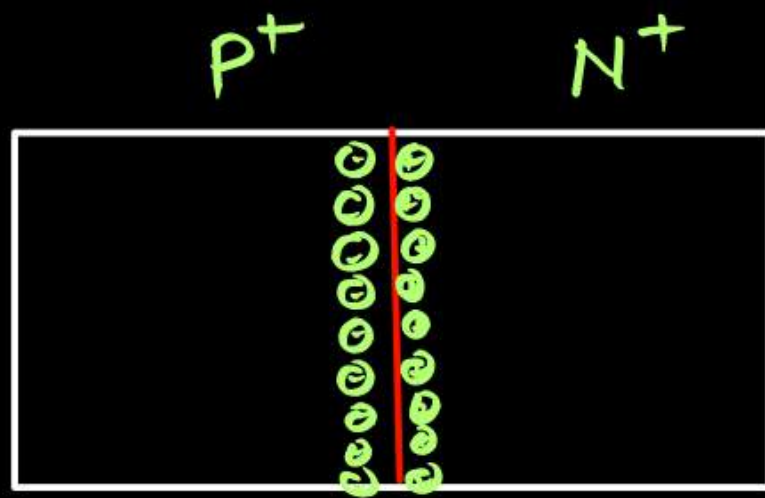


# Construction of Power Diode

$$R_{th} \propto \frac{1}{A \uparrow}$$

2. Large cross-section area also decreases thermal resistance. So it helps in cooling the device.
3. In vertical configuration, it can be easily mounted on heat sink.
4. To increase the voltage rating, we introduce a lightly doped drift region between p<sup>+</sup> and n<sup>+</sup> layer. The drift region increases width of the depletion layer which ultimately increases B.D. voltage.





→ So depletion layer penetrate mainly in lightly doped region.

$$\text{Width of depletion layer} \propto \frac{1}{\text{Doping Density}}$$

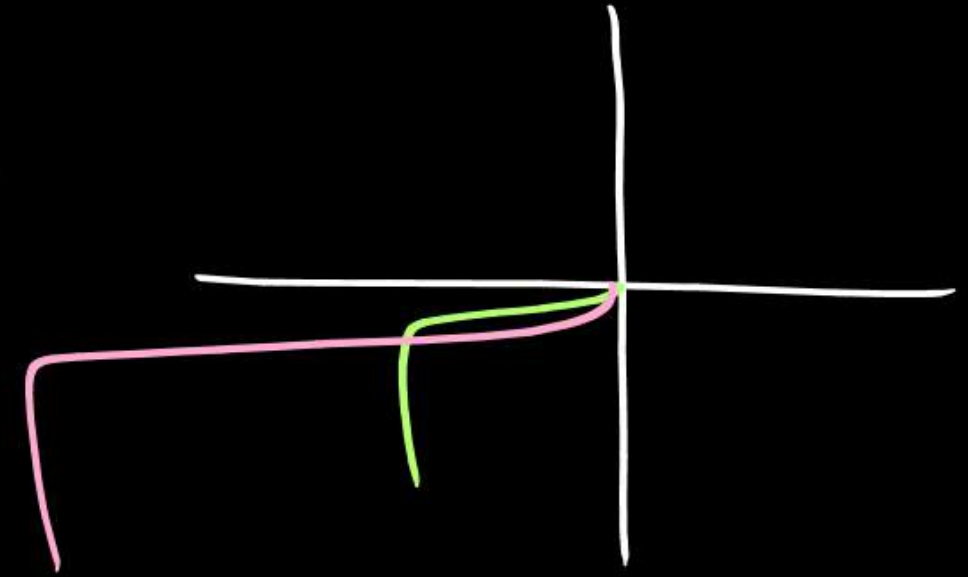
$$\underline{F} = q \underline{E}$$

eg.  $E = 5 \text{ kV/cm}$  Breakdown occur

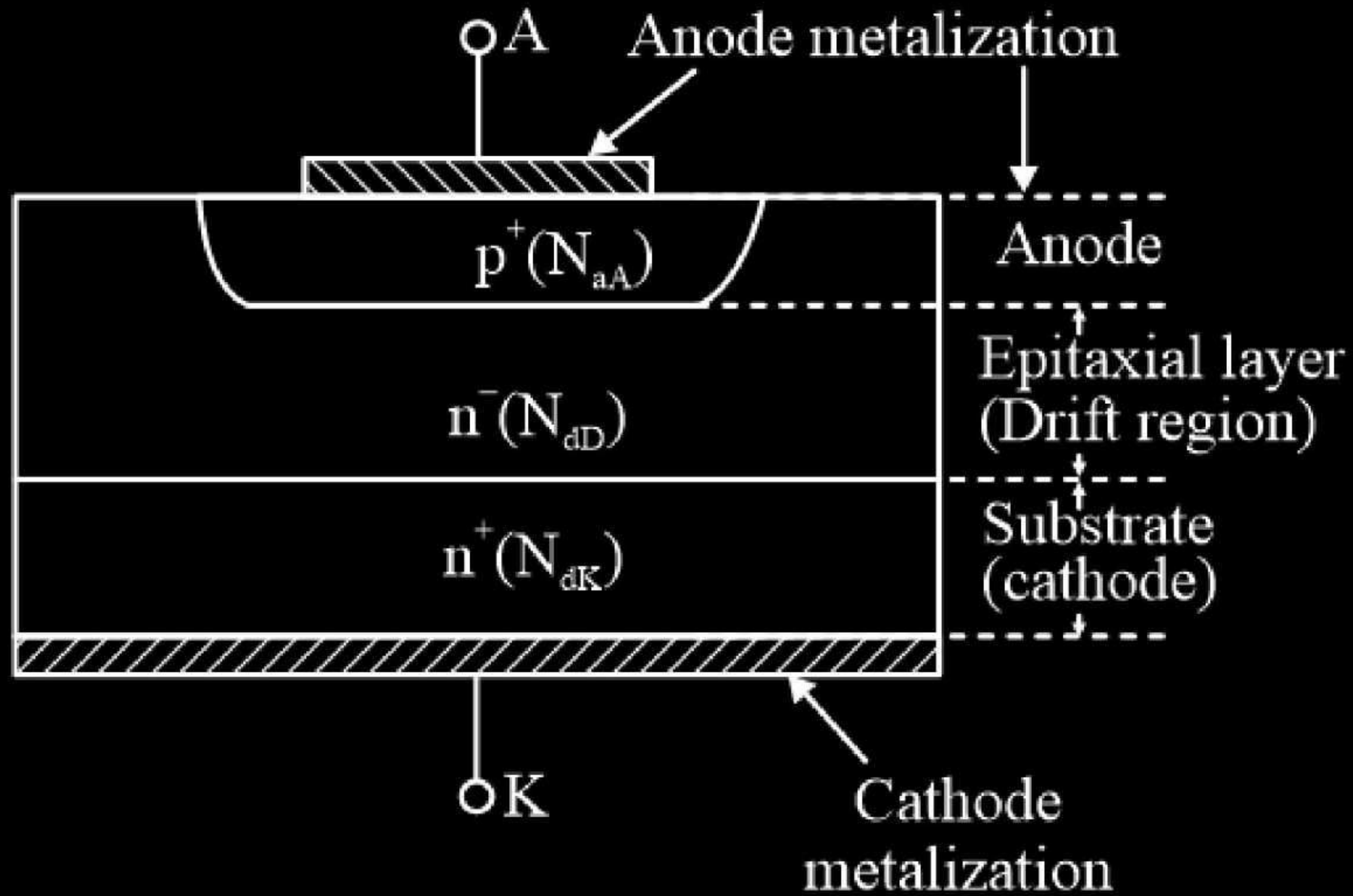
$$V = E x$$

$$x = 1 \text{ cm} \quad V_{BR} = 5 \times 1 = 5 \text{ kV}$$

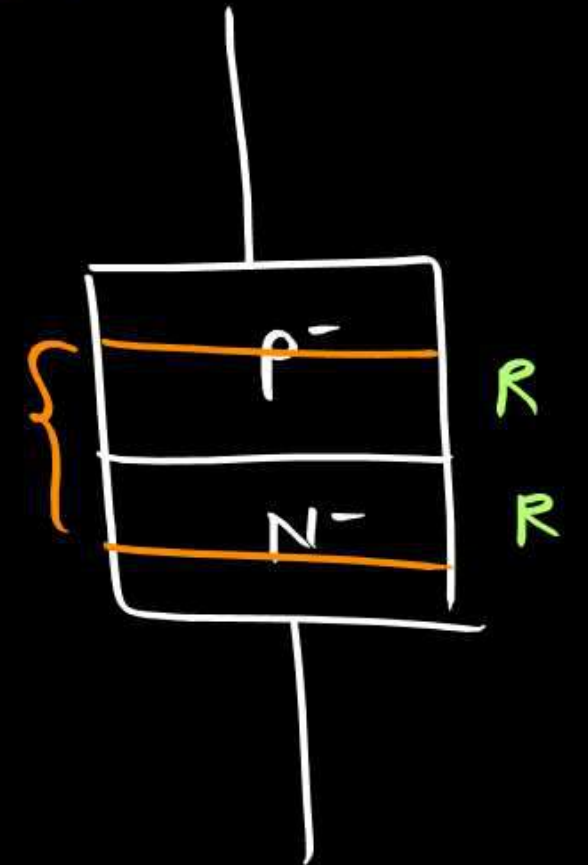
$$x = 10 \text{ cm} \quad V_{BR} = 5 \times 10 = 50 \text{ kV}$$



Voltage Rating = width of Drift Region



V Ratio ↑  
 I Ratio ↓





## 2 Minutes Summary

→ P-N Junction.

→ F.B

→ R.B

→ Breakdown

→ Power diode



**THANK YOU**



# Electrical Engineering

## Power Electronics



Lecture No - 2

Power Semi conductor devices

By- Ajay Gupta Sir



# Recap of Previous class

1. P-N Junction

2. Construction of Power Diode

3. Characteristic of Diode



**Topic is  
To be  
covered**

1. Characteristic of diode

2. Reverse recovery Characteristic

# Construction of Power Diode

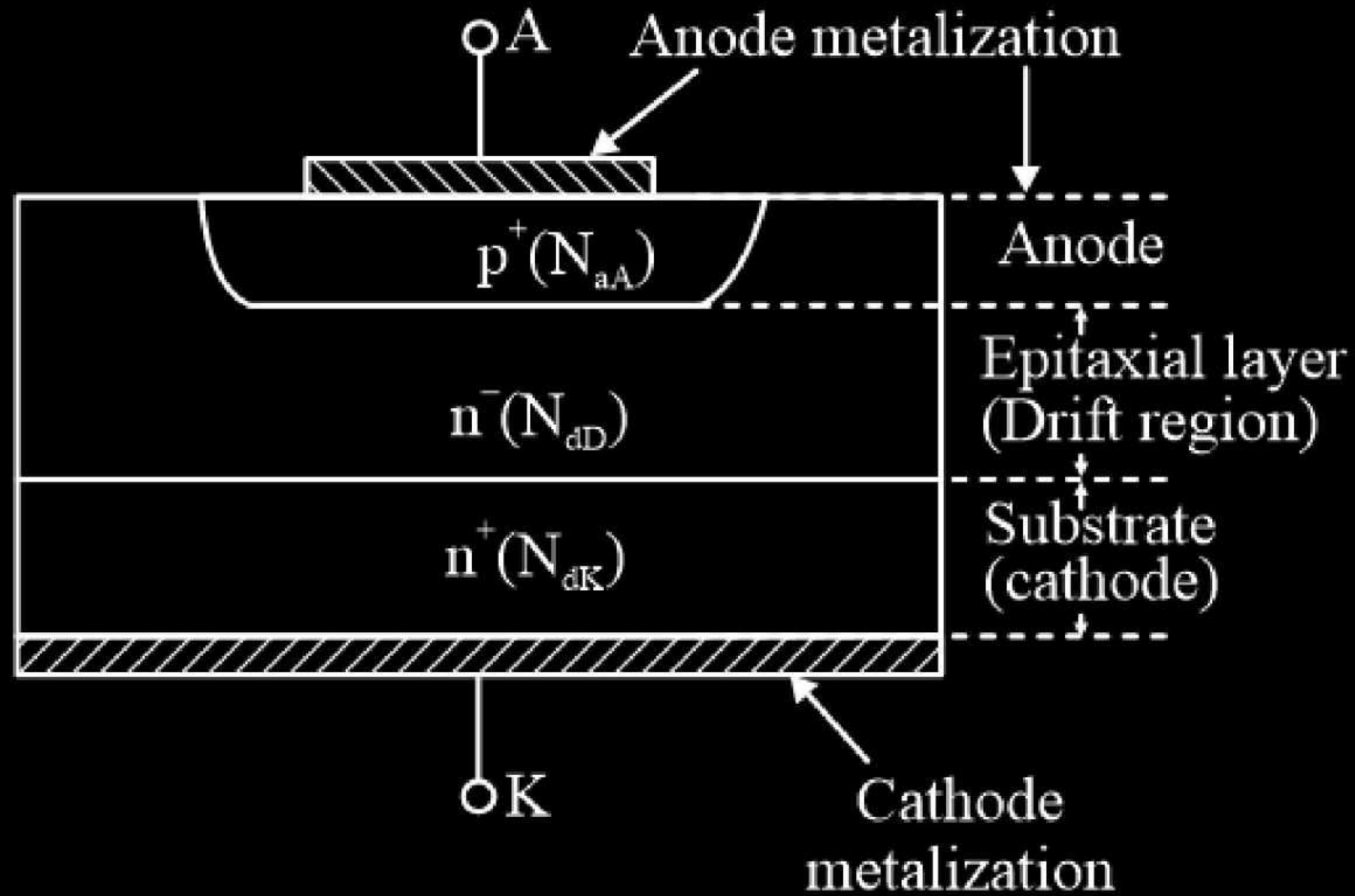
1. In power diode, P & n type semiconductor layers are connected in vertical configuration. In vertical configuration, large cross section area is possible which reduces “on state resistance”  $R_m$ . So more amount of current can be flown without excessive power loss.

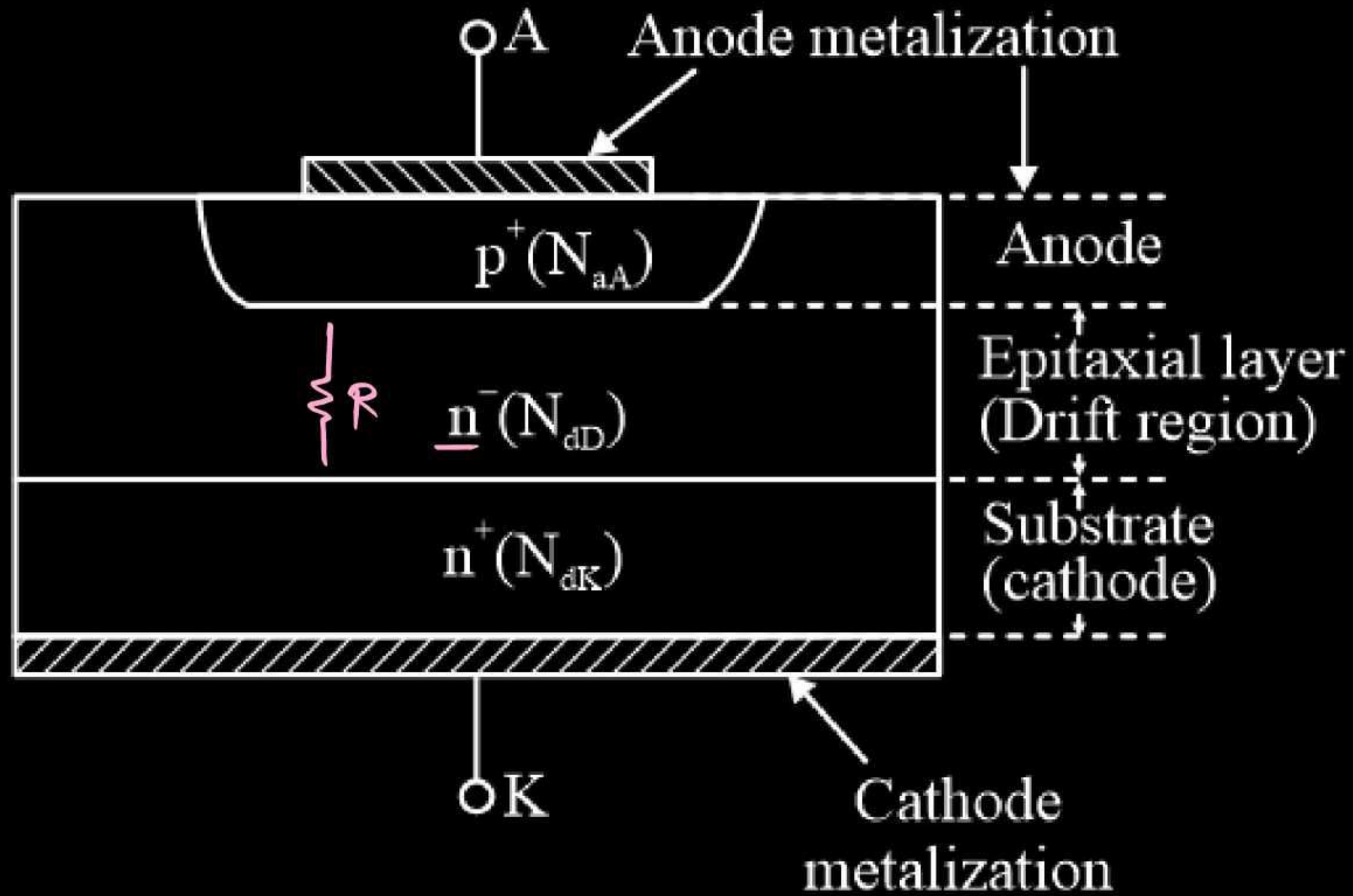
$$R_{on} \downarrow = \frac{\rho l}{A \uparrow}$$

$$P = I_b^2 \uparrow R_{on} \downarrow$$

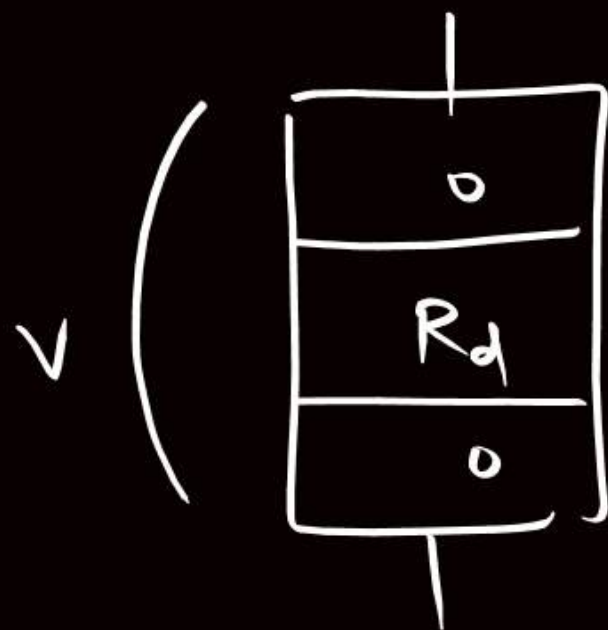
# Construction of Power Diode

2. Large cross-section area also decreases thermal resistance. So it helps in cooling the device.
3. In vertical configuration, it can be easily mounted on heat.
4. To increase the voltage rating, we introduce a lightly doped drift region between  $p^+$  and  $n^+$  layer. The drift region increases width of the depletion layer which ultimately increases B.D. voltage.

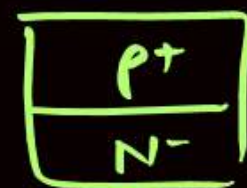
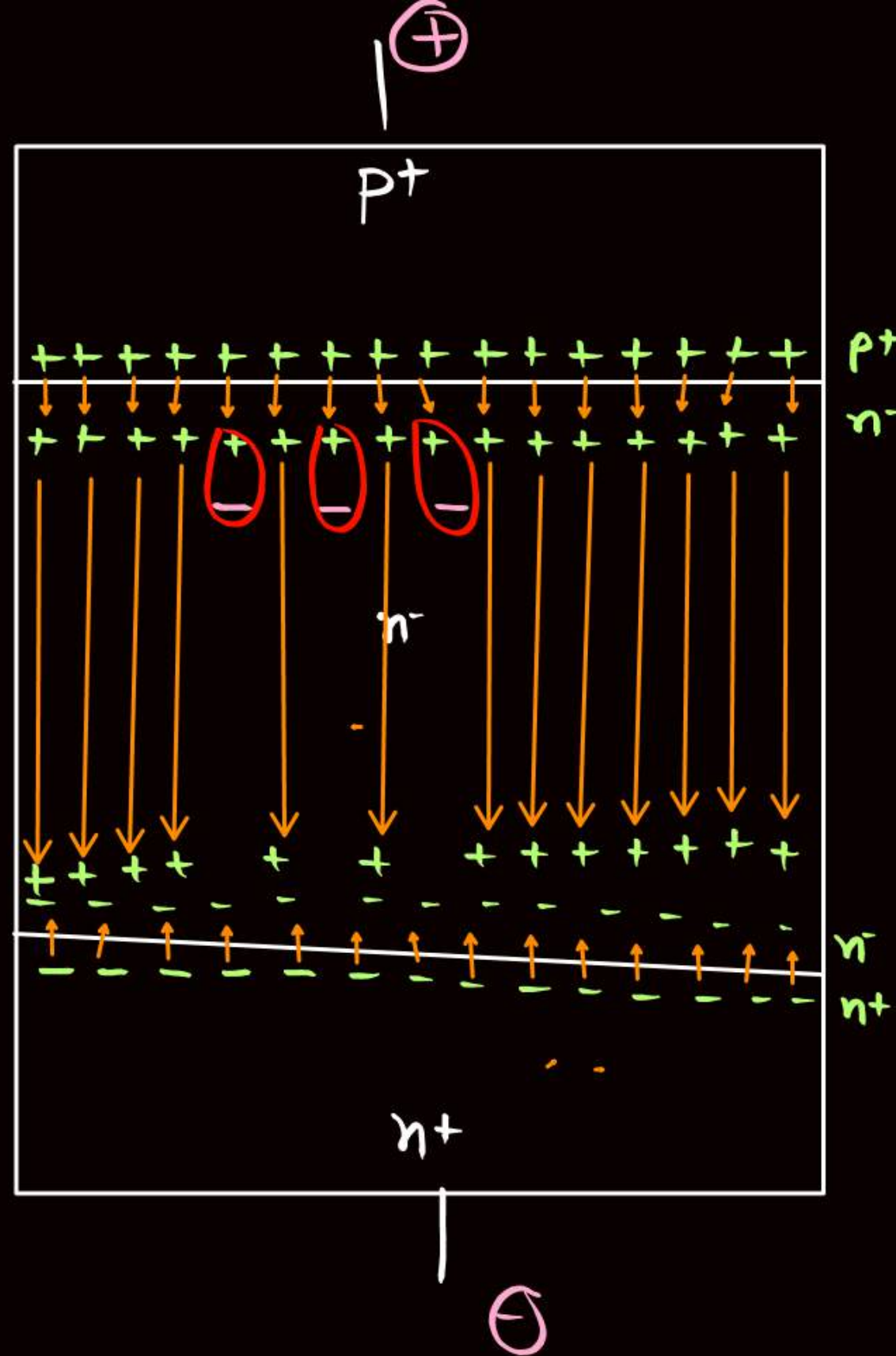




$$\sigma \downarrow = \frac{1}{\rho \uparrow}$$



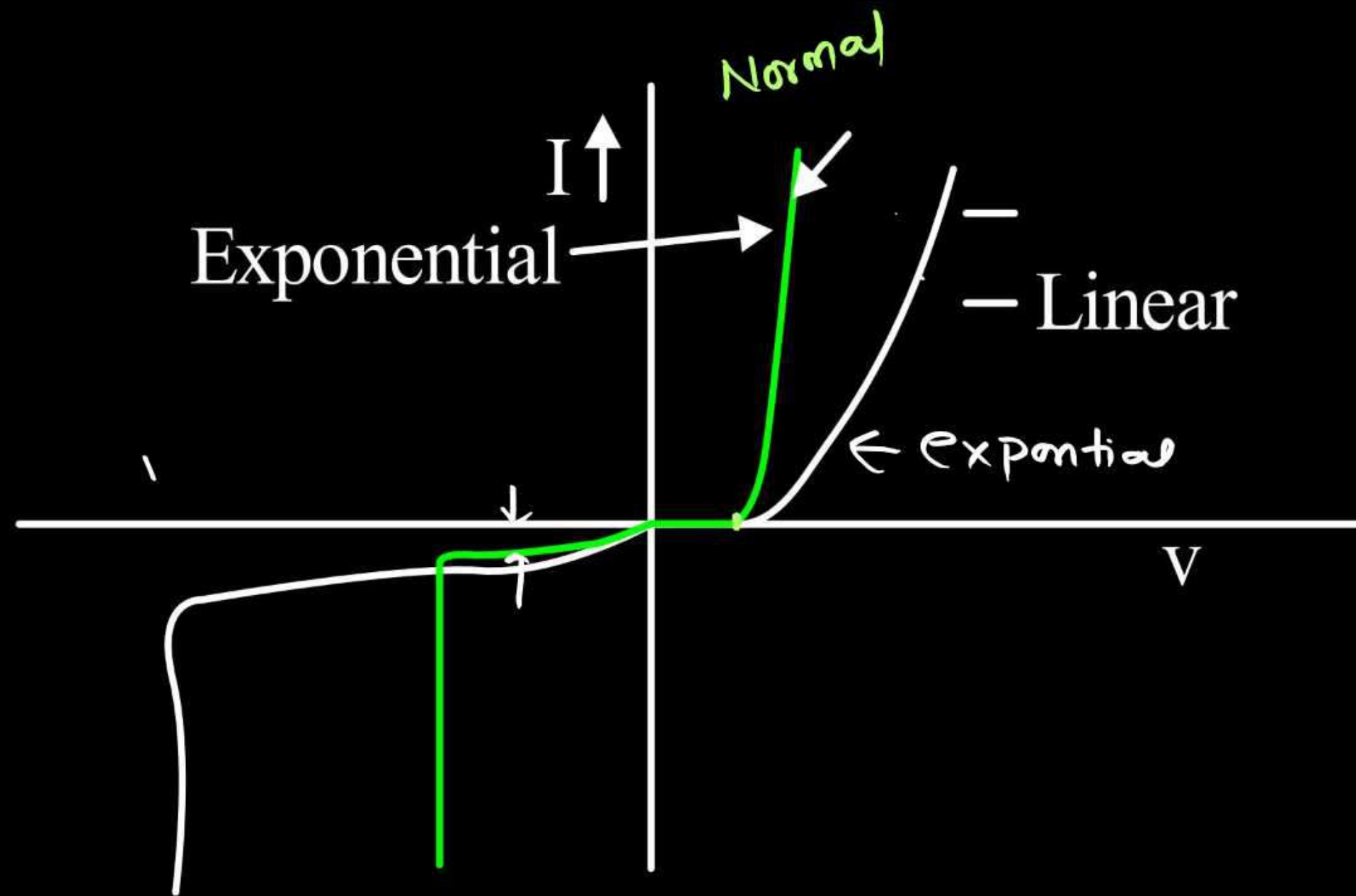
$$V \propto \underline{I} R_d^+$$



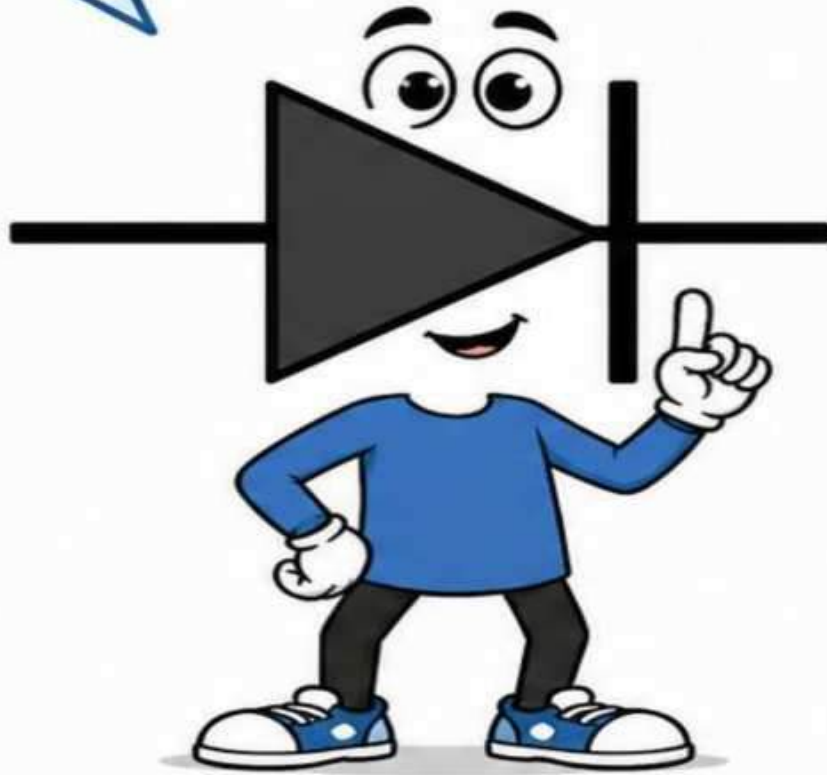
$$q \uparrow \Rightarrow \frac{1}{p \downarrow} \Rightarrow R$$

# Conductivity Modulation

1. When power diode is FB and large amount of Forward current is flowing.
2. The holes are moving from  $p^+$  layer to  $n^-$  Drift region, some of these hole recombine with the electrons in drift region but majority of holes diffuse toward junction ( $n^- n^+$ ).
3. Now, these positive holes start attracting negative electrons from  $n^+$  layer, so at particular instant, the drift region has large number holes and electrons which increase its conductivity. This phenomena is called Conductivity modulation.
4. Due to conductivity modulation, the resistance of Drift layer automatically decreases.



I am a  
**NORMAL DIODE**



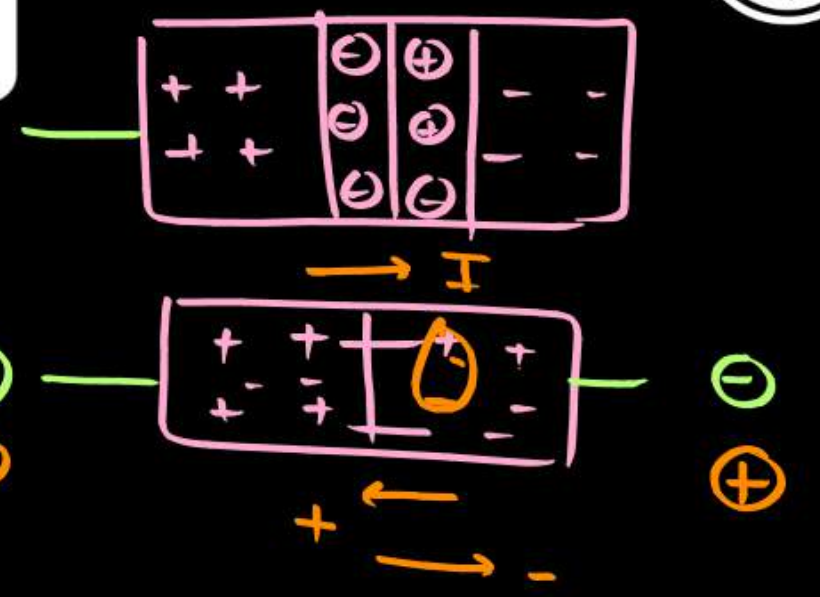
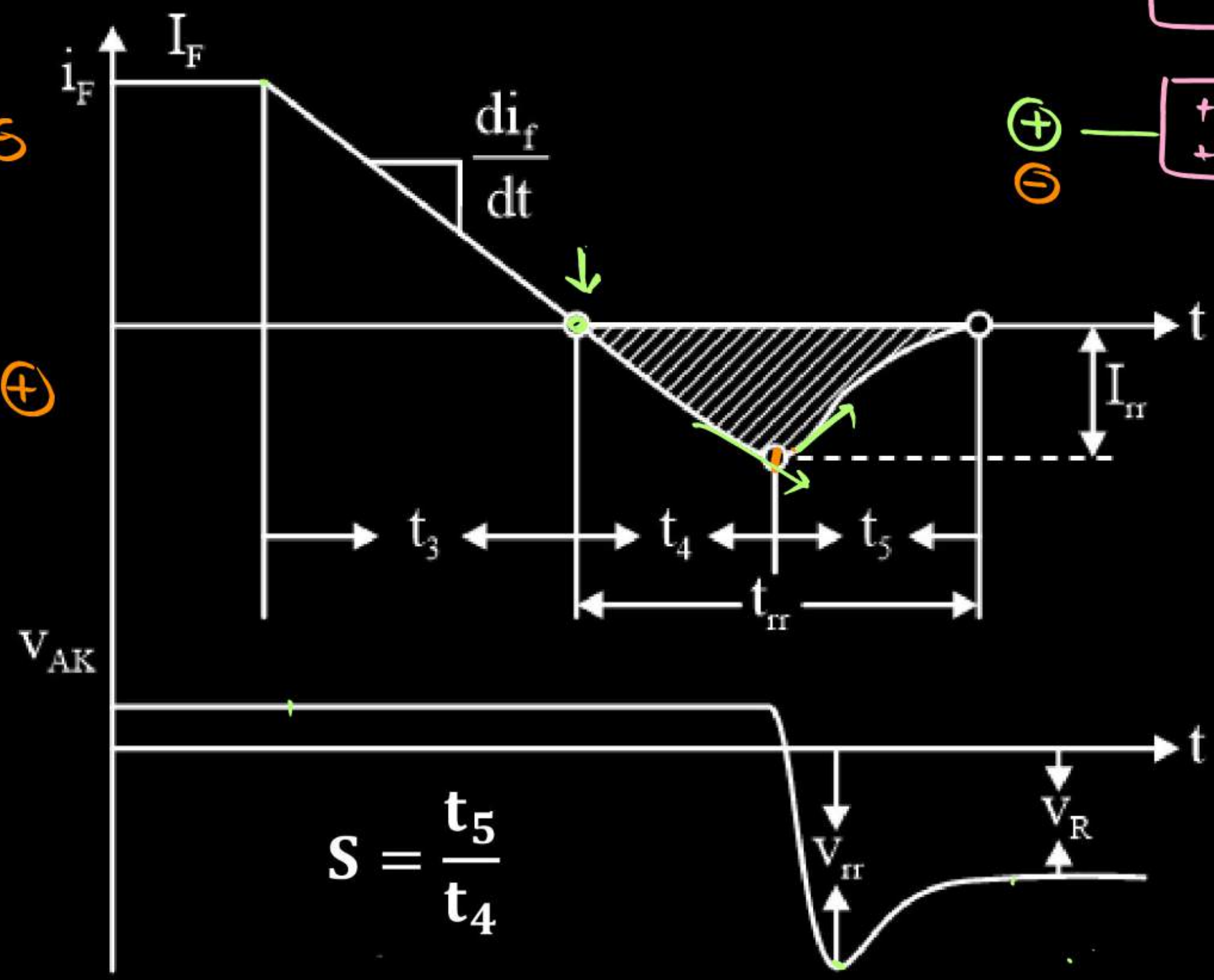
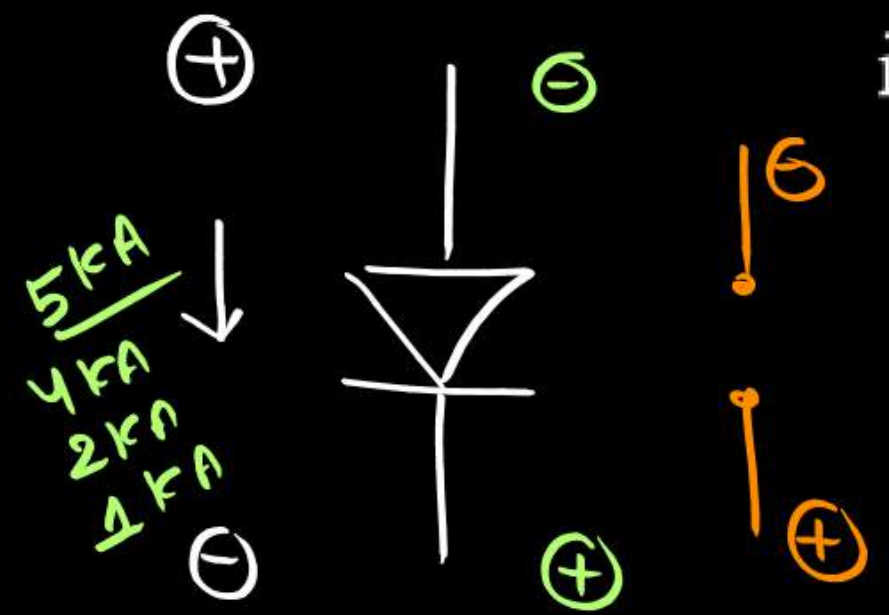
- 1 My leakage current is **LOW**.
- 2 My reverse breakdown voltage is **LOW**.
- 3 In forward direction, my current increases **EXPONENTIALLY**.

I am a  
**POWER DIODE**



- 1 My leakage current is of **HIGH** value.
- 2 My reverse breakdown voltage is **HIGH**.
- 3 In forward direction, my current first increases **EXPONENTIALLY**, then becomes **LINEAR**.

# Reverse Recovery Characteristics



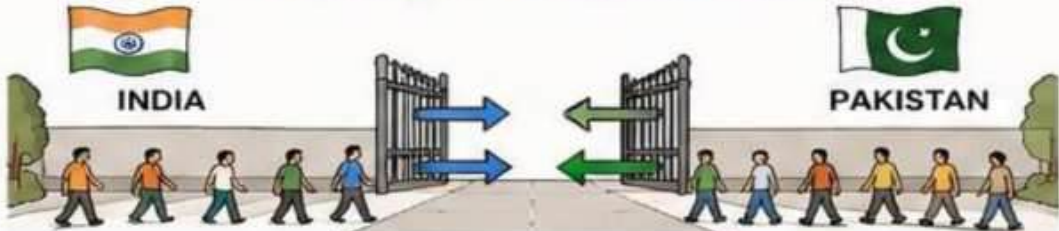
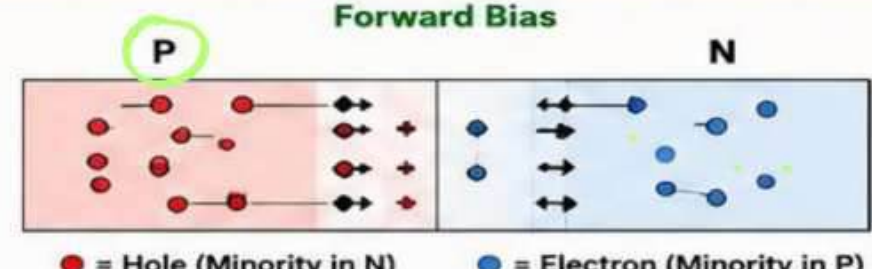
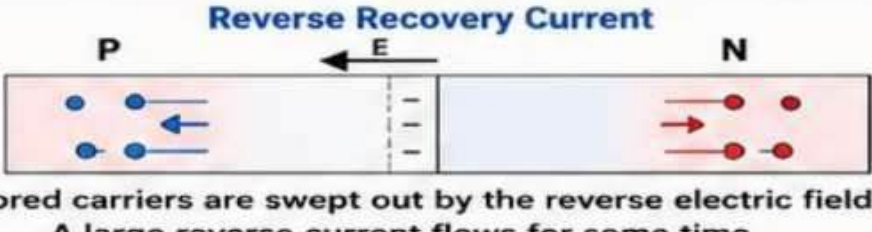
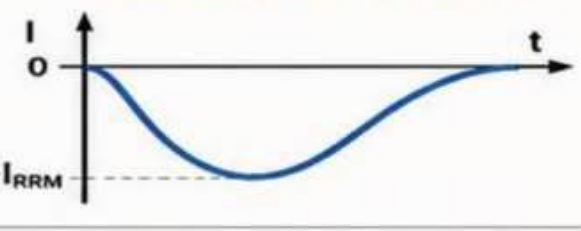
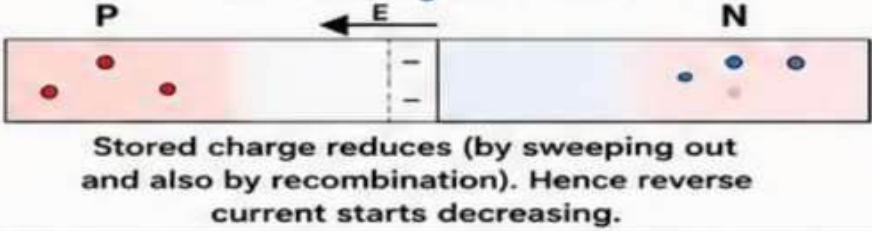
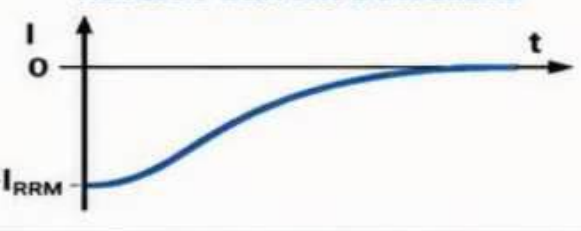
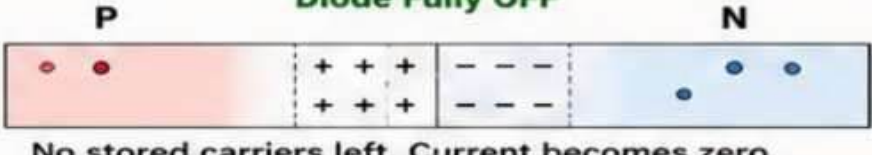
$$V = L \frac{di}{dt}$$

# Reverse Recovery Characteristics

1. Reverse recovery characteristic is the turn off characteristic of the diode.
2. To turn off the diode, we apply RB, due to which forward current becomes zero.
3. But still storage charges exist between semiconductor layer. These storage charges are minority carrier.
4. Until and unless these storage charges are removed, the diode will not be turned off.
5. These storage charges can be removed either by recombination or moving out in outer circuit.

# Reverse Recovery Characteristics

6. Due to which a current flow in reverse direction which is called reverse recovery current.
7. When more than 50% charges are removed, the magnitude of reverse recovery current reduces.
8. Due to which a reverse transient voltage is created (Due to circuit Inductance).

| STAGE                                                       | BORDER ANALOGY (India-Pakistan)                                                                                                                                                                                                       | DIODE / SEMICONDUCTOR VIEW                                                                                                                                                                                                                               | CURRENT vs TIME                                                                                                                  |
|-------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| <b>0</b><br><b>NORMAL CONDITION</b><br>(Forward Conduction) | <b>Gates Open – Normal Movement</b><br><br>People are moving from India to Pakistan and Pakistan to India.                                          | <b>Forward Bias</b><br><br>• = Hole (Minority in N)    • = Electron (Minority in P)<br>Large number of carriers are injected and stored on both sides of the junction. | <b>Forward Current (<math>I_F</math>)</b><br> |
| <b>1</b><br><b>GATES CLOSING</b><br>(Reverse Bias Applied)  | <b>Order to Close the Gates</b><br><br>Disturbance occurs. Order comes to close the gates. Forward movement starts reducing.                        | <b>Reverse Bias Applied</b><br><br>Electric field reverses. It starts removing (sweeping out) stored minority carriers.                                               | <b>Forward Current Decreases</b><br>          |
| <b>2</b><br><b>REVERSE CURRENT STARTS</b>                   | <b>People Sent Back (Opposite Movement)</b><br><br>Now, people who had crossed or were on the other side are being sent back to their own country. | <b>Reverse Recovery Current</b><br><br>Stored carriers are swept out by the reverse electric field. A large reverse current flows for some time.                     | <b>Reverse Current Increases</b><br>         |
| <b>3</b><br><b>REVERSE CURRENT DECREASES</b>                | <b>Fewer People Left to Send Back</b><br><br>As most people are sent back, only a few remain. Reverse movement reduces.                           | <b>Stored Charge Decreases</b><br><br>Stored charge reduces (by sweeping out and also by recombination). Hence reverse current starts decreasing.                   | <b>Reverse Current Decreases</b><br>        |
| <b>4</b><br><b>RECOVERY COMPLETE</b><br>(Current = 0)       | <b>Normal – No Movement</b><br><br>Finally everyone is back. No movement remains.                                                                 | <b>Diode Fully OFF</b><br><br>No stored carriers left. Current becomes zero. Diode has completely recovered.                                                        | <b>Current Becomes Zero</b><br>             |

#### KEY POINTS

- Forward conduction → People move both ways.
- Reverse bias applied → Gates close.
- Stored people (carriers) are sent back → Reverse current flows.
- As stored population reduces (by sweeping + recombination) → Reverse current reduces to zero.

#### RECOMBINATION (How to show in analogy)



Some people from India side and Pakistan side meet in between and "settle" (recombine). They do not contribute to movement anymore.

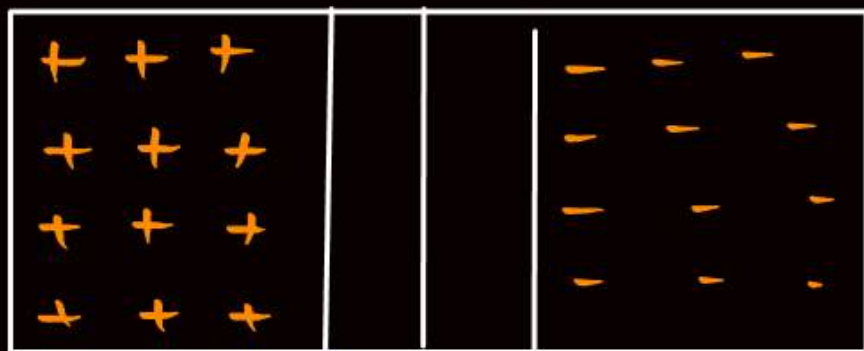
#### IN SEMICONDUCTOR



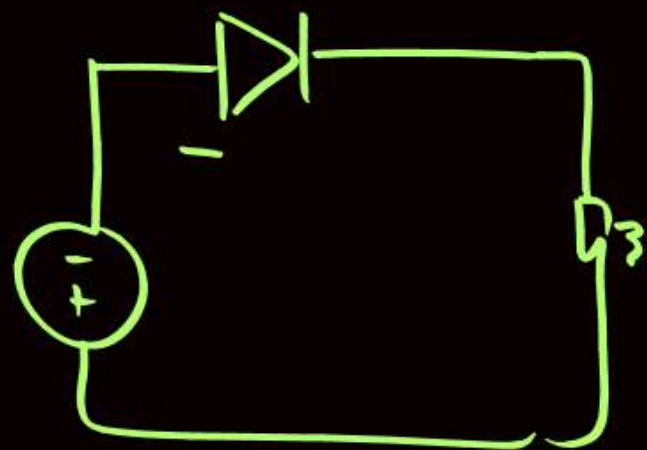
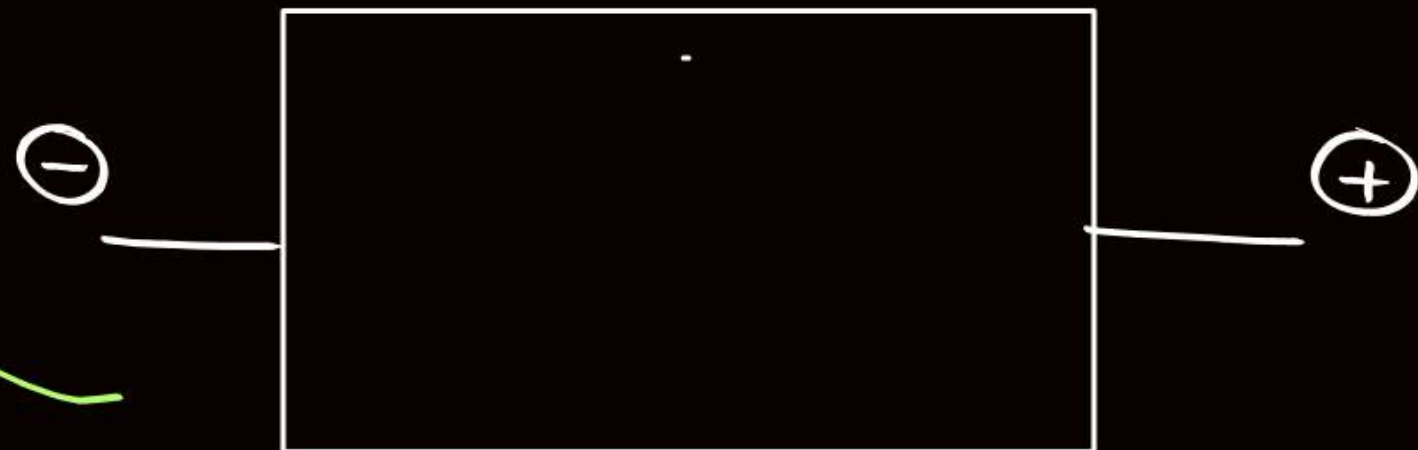
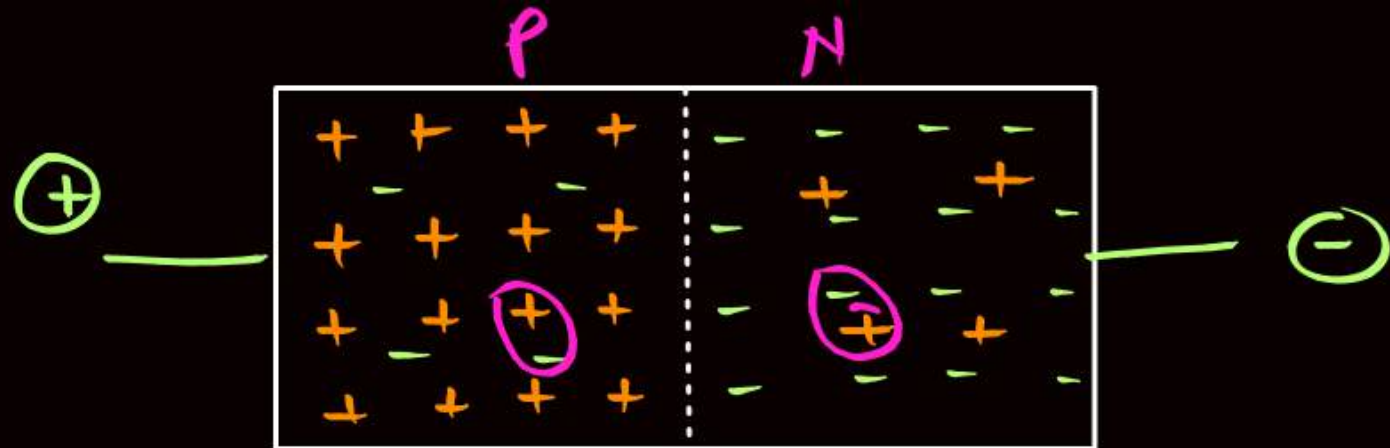
Electron + Hole → Recombination  
(They disappear as mobile carriers)

#### OVERALL RESULT

Stored charge decreases  
( by sweeping out  
+ recombination )  
⇒  
Reverse current reduces  
to zero.



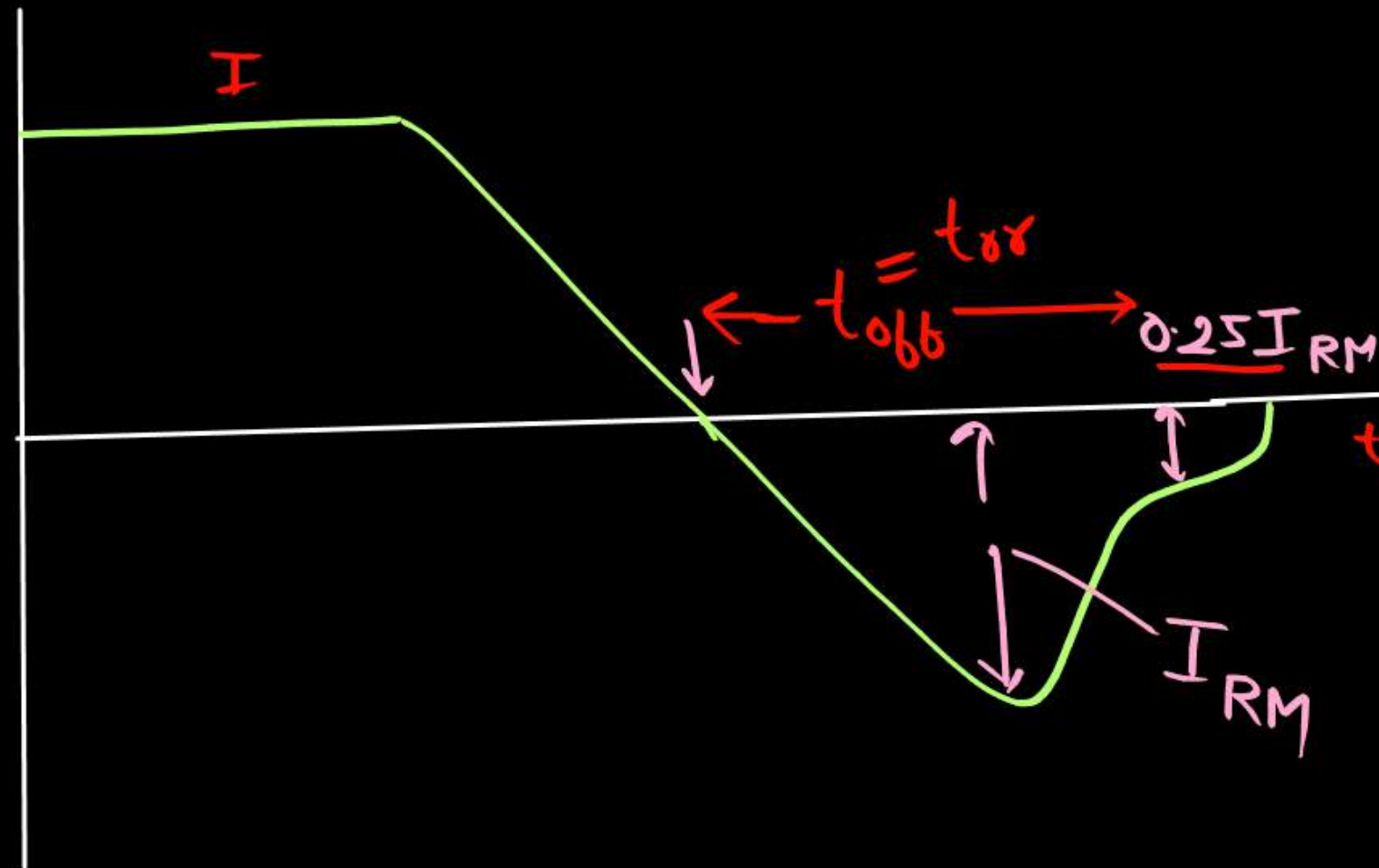
Depletion

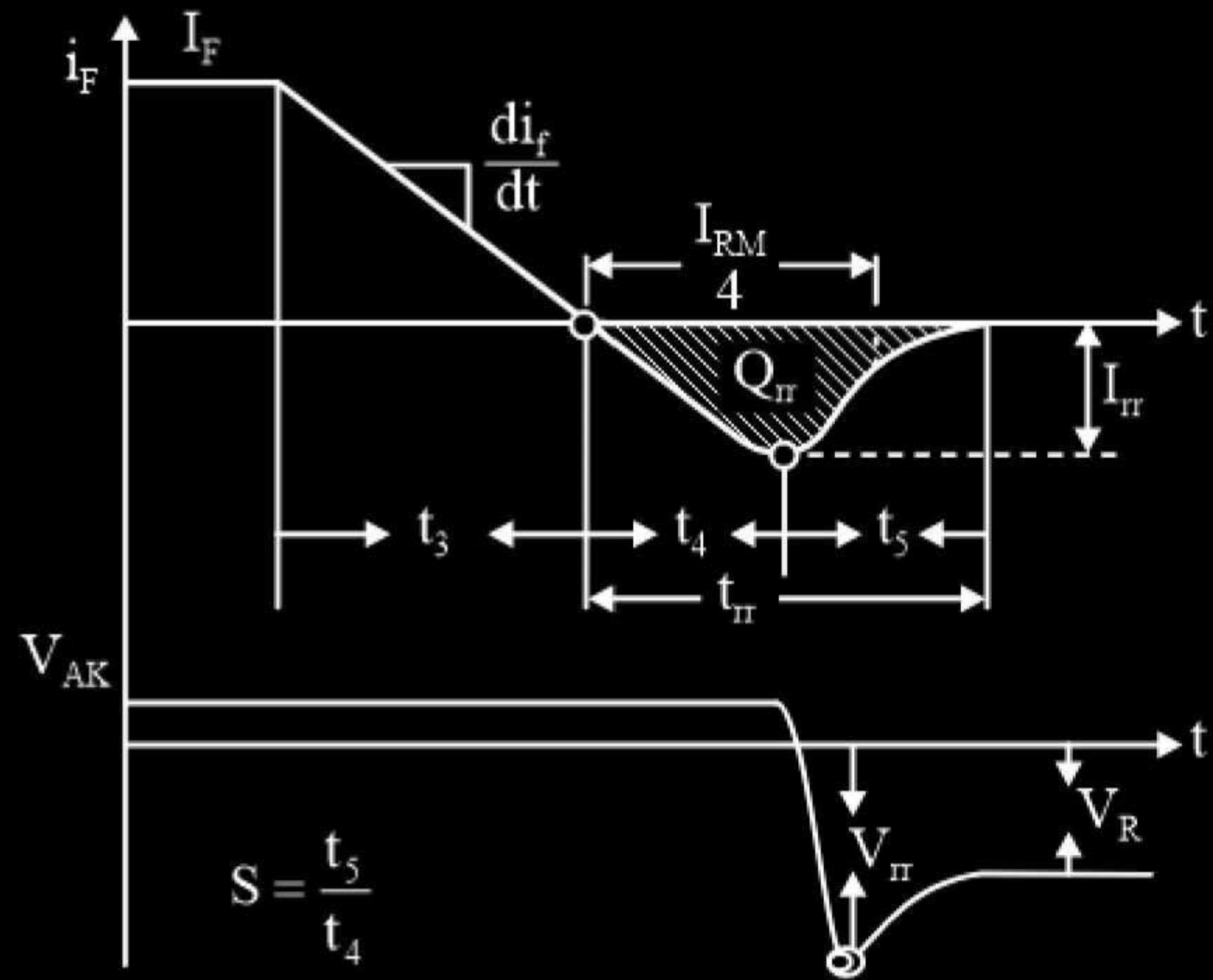


$$V_F \leq L \frac{di}{dt}$$

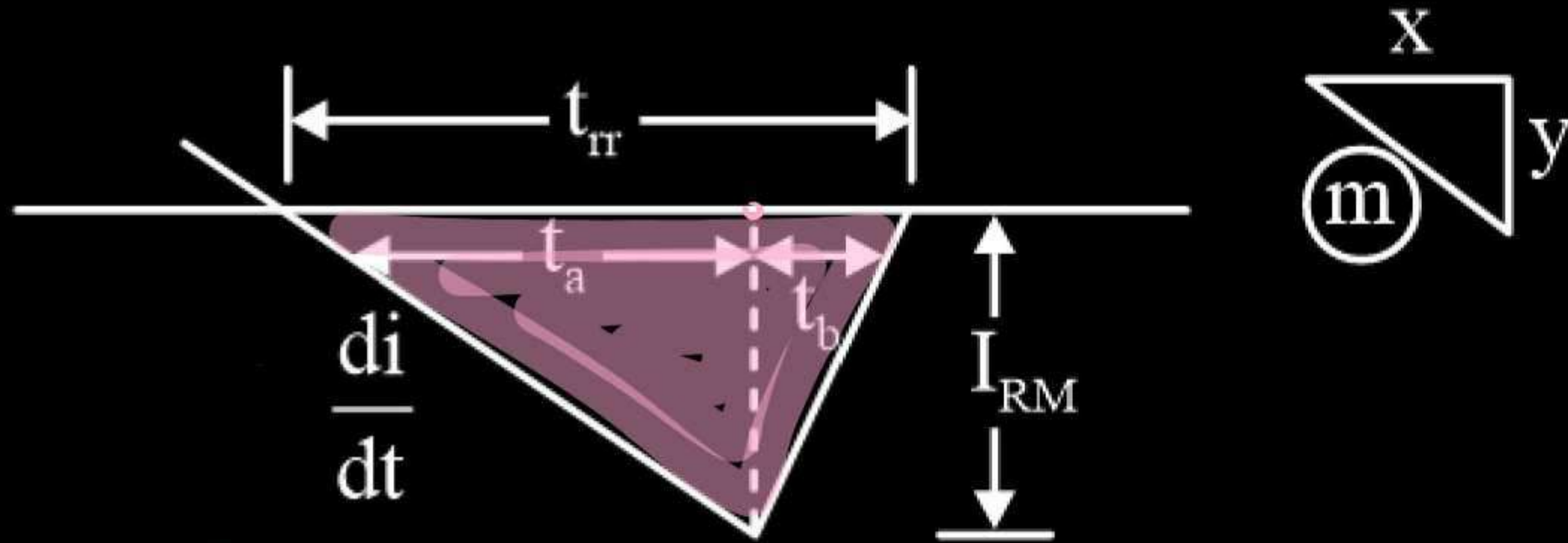
# Reverse Recovery Characteristics

- $I_{RM}$  = Peak value of reverse recovery current.
- $t_{rr} = t_{off}$  = Time from the Instant  $I_F = 0$  to the instant current becomes 25% of  $I_{RM}$ .





$$Q_r = \int i dt$$



$t_a$  = During  $t_a$  time, we remove the storage charge from depletion region.  
 $t_b$  = During  $t_b$  time, storage charges are removed from other semiconductor layer

$$t_{rr} = t_a + t_b$$

$$t_{rr} = t_a + S t_a$$

$$t_{rr} = (1 + S) t_a$$

$$\rightarrow t_a = \frac{t_{rr}}{(1 + S)} \quad - (1)$$

$$\rightarrow \tan \phi = \frac{\overline{I}_{RM}}{t_a}$$

$$\text{Softness factor } S = \frac{t_b}{t_a}$$

$$t_b = S t_a$$

$$\frac{di^o}{dt} = \frac{I_{RM}}{t_a}$$

$$I_{RM} = t_a \frac{di^o}{dt} = \frac{t_{rr}}{(1+s)} \frac{di^o}{dt} \quad - (1)$$

→  $Q_R = \frac{1}{2} t_{rr} \cdot I_{RM}$

$$Q_R = \frac{1}{2} t_{rr} \cdot \frac{t_{rr}}{(1+s)} \frac{di^o}{dt}$$

$$\phi_R = \frac{1}{2} \frac{t_{rr}^2}{(1+s)} \cdot \frac{di^0}{dt}$$

$$t_{rr} = \sqrt{\frac{2\phi_R(1+s)}{di/dt}}$$

Put value of  $t_{rr}$  in eqn (1)

$$I_{RM} = \sqrt{\frac{2\phi_R(1+s)}{di/dt}} \cdot \frac{di/dt}{(1+s)}$$

$$I_{RH} = \sqrt{\frac{2\Phi_R (di/dt)}{(1+s)}}$$

## Note

- In slow recovery diode (Normal diode),  $S = 1$ .
- In Fast recover diode  $S \ll 1$ .

$$S = \frac{t_b}{t_a}$$

$$1 + S \simeq 1$$

$$t_{rr} = \sqrt{\frac{2\phi_R}{di/dt}}$$

$$I_{RM} = \sqrt{2\phi_R \cdot \frac{di}{dt}}$$



The reverse recovery time of a diode is 2 microsec and rate of fall diode current  $di/dt$  is 20 amp/microsec. The storage charge and peak inverse current I<sub>RM</sub> will be respectively?

- A 40 micro C , 40 amp
- B 80 micro C, 40 amp
- C 160 micro C, 80 amp
- D Diode not conduct

$$t_{rr} = 2 \times 10^{-6}$$

$$di/dt = \frac{20 \text{ A}}{10^{-6} \text{ sec}}$$

$$Q_R = ?$$

$$I_{RM} = ?$$

$$t_{rr} = \sqrt{\frac{2Q_R}{di/dt}}$$

$$2 \times 10^{-6} = \sqrt{\frac{2Q_R}{\frac{20}{10^{-6} \text{ Sec}}}}$$

$$4 \times \cancel{10^{-12}}^{10^{-6}} = \frac{2Q_R}{20} \times \cancel{10^{-6}}$$

$$Q_R = \frac{80}{2} \times 10^{-6}$$

$$Q_R = 40 \times 10^{-6} = 40 \mu\text{C}$$

$$I_{RM} = \sqrt{2Q_R \frac{di}{dt}}$$

$$= \sqrt{2 \times 40 \times \cancel{10^{-6}} \times \frac{20}{\cancel{10^{-6}}}}$$

$$= \sqrt{40 \times 40}$$

$$= 40 \text{ Ams}$$


$$t_{obb} = t_{rr} \uparrow = \sqrt{\frac{2Q_R \uparrow}{di/dt}}$$

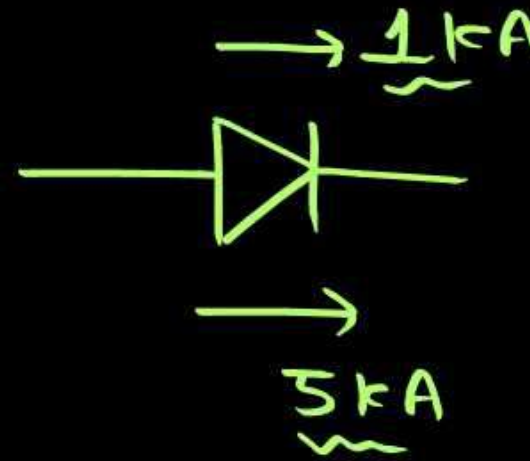
$$t_{obb} \uparrow = Q_R \uparrow$$

$$Q_R \uparrow = I_F \uparrow$$

- Imp So, Turn off time of diode is ultimately dependent on forward current.
- $t_{\text{off}} \downarrow \rightarrow \text{Fast} \uparrow \rightarrow \text{High Switching} \uparrow$

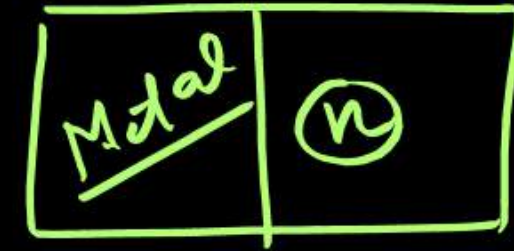
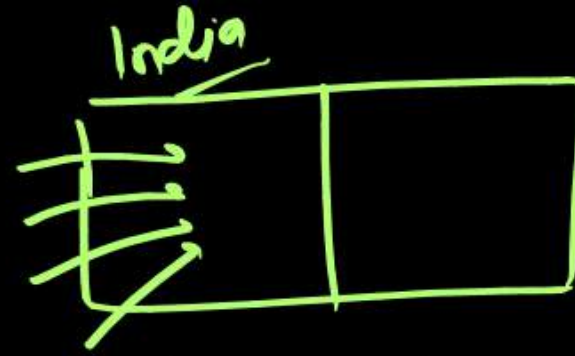
## Diode Family Device

1. Slow recovery diode
2. Fast recovery diode
3. Schottky diode



| Slow recovery diode ✓                                   | Fast recovery Diode ✓                                      | Schottky Diode                             |
|---------------------------------------------------------|------------------------------------------------------------|--------------------------------------------|
| 1. $t_{rr} = \underline{25 \text{ micros}}$             | 1. $t_{rr} = \underline{5 \text{ micros}}$                 | 1. $T_{rr} = \underline{\text{nano sec.}}$ |
| 2. Voltage rating up to 5 kv ✓                          | 2. Up to 3 kV ✓                                            | 2. Up to 100 V                             |
| 3. Current Rating up to several thousand Amp ✓          | 3. Up to several thousand Amp                              | 3. Up to 300 A                             |
| 4. Application - <u>Line</u> <u>frequency</u> Rectifier | 4. In <u>chopper</u> & <u>Inverter</u> commutation circuit | 4. In <u>SMPS</u>                          |

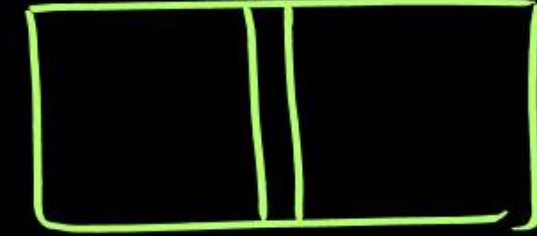
# Diode Family Device

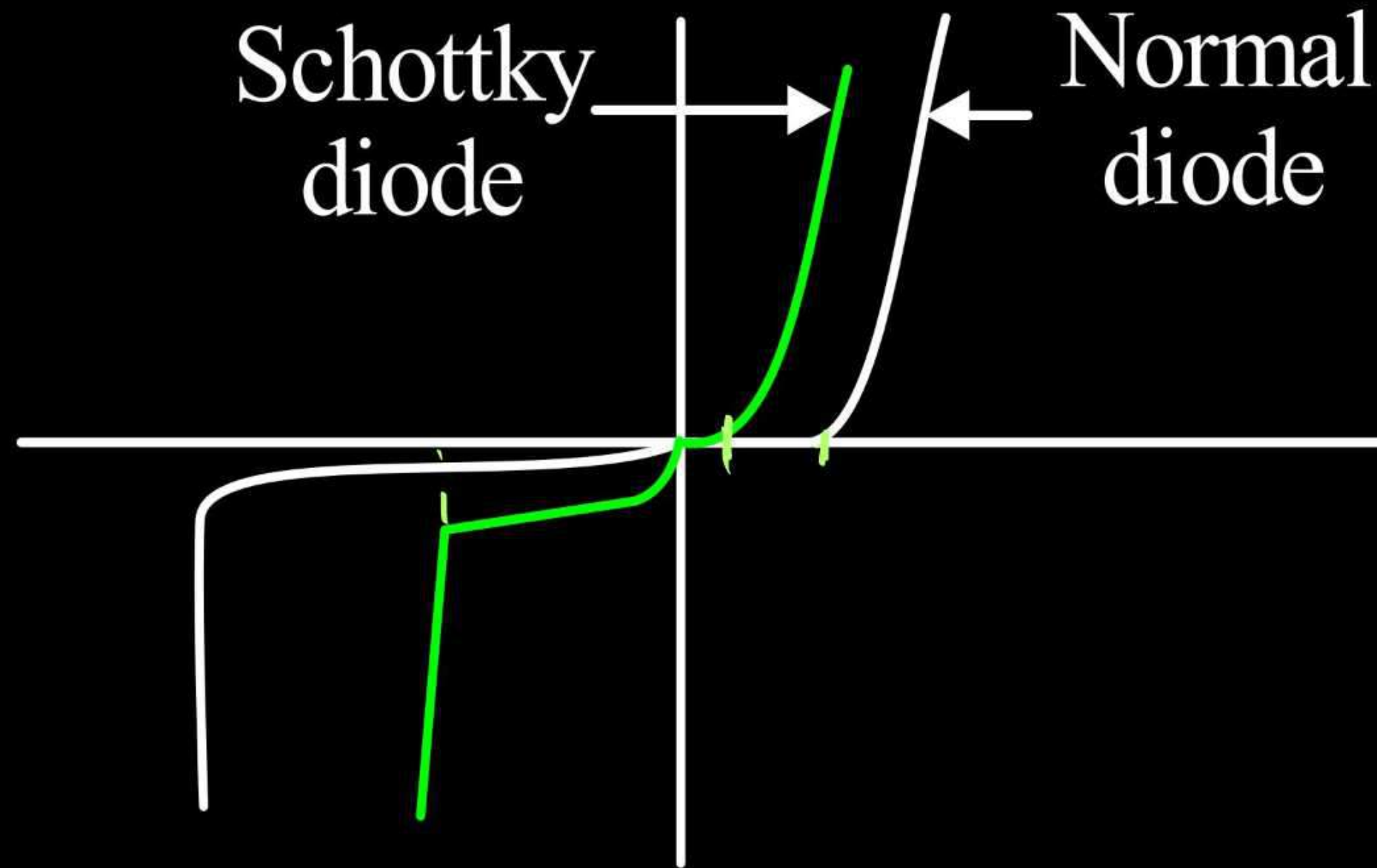


- In fast recovery diode, we do gold & platinum doping. This will increase recombination rate, so average life span of the charge is reduced and its turn off time will be reduced. But, its on state voltage drop (due to on state resistance) is more.
- The Schottky diode is a Metal to semiconductor junction diode in which conduction occurs only due to Majority carrier (electron). So, due to absence of Minority charge carriers, this diode can be turned off in nano sec. So, it can be used in High frequency applications.

## Note – Schottky Diode

- The cut-in voltage of Schottky diode is low.
- The reverse voltage blocking capacity (BD voltage) is less.
- In Magnitude of leakage current is high.
- The width of depletion layer is less.







## 2 Minutes Summary

→ Power diode

→ Diode family

→ Reverse recovery characteristic

A dark blue, 3D-style banner with a folded effect, featuring the words 'THANK YOU' in large, white, bold, sans-serif capital letters.

**THANK YOU**



# Electrical Engineering

## Power Electronics



Lecture No – 3

Power Semi conductor devices

By- Ajay Gupta Sir



# Recap of Previous class

1. Reverse recovery characteristic.

2. Types of diode

3.



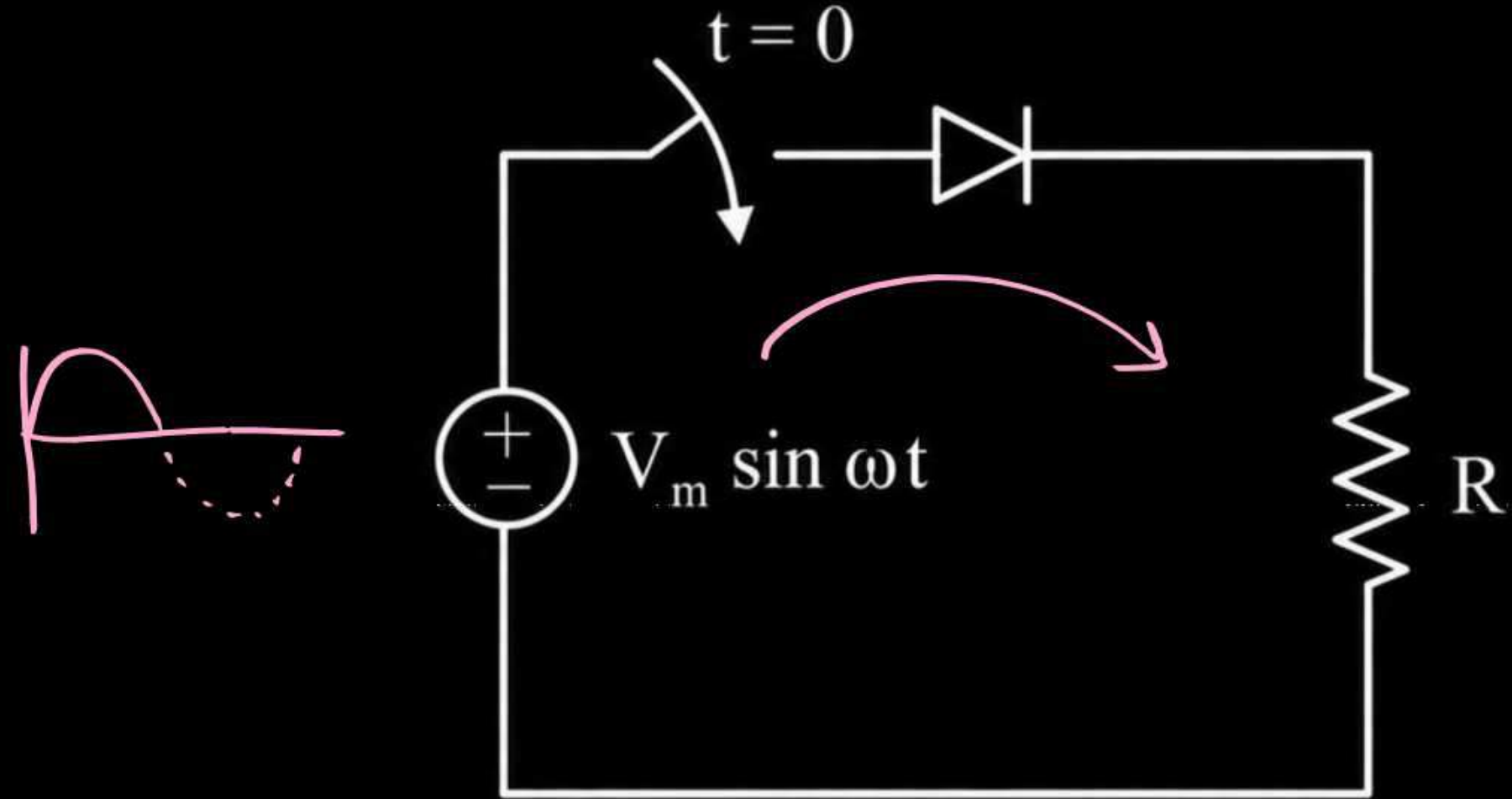
**Topic is  
To be  
covered**

1. Diode circuit

2.

Q. If switch is closed at  $t = 0$  sec, the diode will conduct for

- A  $\frac{\pi}{2}$
- B  $\pi$
- C  $2\pi$
- D  $\frac{\pi}{4}$



Q.

If switch is closed at  $t = 0$  sec, the diode will conduct for

A

$$\frac{\pi}{2}$$

B

$$\pi$$

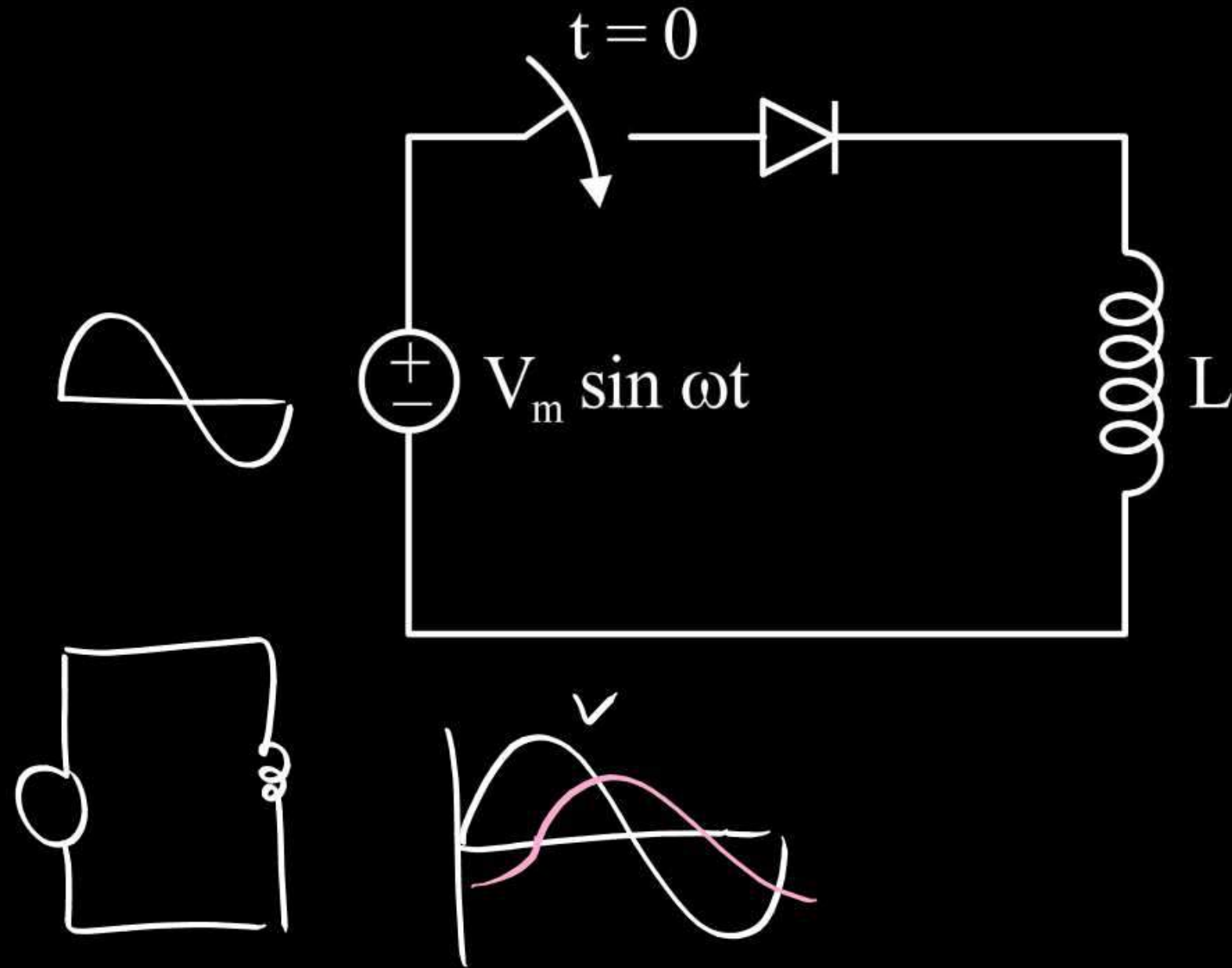
C

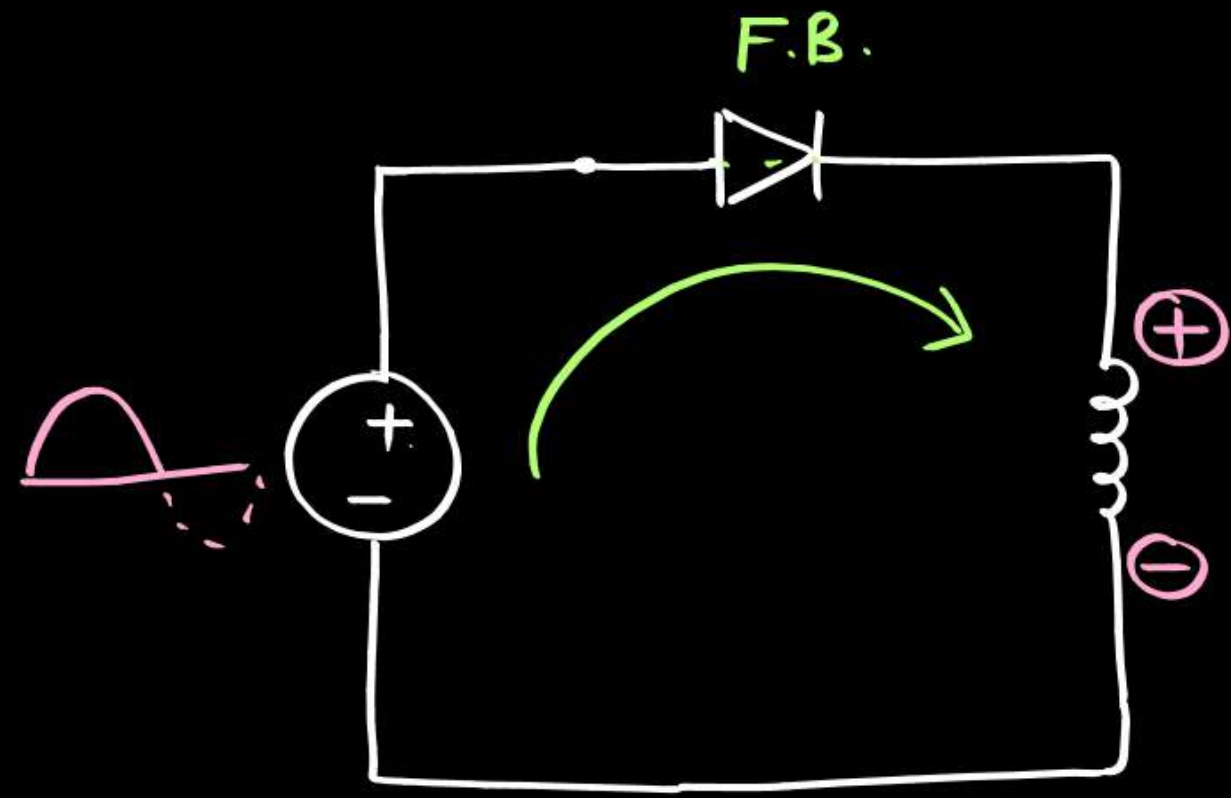
$$2\pi$$



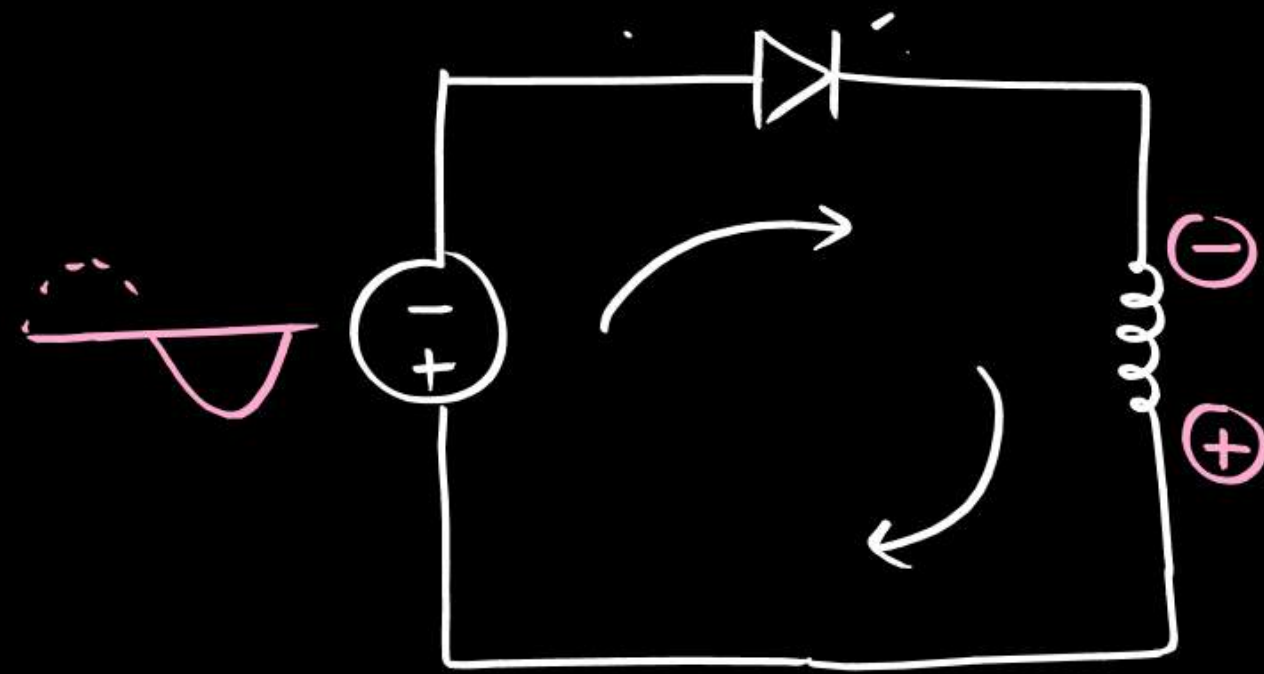
D

$$\frac{\pi}{4}$$



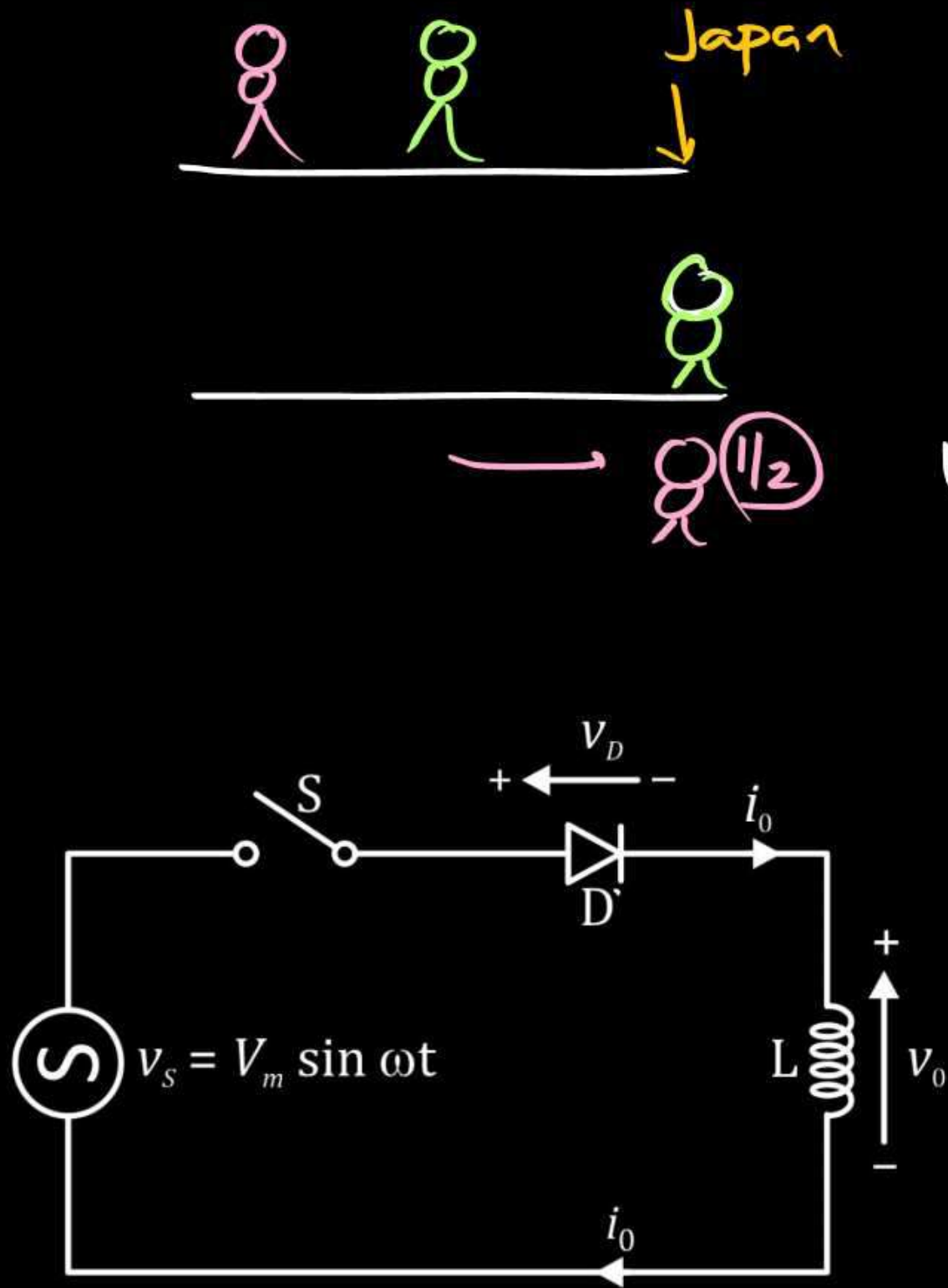


$$\underline{\uparrow E} = \frac{1}{2} L \underline{\dot{i}^2} \uparrow$$

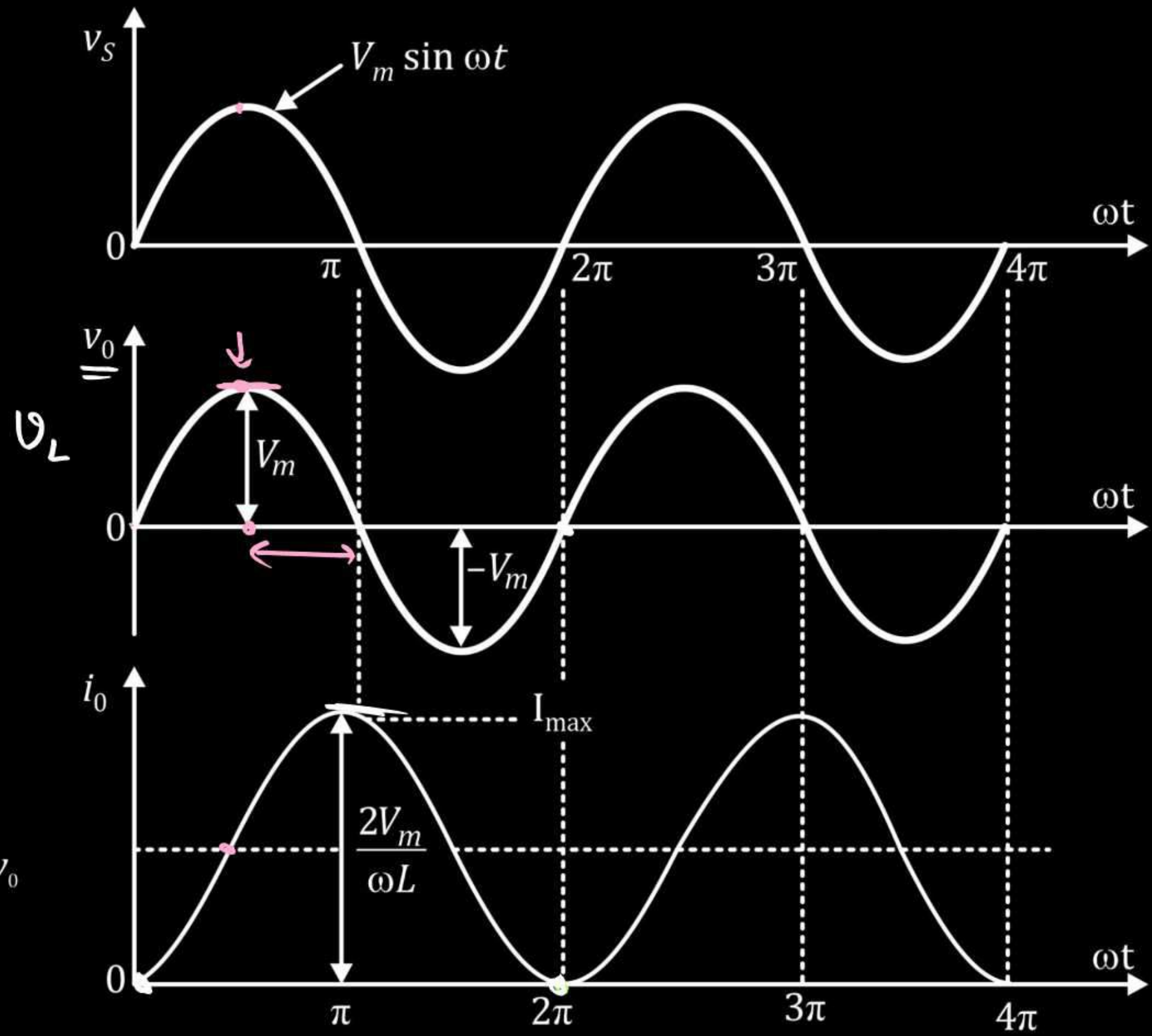


$$\underline{\downarrow E} = \frac{1}{2} L \underline{\dot{i}^2} \downarrow$$

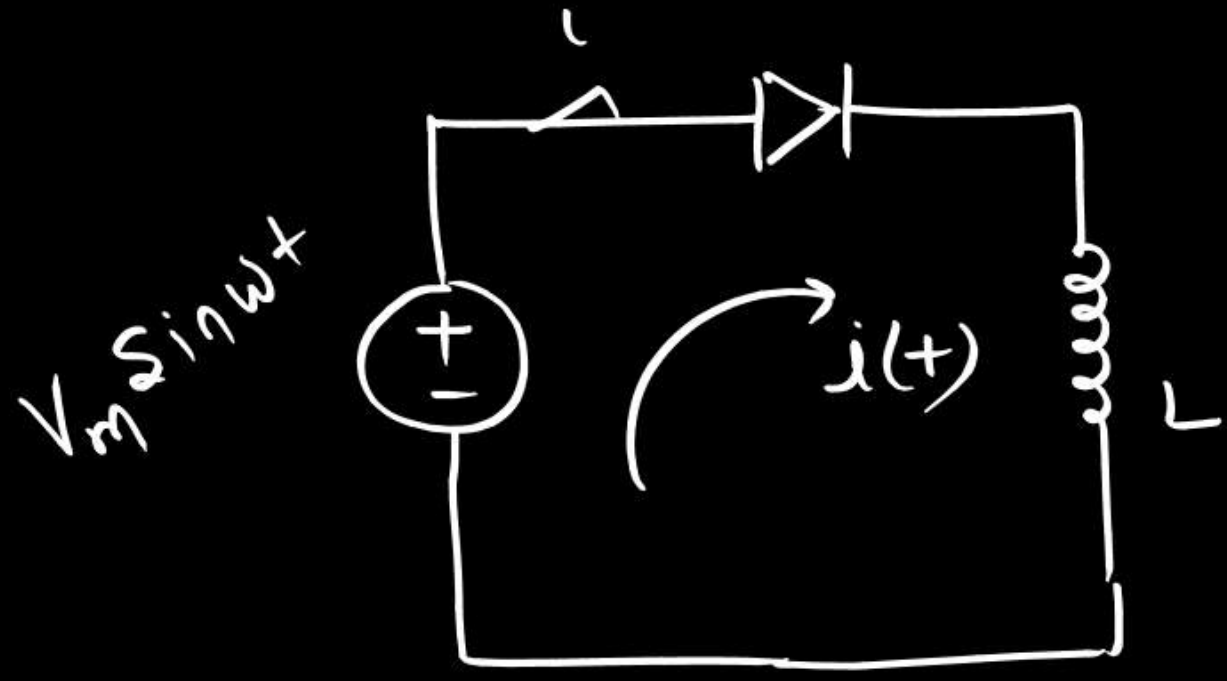
$$V = L \frac{di}{dt}$$



(a)



(b)



$$V_L = L \frac{di}{dt}$$

$$V_m \sin \omega t = L \frac{di}{dt}$$

$$di = \frac{V_m}{L} \sin \omega t \, dt$$

$$i = \int \frac{V_m}{\omega L} \sin \omega t \, d^{\omega}t$$

$$i = \frac{V_m}{\omega L} [-\cos \omega t] + K \quad - \textcircled{1}$$

at  $t=0 \Rightarrow i^0=0$

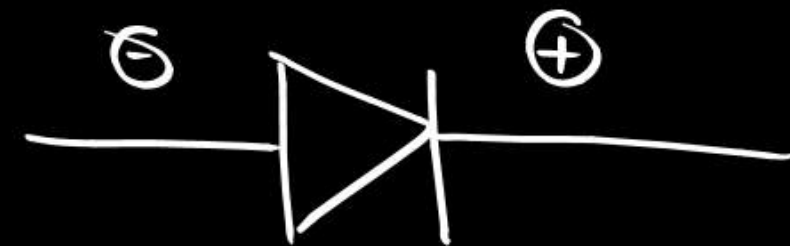
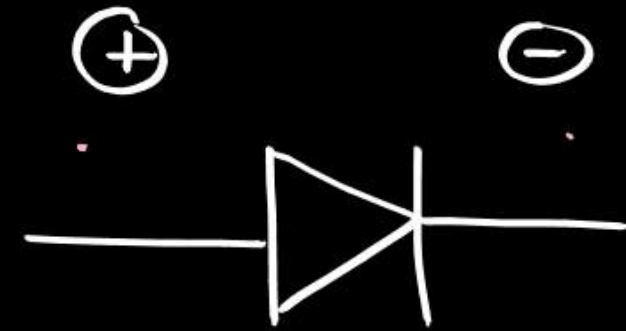
$$0 = \frac{V_m}{\omega L} [-\cos 0^\circ] + K$$

$$K = \frac{V_m}{\omega L}$$

Put the value of  $K$  in eqn No ①

$$i^0 = -\frac{V_m}{\omega L} \cos \omega t + \frac{V_m}{\omega L}$$

$$i(t) = \frac{V_m}{\omega L} [1 - \cos \omega t]$$

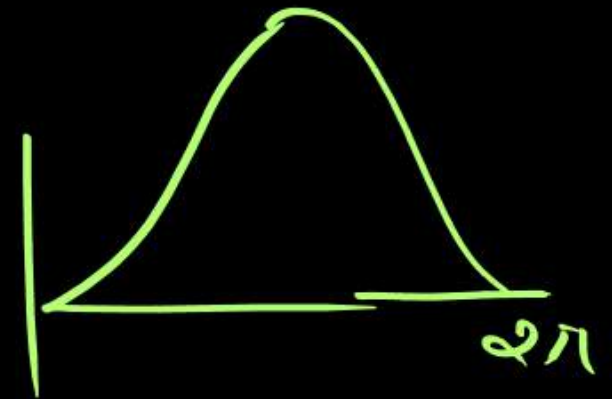


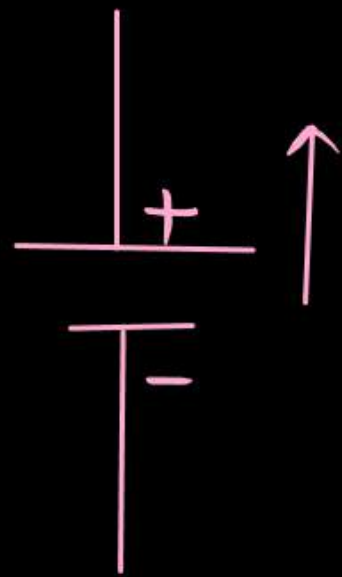
When current will be zero

$$\frac{V_m}{\omega L} [1 - \cos \omega t] = 0$$

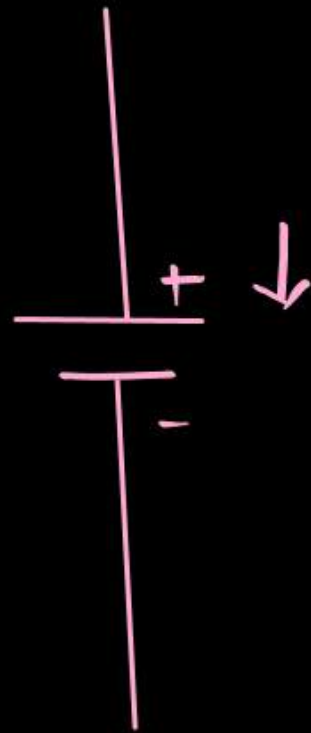
$$\cos \omega t = 1$$

$$\omega t = 0, \underline{\underline{2\pi}}$$





Source



Load

## Inductor



Inductor is taking energy.



Inductor is releasing energy.

$$\xrightarrow{I}$$

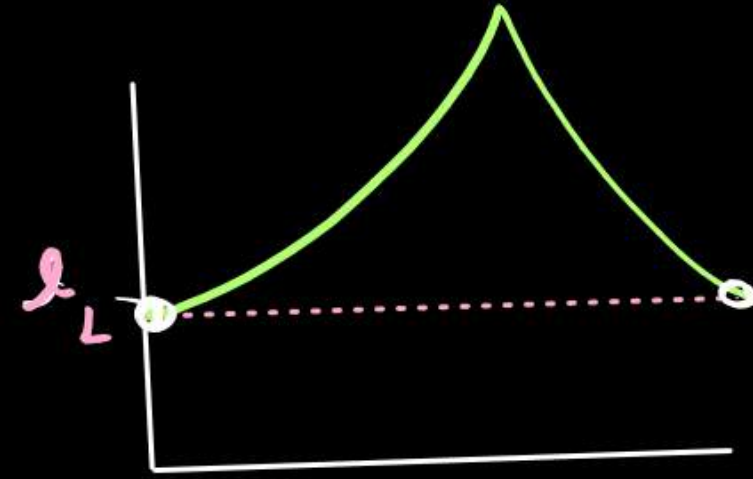
$$V_L = L \frac{di}{dt}$$

1> When Inductor give the energy, the direction of current does not change. its change its voltage polarity.

$$2> E = \frac{1}{2} L i^2$$

The Inductor energy depend upon the current flow through inductor.  $E = \frac{1}{2} L i^2$

3> When Inductor takes energy, the Mag. of current will increase.



4> When Inductor release energy, the Mag. of current decreases.

5> In a power cycle the avg. energy of inductor is zero

$$P_{avg} = V_{avg} I_{avg}$$

$$0 = V_{avg} (+)$$

$$V_{avg} = 0$$

→ In a power cycle, the average value of inductor is zero

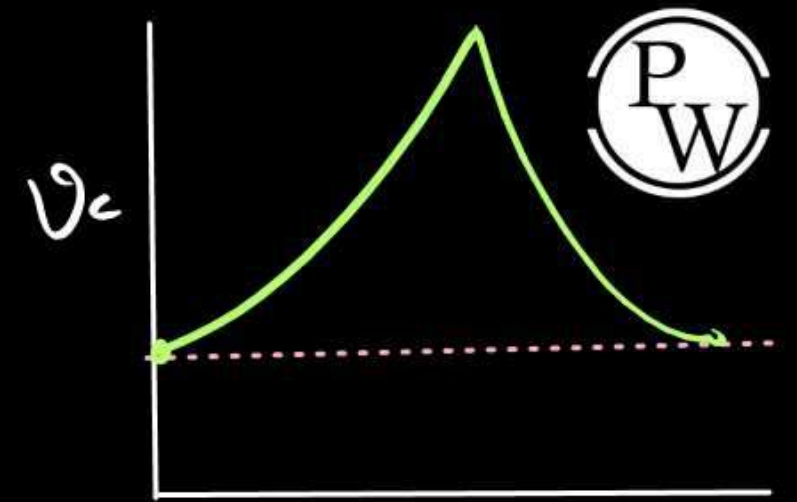
# Capacitor



Capacitor storing the energy  
(Capacitor is charging)



Capacitor releasing the energy  
(capacitor is discharging)



- In a power cycle, the overall power consumed by the Capacitor is zero.
- $P_{av} = V_C I_C \Rightarrow 0 = \oplus (I_C)_{avg}$
- ✓  $(I_C)_{avg.} = 0$
- In a power cycle, average current through the Capacitor is equal to zero.

- When Capacitor release its energy. its polarity remain same. the direction of current get reversed.
- $E = \frac{1}{2} CV_c^2$  . its energy depend on voltage.
- When capacitor takes energy its voltage will increase  
When its release its energy its voltage will decrease.

Q.

The diode will conduct for

A

$$\frac{\pi}{4}$$

B

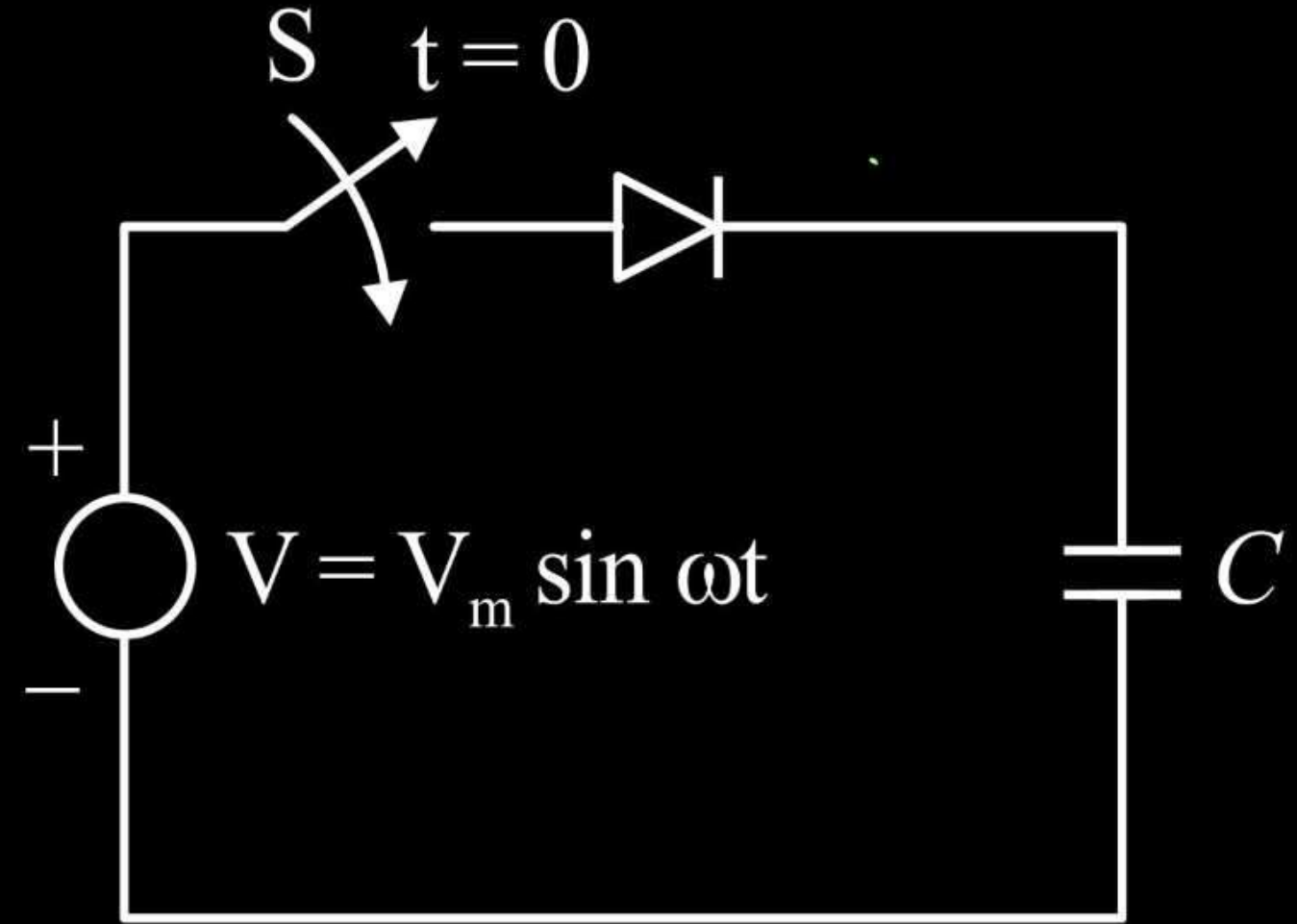
$$\frac{\pi}{2}$$

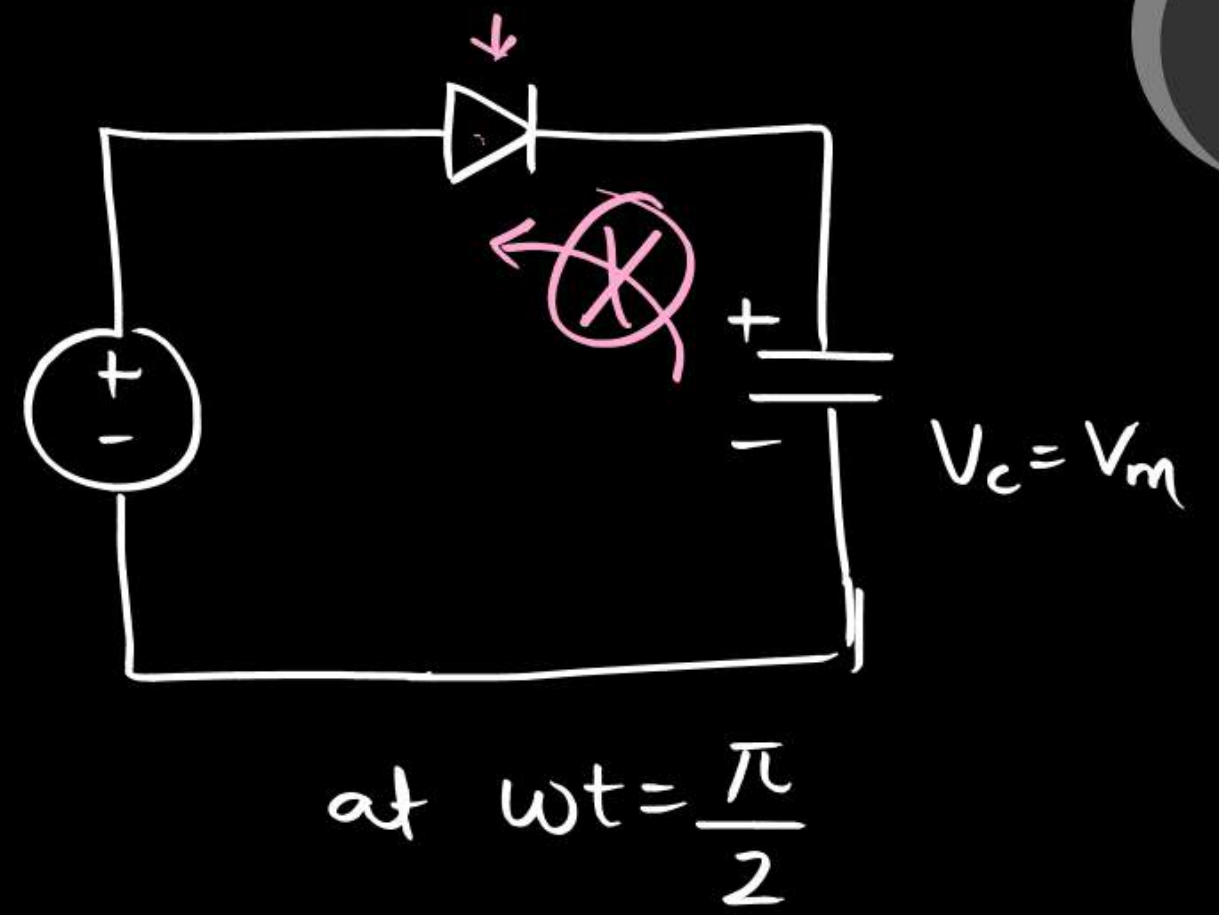
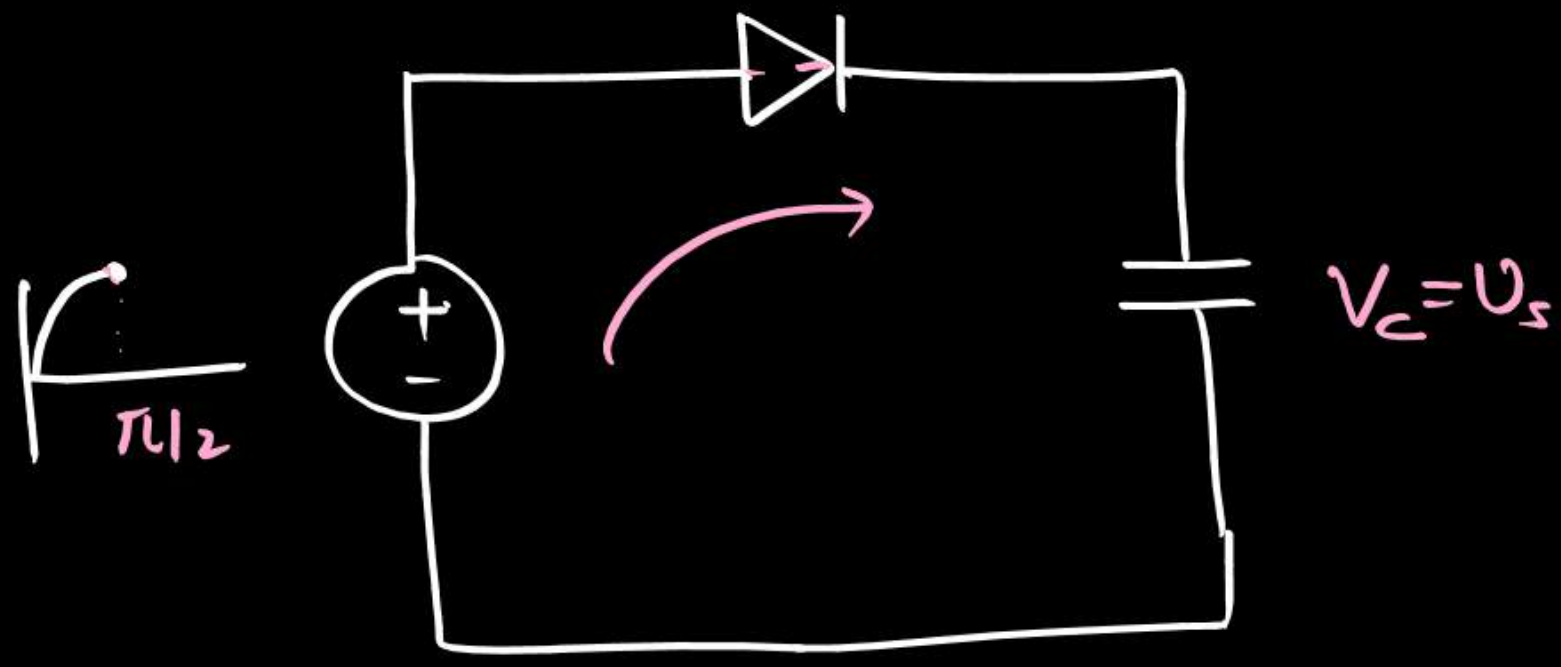
C

$$\pi$$

D

$$2\pi$$





1) At  $\omega t = 0$ , Diode = FB, So current start flowing and

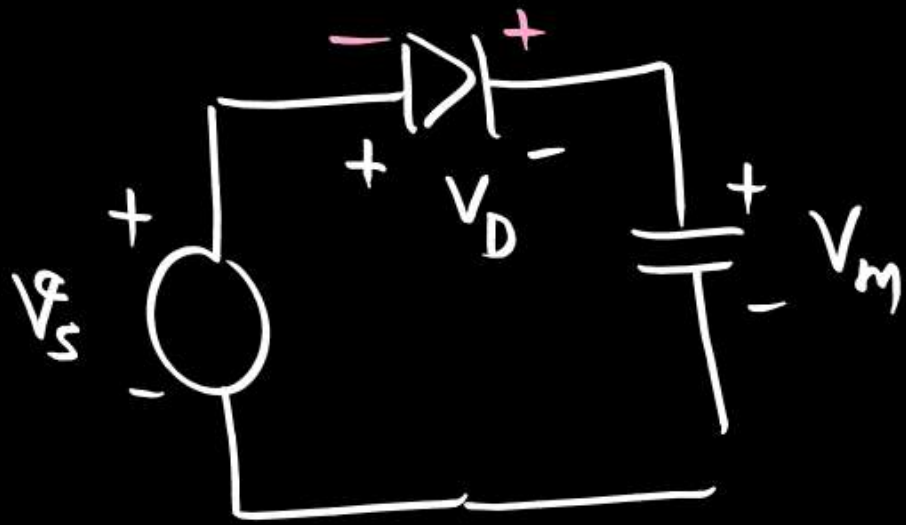
Now behave like S/C

2)  $V_c = V_s$

3> At  $\omega t = \frac{\pi}{2}$ ,  $V_c = V_m$  Now capacitor has Max<sup>m</sup> energy.

4> Now its try to release its energy by reversing the current. But Diode does not allow reverse current.

⑤ At  $\omega t = \pi/2$



KVL

$$V_s - V_D - V_m = 0$$

$$V_D = V_s - V_m$$

$$V_D = \ominus$$



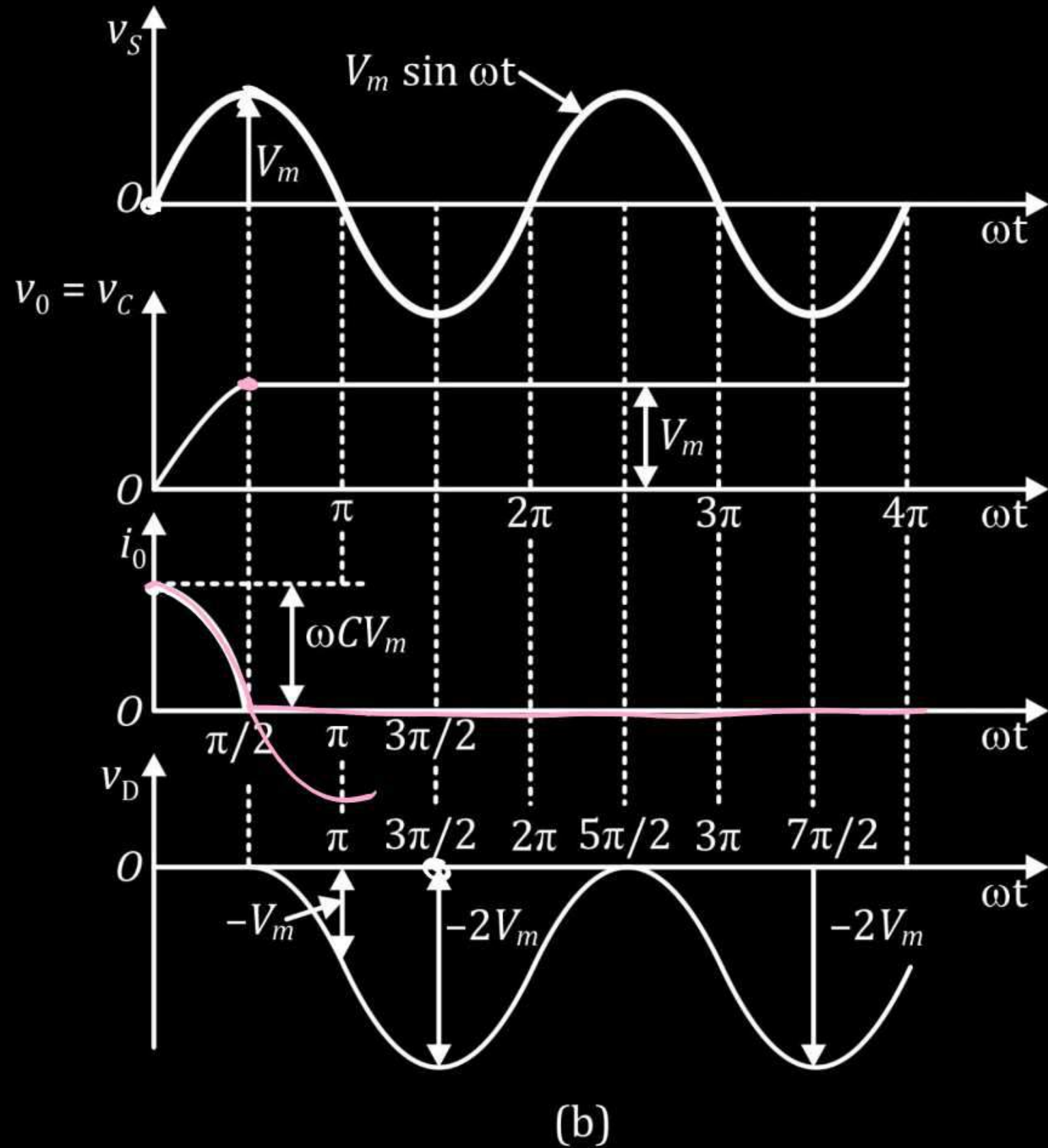
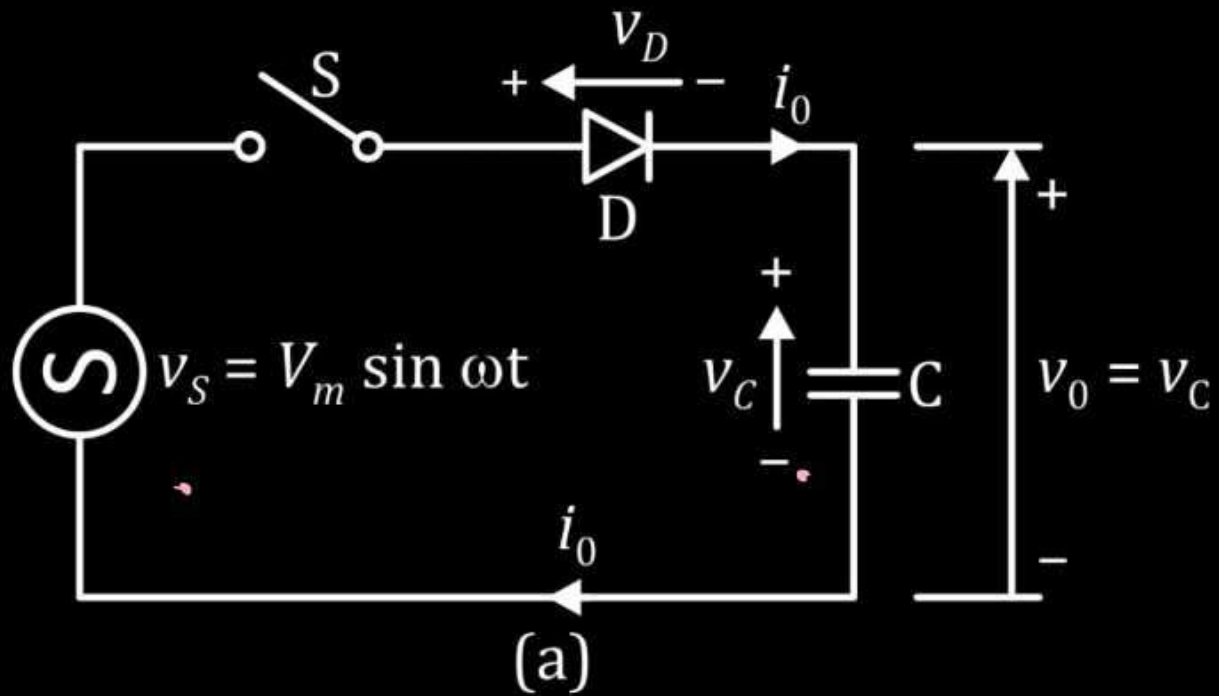
$$V_s < V_m$$

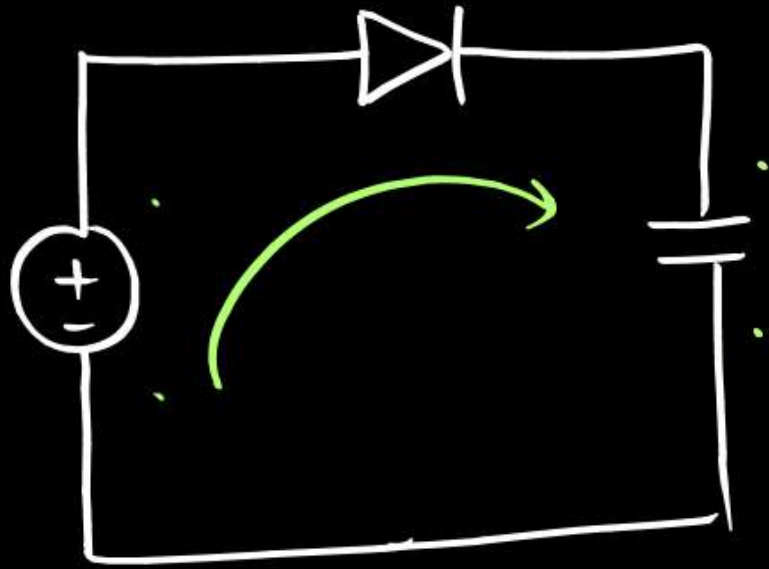
$$V_D = V_S - V_m$$

$$V_D = V_m \sin \omega t - V_m$$

at  $\omega t = 270$

$$V_D = -V_m - V_m$$





$$i = C \frac{dV_c}{dt}$$

$$i = C \frac{d}{dt} (V_m \sin \omega t)$$

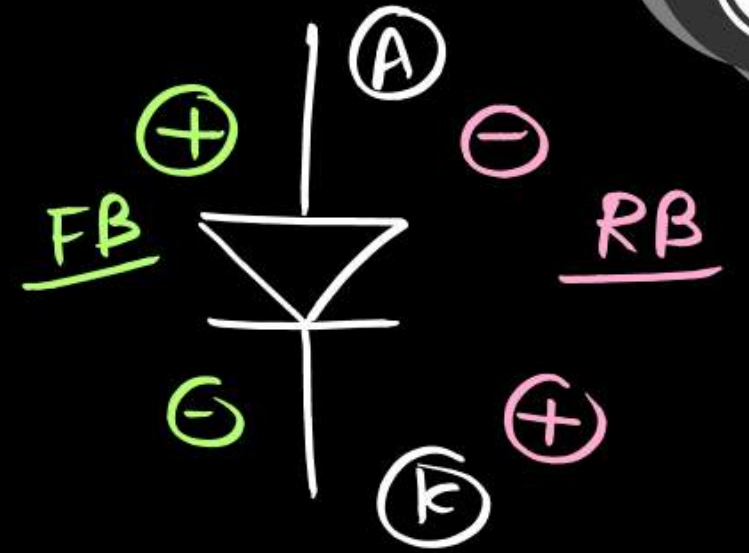
$$i = C V_m \omega \cos \omega t$$

When current will be zero

$$i = 0 = \omega C V_m \cos \omega t$$

$$\cos \omega t = 0$$

$$\omega t = \underline{\pi/2}$$



# Conduction Period of AC Circuit

Same AC Circuit ... Different Loads ... Different Journey Length!



Stops early...  
conduction for  
only  $\pi/2$



Distance =  $\pi/2$

- Current leads voltage
- Diode conducts in first quarter cycle
- Conduction period:  $\pi/2$



Goes further...  
conduction for  
 $\pi$



Distance =  $\pi$

- Current in phase with voltage
- Diode conducts in first half cycle
- Conduction period:  $\pi$



Goes the longest...  
conduction for  
 $2\pi$

- Current lags voltage
- Diode conducts in both half cycles
- Conduction period:  $2\pi$



Distance =  $2\pi$

Same AC Circuit... Different Loads... Different Conduction Periods!

## Note

- For R load      D conducts for  $\pi$  ✓
- L load      D conducts for  $2\pi$  ✓
- R – L load      D conducts for  $\pi$  to  $2\pi$
- C load      D conducts for  $\frac{\pi}{2}$

Q.

The switch is closed at  $t = 0$ , then diode will conduct for

A

$$\pi\sqrt{LC}$$

B

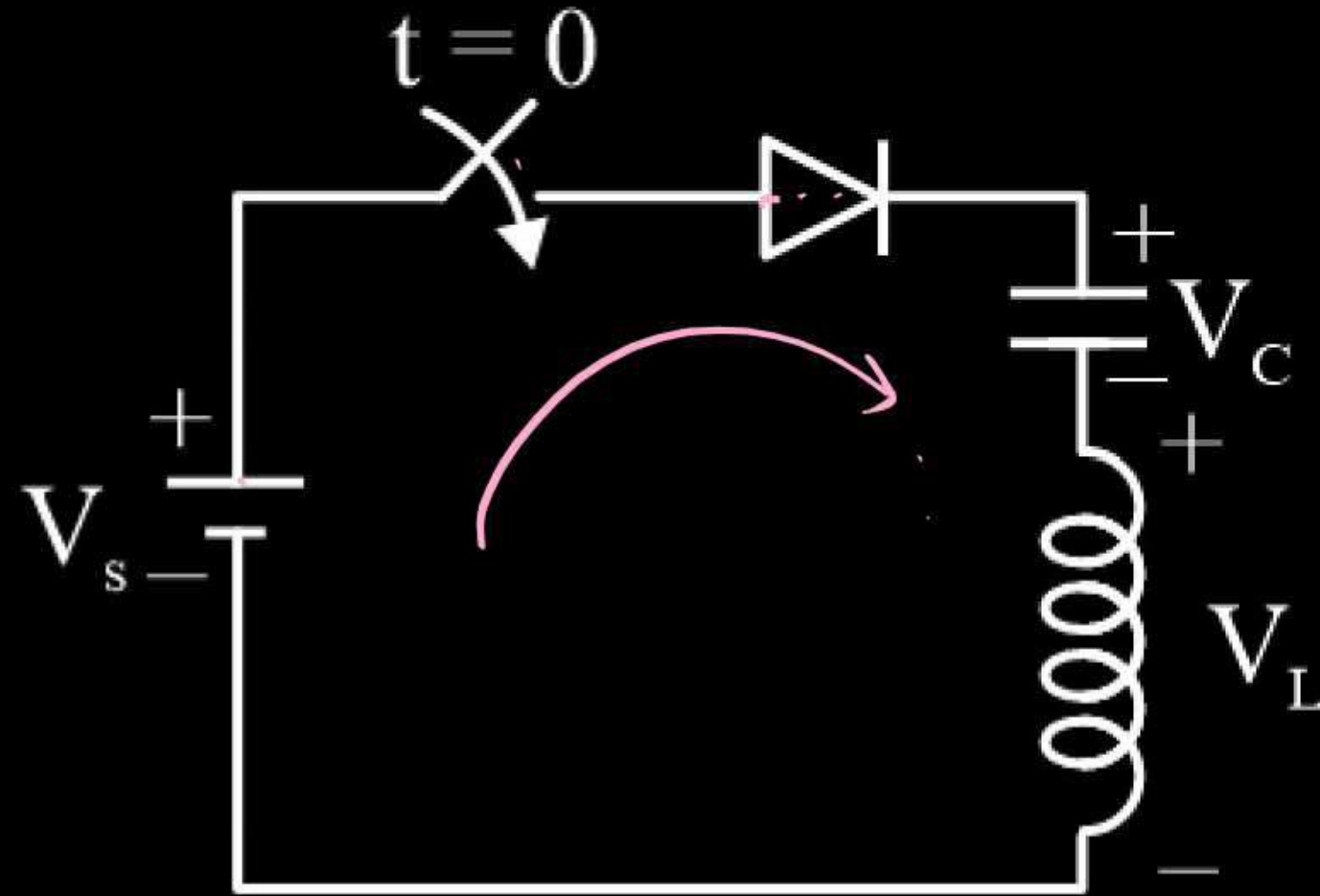
$$\frac{\pi}{2}\sqrt{LC}$$

C

$$2\pi\sqrt{LC}$$

D

Diode not conduct



At  $t=0$ , Diode is FB  $\underline{V_D = 0}$

KVL

$$V_s - V_c - V_L = 0$$

$$V_s = V_c + V_L$$

$$V_s = L \frac{di}{dt} + \frac{1}{C} \int i dt$$

$$\mathcal{L} [sI(s) - i(0)]$$

Laplace

$$\frac{V_s}{s} = \mathcal{L} [sI(s) - i(0)] + \frac{1}{C} \frac{I(s)}{s}$$

$$\frac{V_s}{s} = I(s) \left[ sL + \frac{1}{sC} \right]$$

$$\frac{V_s}{\cancel{s}} = I(s) \left[ \frac{s^2 Lc + 1}{\cancel{sc}} \right]$$

$$\int \sin \omega t = \frac{\omega}{s^2 + \omega^2}$$

$$I(s) = \frac{V_s c}{s^2 Lc + 1} = \frac{\frac{V_s}{L}}{s^2 + \frac{1}{Lc}}$$

Dividing by  $Lc$

$$I(s) = \frac{V_s}{L} \cdot \frac{1}{s^2 + \frac{1}{Lc}}$$

$$\text{Let } \omega_0^2 = \frac{1}{Lc} \Rightarrow \omega = \frac{1}{\sqrt{Lc}}$$

$$I(s) = \frac{V_s}{\omega_0 L} \cdot \left( \frac{\omega_0}{s^2 + \omega^2} \right)$$

Inverse Laplace

$$i(t) = \frac{V_s}{\omega_0 L} \sin \omega_0 t$$

$$i(t) = \frac{V_s \sqrt{L/C}}{1} \sin \omega_0 t$$

$$i(t) = V_s \sqrt{\frac{C}{L}} \sin \omega_0 t$$

When current is zero  $0 = \sin \omega_0 t$

$$\omega_0 t = 0, \pi, 2\pi$$

$$\omega_0 t = \pi$$

$$t = \frac{\pi}{\omega_0} = \pi \sqrt{LC}$$

$$t = \pi \sqrt{LC}$$

Different  
Loads...  
Different  
Love Stories

Will you be with me  
for my entire  
life? ♥

No, I can be with you  
only for  $\pi\sqrt{LC}$  time.  
After that, Diode  
will not allow me  
to stay with you.

After  
 $\pi\sqrt{LC}$ ,  
he is mine  
**ONLY!**

LC  
Circuit

DC  
Source

Diode

SAME  
CIRCUIT...  
DIFFERENT  
STORIES ♥

### Moral of the Story:

In an LC circuit excited by a DC source, the current flows only for  $\pi\sqrt{LC}$  time. ♥



## 2 Minutes Summary

→ Diode A.C Clct — Rload  
                                  — Lload  
                                  — Cload.

→ Diode clct D.C Source + LCload  $\pi JLC$

A dark blue, 3D-style banner with a folded effect, featuring the words 'THANK YOU' in large, white, bold, sans-serif capital letters.

**THANK YOU**



# Electrical Engineering

## Power Electronics



Lecture No - 4

Power Semi conductor devices

By- Ajay Gupta Sir



# Recap of Previous class

1. Reverse recovery characteristic.

2. Types of diode

3.



**Topic is  
To be  
covered**

1. Diode circuit

2. BJT

Q.

When diode stops conducting, the voltage of capacitor is



A

$$2V_s$$

$$i(t) = \frac{V_s}{\omega_0 L} \sin \omega_0 t$$

B

$$V_s$$

or

$$i(t) = V_s \sqrt{\frac{C}{L}} \sin \omega_0 t$$

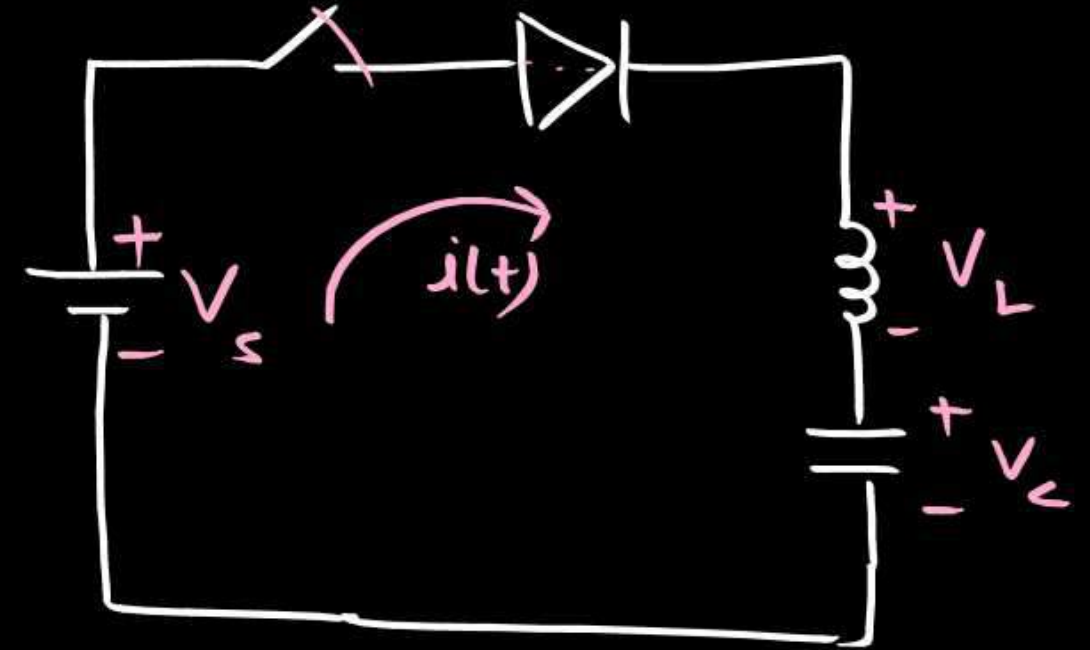
C

$$-V_s$$

D

$$-2V_s$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$



KVL

$$V_s - V_L - V_c = 0$$

$$V_s = V_L + V_c$$

$$V_s = V_s \cos \omega_0 t + V_c$$

$$V_c = V_s (1 - \cos \omega_0 t)$$

$$V_L = L \frac{di}{dt}$$

$$V_L = L \frac{d}{dt} \left( \frac{V_s}{\omega_0 L} \sin \omega_0 t \right)$$

$$V_L = L \cancel{\omega_0} \frac{V_s}{\cancel{\omega_0 L}} \cos \omega_0 t$$

$$V_L = V_s \cos \omega_0 t$$

Diode stop conducting

$$\sin \omega_0 t = 0$$

$$\omega_0 t = \pi \Rightarrow t = \frac{\pi}{\omega_0} = \pi \sqrt{LC}$$

$$\text{at } \omega_0 t = \pi$$

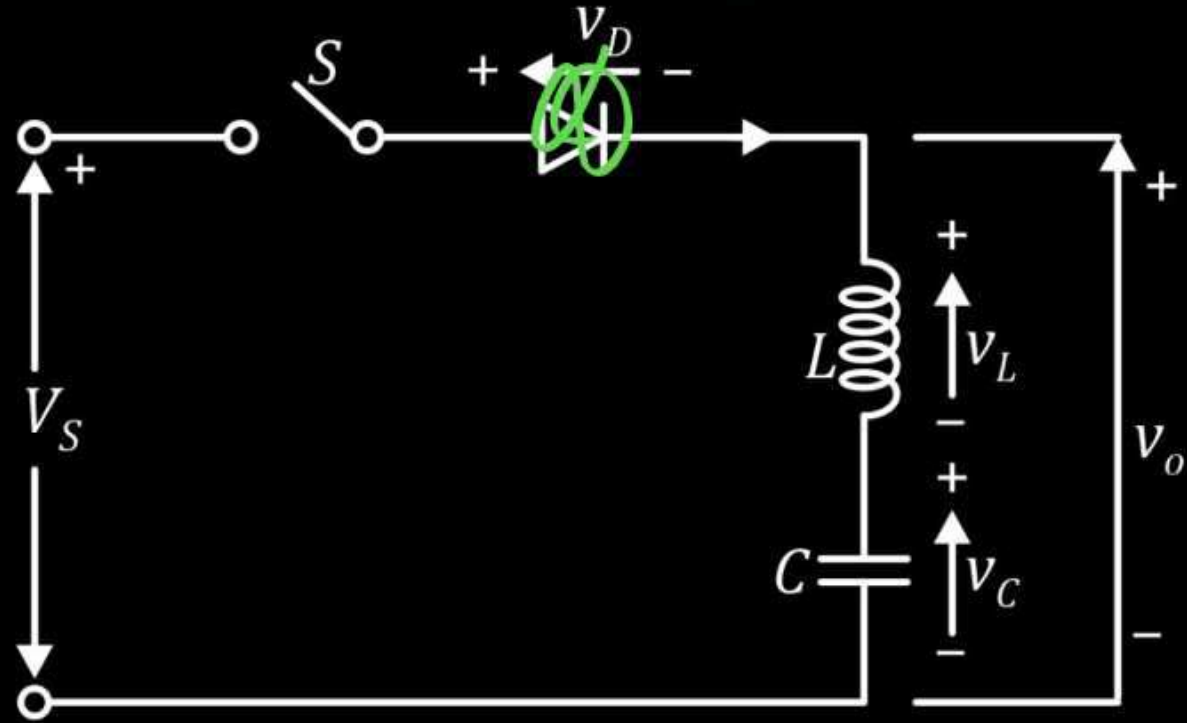
$$V_c = V_s (1 - \cos \pi)$$

$$V_c = 2V_s$$

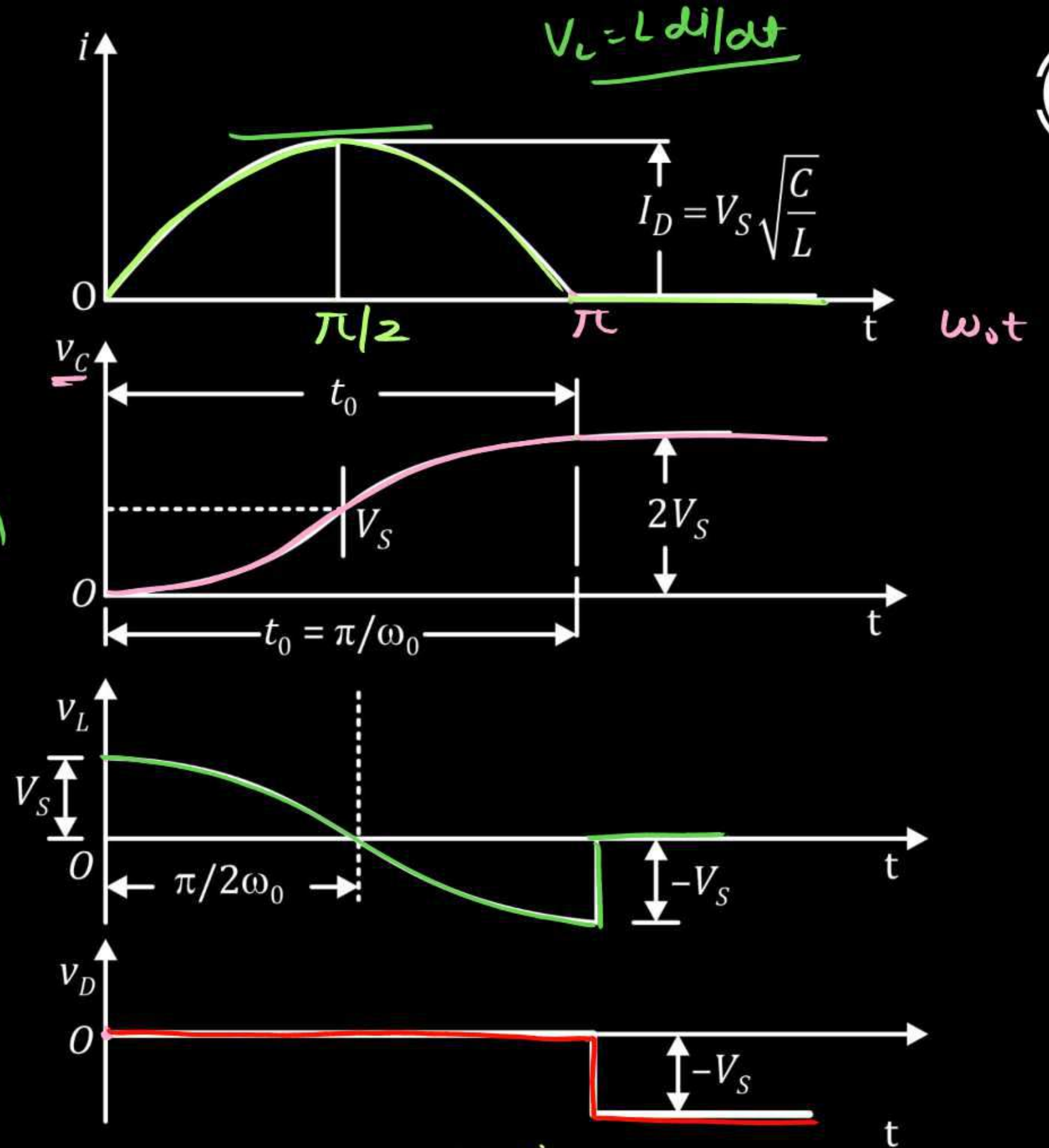
$$i = \frac{V_s}{\omega_0 L} \sin \omega_0 t$$

$$V_c = V_s (1 - \cos \omega_0 t)$$

$$V_L = V_s \cos \omega_0 t$$



(a)

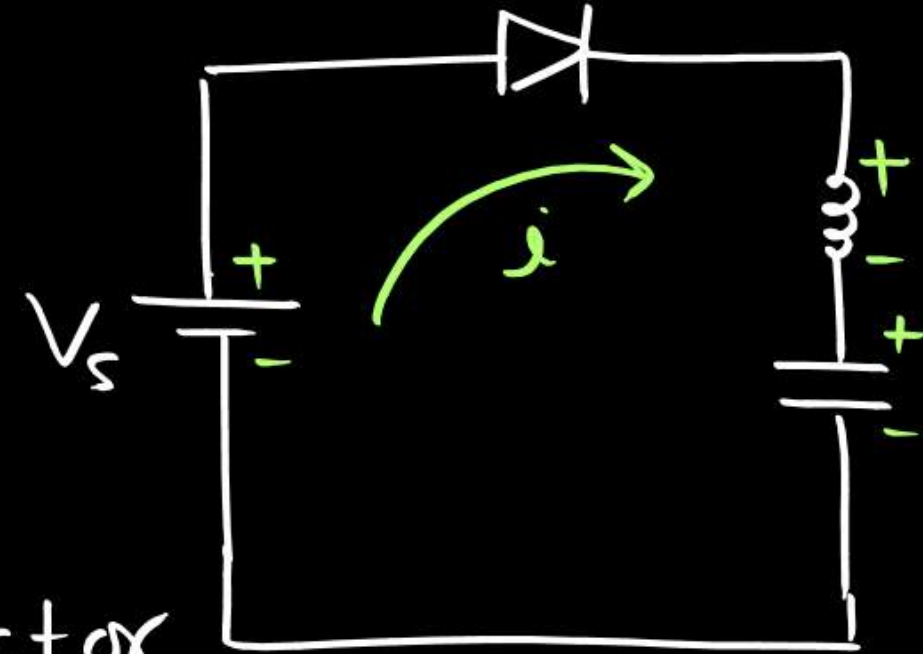


(b)

0 to  $\pi/2$

Diode  $\rightarrow$  FB

Current is flowing



Source is giving energy to inductor

and Capacitor

$$V_L = L \frac{di}{dt}$$

$$\text{Source} \rightarrow \frac{1}{2} L i^2 \uparrow + \frac{1}{2} C V_c^2 \uparrow$$

→ So Current through inductor and Voltage across Capacitor is increasing

$$\underline{\text{At } \omega_0 t = \pi/2} \quad i = \text{Max}^m$$

So Now Inductor is having  $\text{Max}^m$  energy.

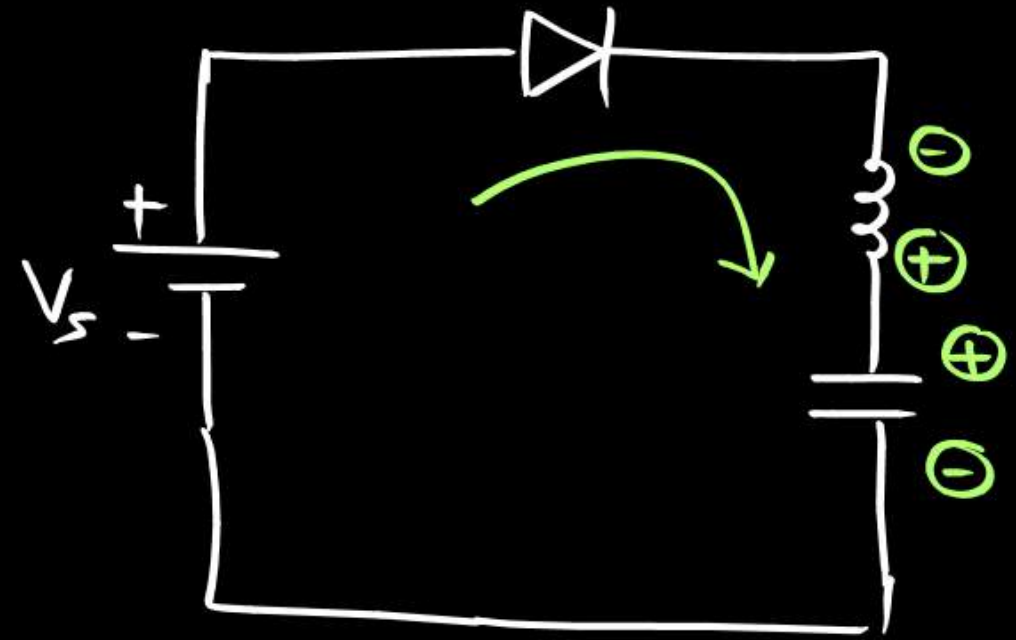
$$\underline{\text{At } \omega_0 t = \frac{\pi}{2} \text{ to } \pi} \quad \text{Now inductor is releasing its energy.}$$

$$\text{Source} + \frac{1}{2} L \dot{i}^2 \downarrow \rightarrow \frac{1}{2} C V_c^2 \uparrow$$

$$\frac{1}{2} L \dot{i}^2 \downarrow = \dot{i} \downarrow$$

$$\frac{1}{2} C V_c^2 \uparrow = V_c \uparrow$$

So current will decrease and Capacitor voltage will increase.



at  $\omega_0 t = \pi$

$$\omega_0 t = \pi$$
$$t = \frac{\pi}{\omega_0} = \underline{\underline{\pi \sqrt{LC}}}$$

Now capacitor is having max<sup>m</sup> energy and it will try to release its energy. By reversing

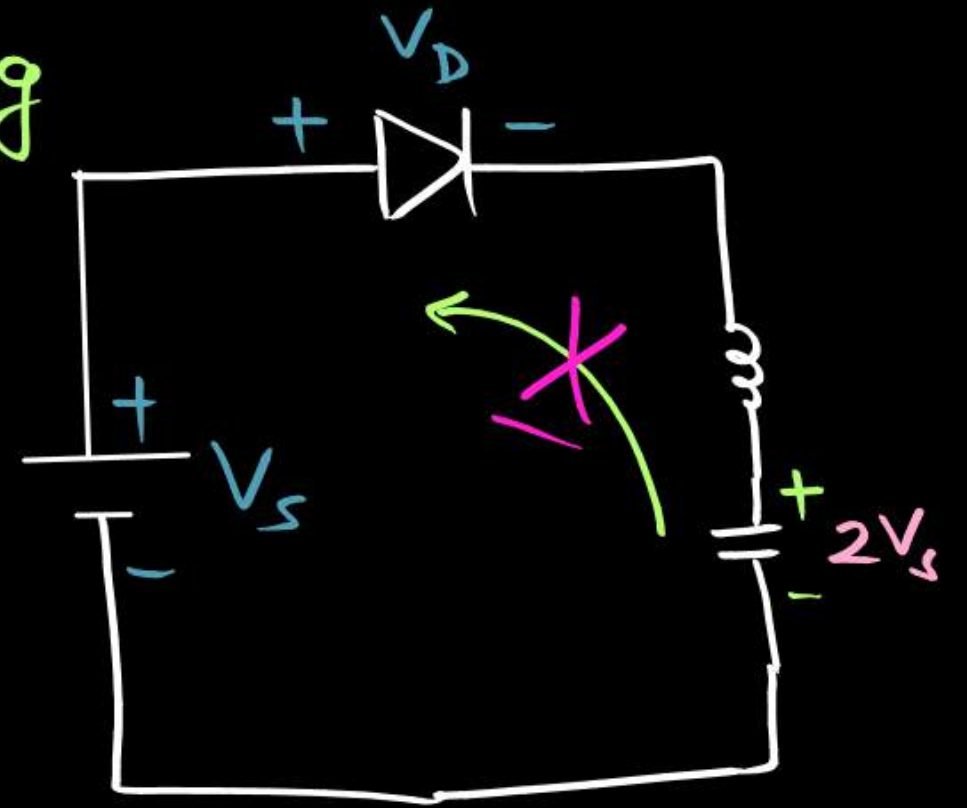
the current. But diode does not allow reverse current so it stops

conducting.

KVL

$$V_s - V_D - 2V_s = 0$$

$$\underline{V_D = -V_s \text{ (R.B.)}}$$

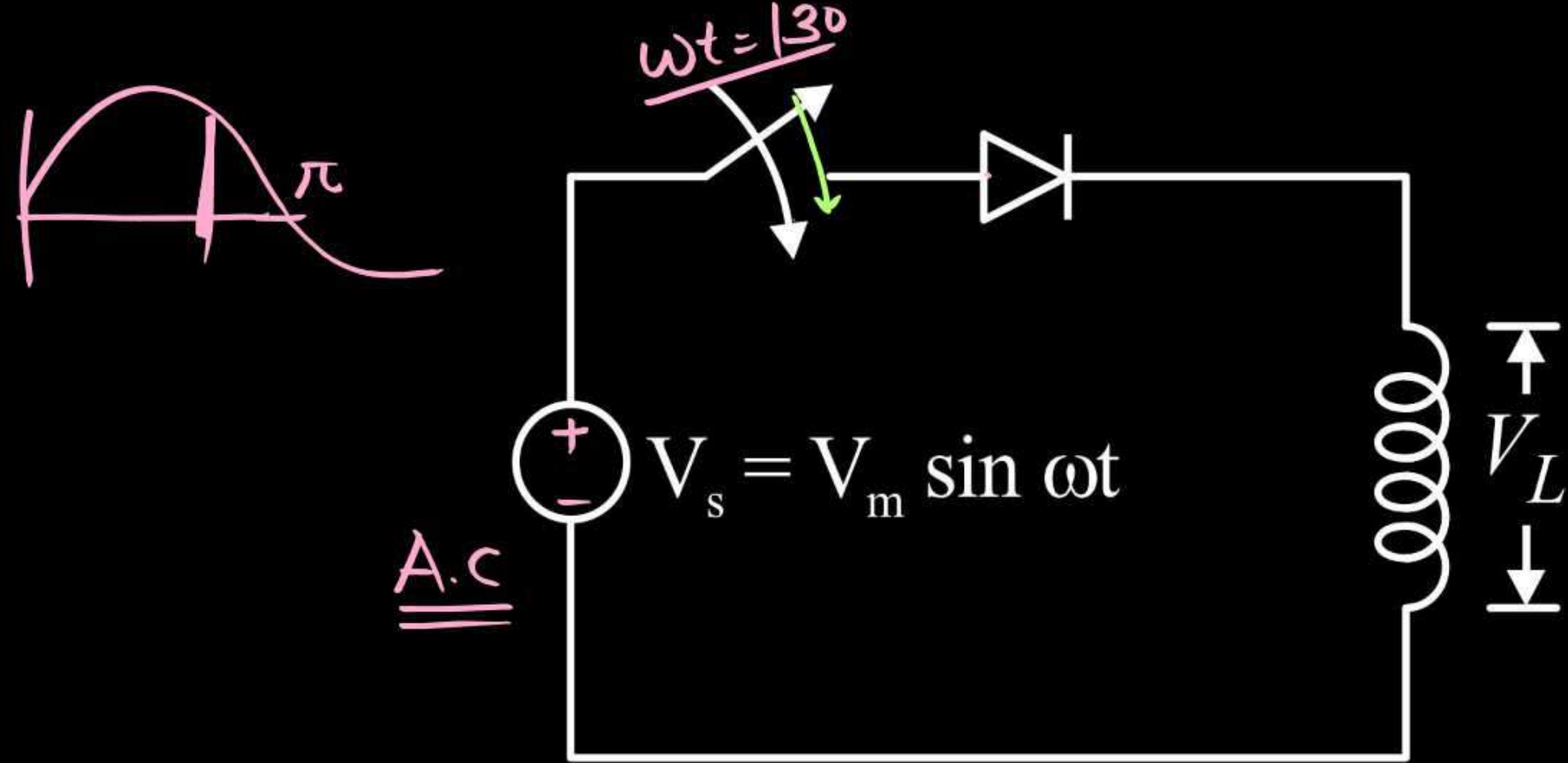


Q.

Switch is closed at  $\omega t = 130^\circ$ . The current will become zero at



- A  $\omega t = 180$
- B  $\omega t = 360$
- C  $\omega t = 230$
- D  $\omega t = 300$



at  $\omega t = 130$ , Diode = F.B. (Positive cycle)

So current start flowing.

$$V_L = V_s = V_m \sin \omega t$$

$$V_L = L \frac{di}{dt}$$

$$V_m \sin \omega t = L \frac{di}{dt}$$

$$\int di = \frac{V_m}{\omega L} \int \sin \omega t \, d\omega t$$

$$i = \frac{V_m}{\omega L} [-\cos \omega t] + K \quad - (1)$$

at  $\omega t = 130^\circ \Rightarrow i = 0$

$\omega t = 0$   


$$0 = \frac{V_m}{\omega L} [-\cos 130] + K$$

$$0 = \frac{V_m}{\omega L} [0.64278] + K$$

$$K = -\frac{V_m}{\omega L} [0.64278]$$

Put this value in eqn (1)

$$0 + 360 = 0$$

$$0 - 360 = 0$$

$$i = \frac{V_m}{\omega L} [-\cos \omega t] - \frac{V_m}{\omega L} [0.64278]$$

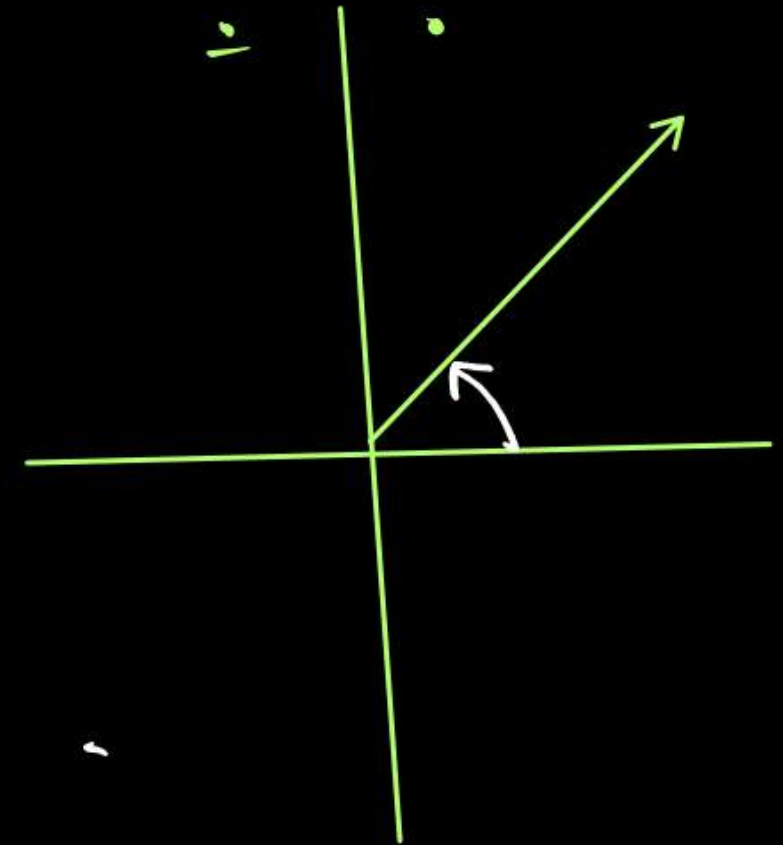
$$i = \frac{V_m}{\omega L} [-\cos \omega t - 0.64278]$$

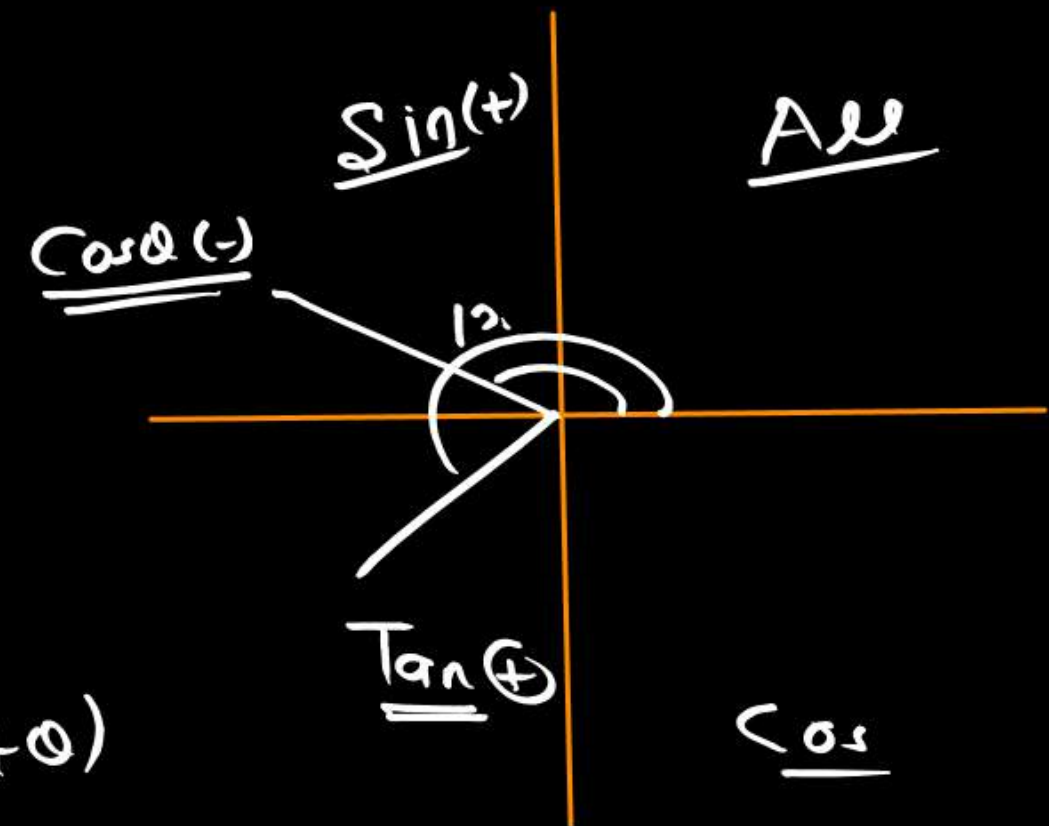
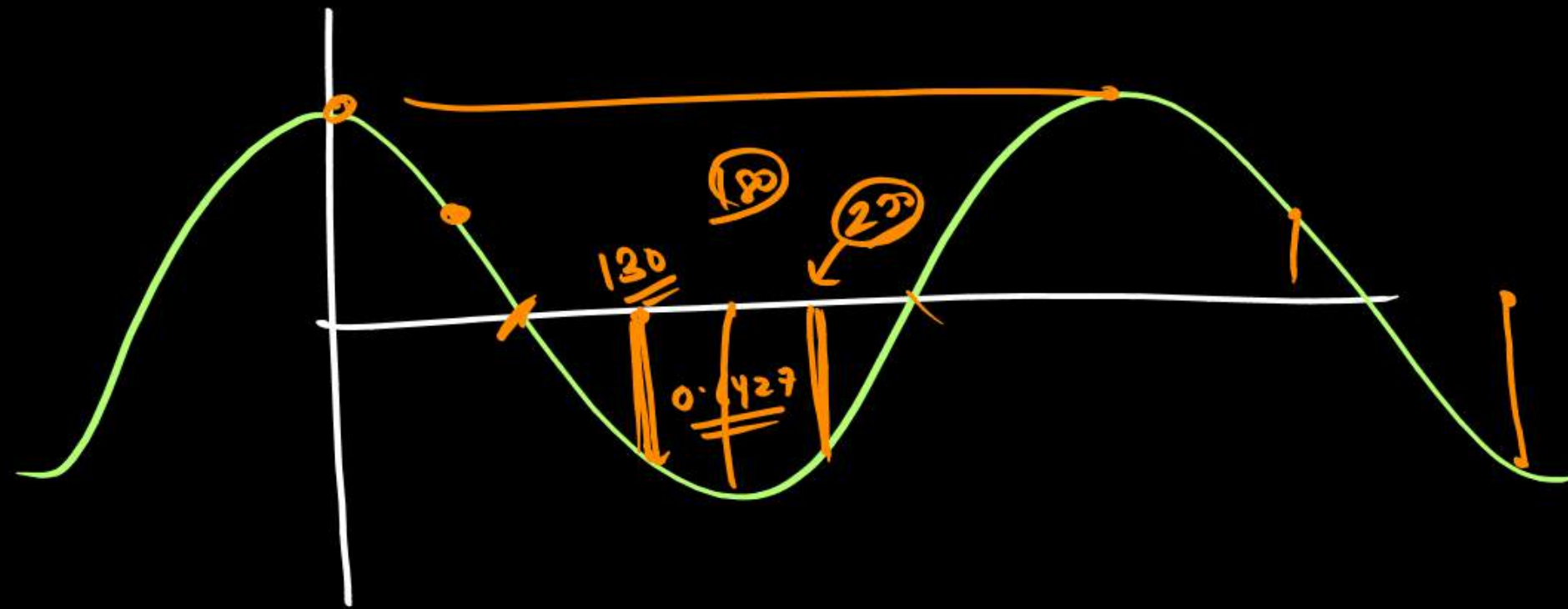
Current will be zero

$$-\cos \omega t - 0.64278 = 0$$

$$\cos \omega t = -0.64278$$

$$\omega t = 130, 230 \checkmark$$

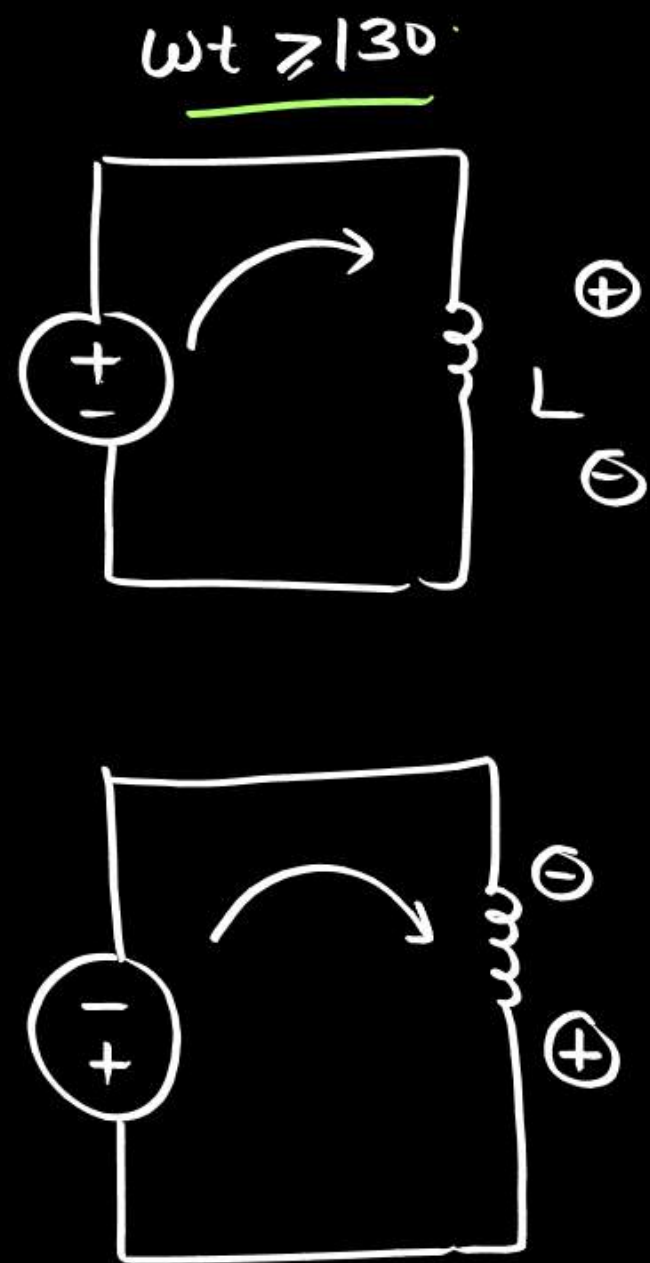
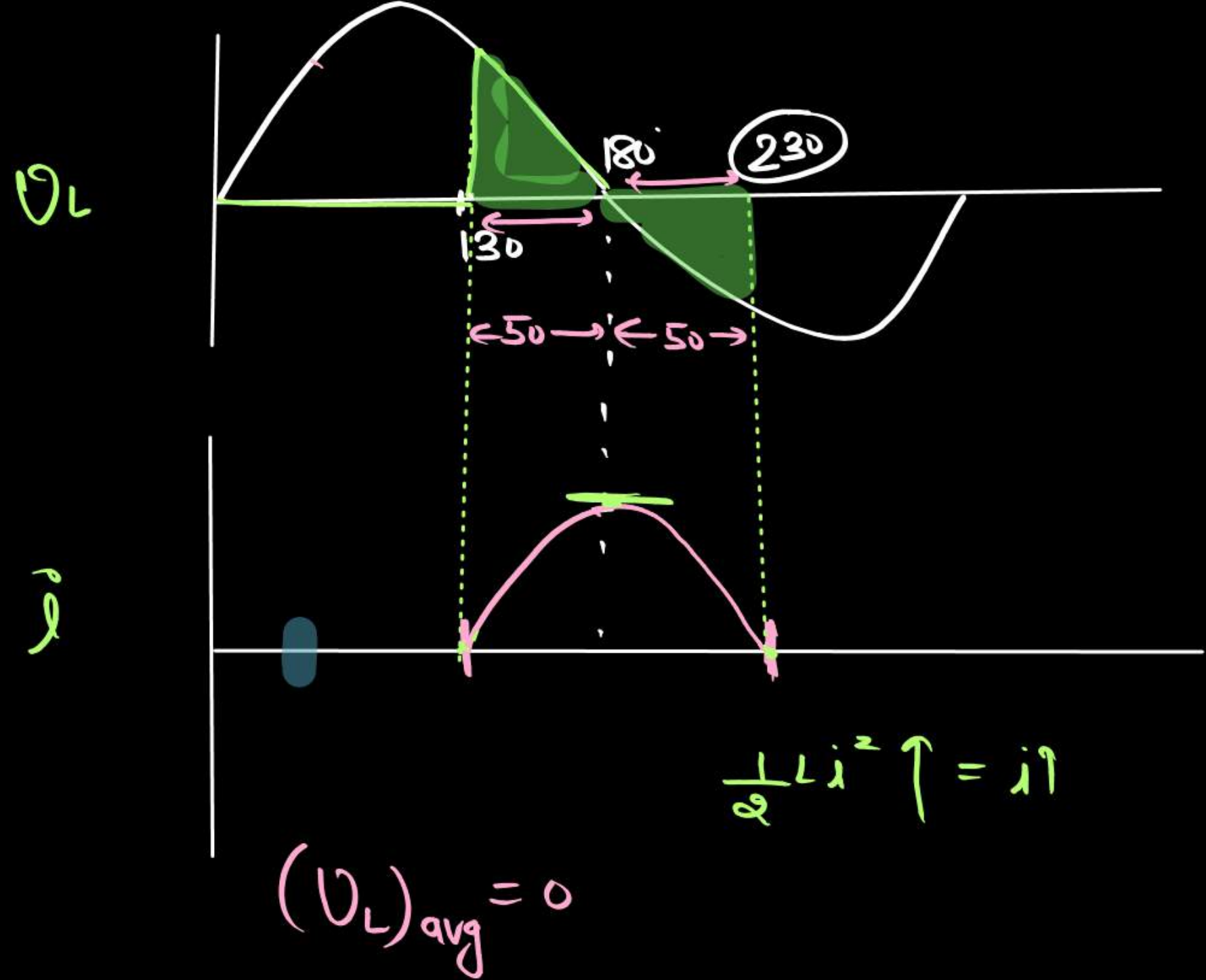




130

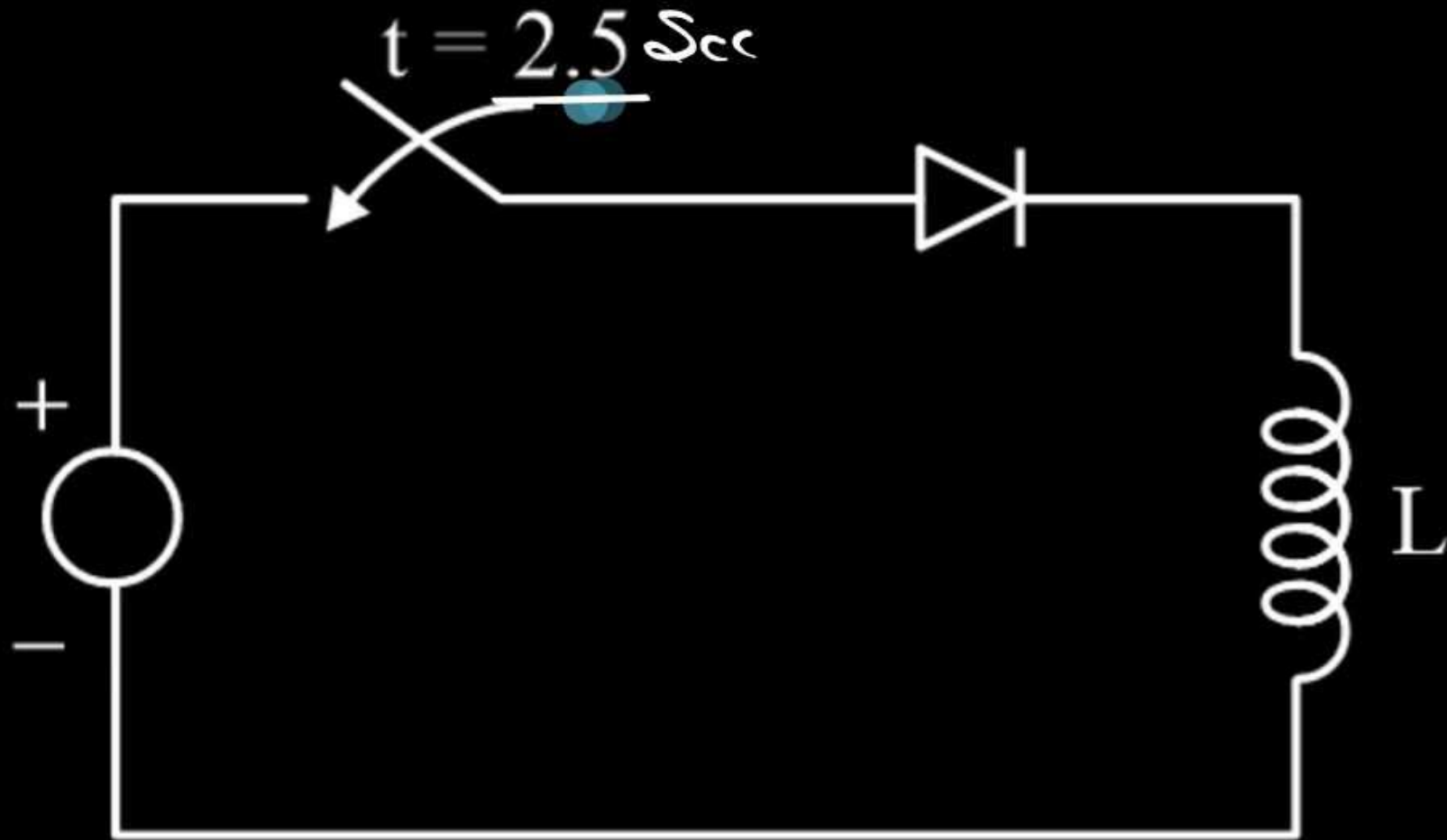
$$\cos(180 - \theta) = \cos(180 + \theta)$$

$\downarrow$                        $\downarrow$   
 130                      270



Q.

A diode circuit feeds an ideal Inductor. Given that,  $V_s = \overset{V_m}{100} \sin \omega t$  where,  $\omega = 100 \pi$  and  $L = 31.83 \text{ mH}$ . The initial value of inductor current is zero. Switch S is closed at  $t = 2.5 \text{ ms}$ . The peak value of Inductor current in the first cycle will be



$$\omega t = 100\pi (2.5 \times 10^{-3})$$

$$= \frac{2.5}{1000} \cdot 100\pi$$

$$\omega t = \frac{\pi}{4}$$

at  $\omega t = \frac{\pi}{4}$  current will start flowing.

$$V_s = L \frac{di}{dt}$$

$$V_m \sin \omega t = L \frac{di}{dt}$$

$$i = \frac{V_m}{L} \int \sin \omega t \, dt$$

$$i = \frac{V_m}{\omega L} [-\cos \omega t] + k \quad - (1)$$

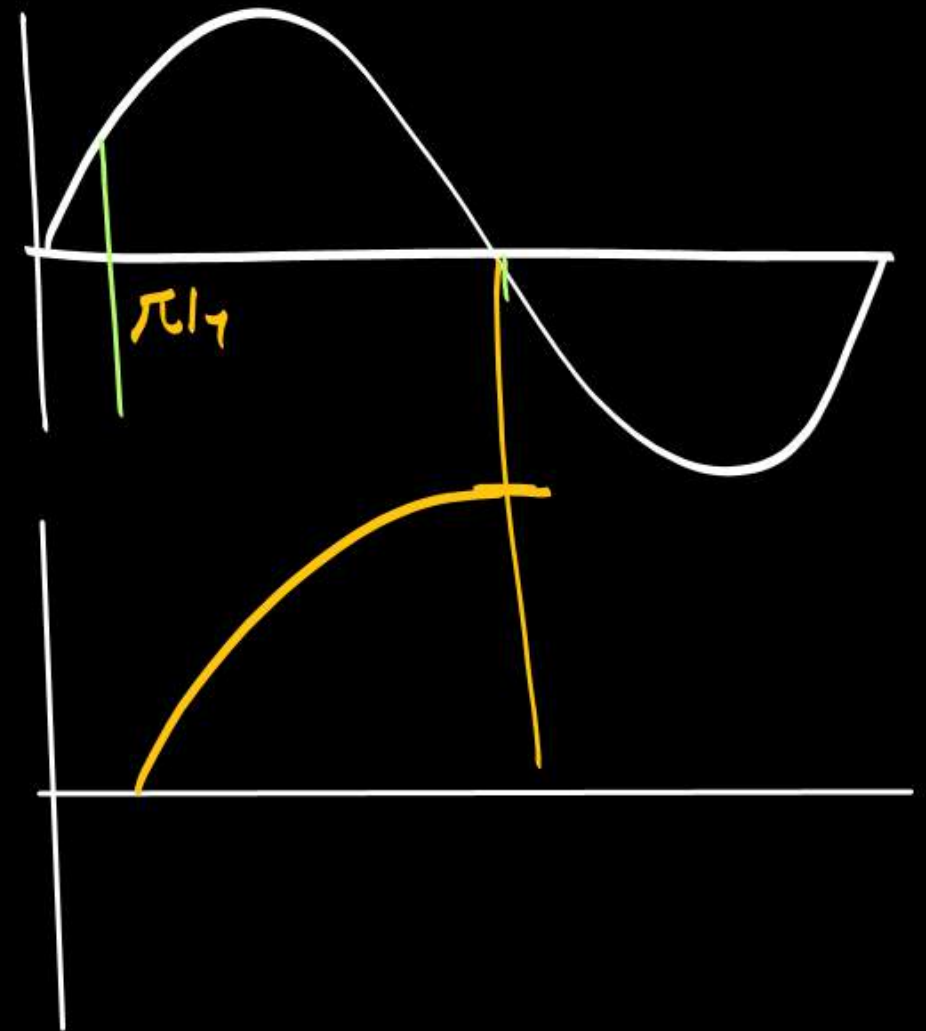
$$\text{at } \omega t = \frac{\pi}{4} \Rightarrow i^0 = 0$$

$$0 = \frac{V_m}{\omega L} \left[ -\cos \frac{\pi}{4} \right] + K$$

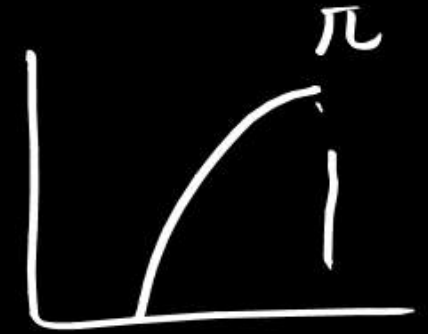
$$K = \frac{V_m}{\omega L} \cdot \frac{1}{\sqrt{2}}$$

Put value of  $K$  in eq<sup>n</sup> (1)

$$i^0 = \frac{V_m}{\omega L} [-\cos \omega t] + \frac{V_m}{\omega L} \cdot \frac{1}{\sqrt{2}}$$



$$i = \frac{V_m}{\omega L} \left[ -\cos \omega t + \frac{1}{\sqrt{2}} \right]$$

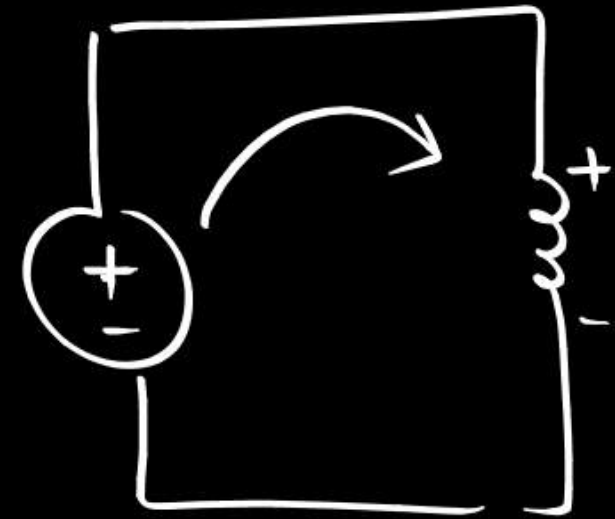


For Max<sup>m</sup> Current  $\cos \omega t = -1$

$$i_{\max} = \frac{V_m}{\omega L} \left[ 1 + \frac{1}{\sqrt{2}} \right]$$

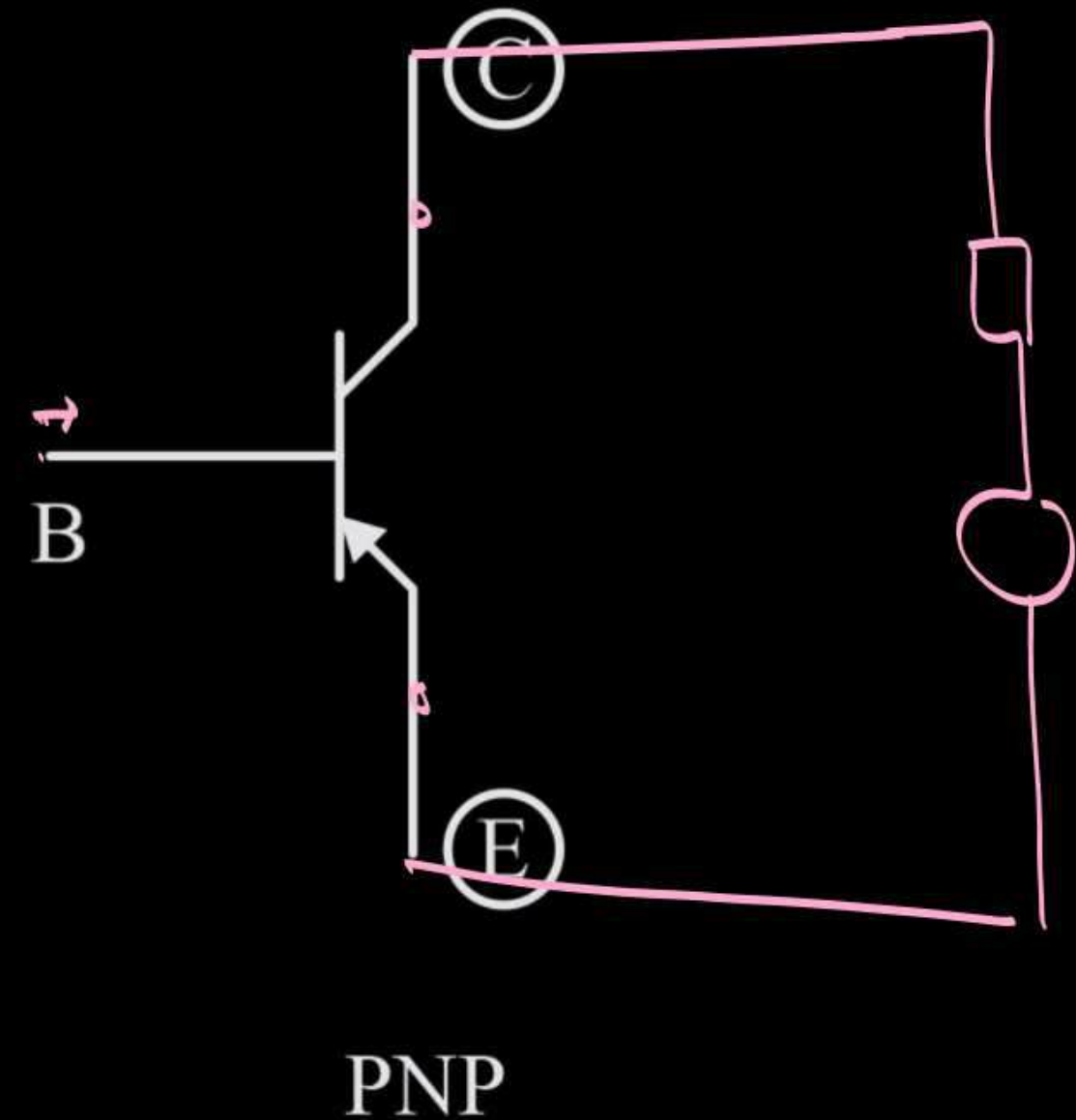
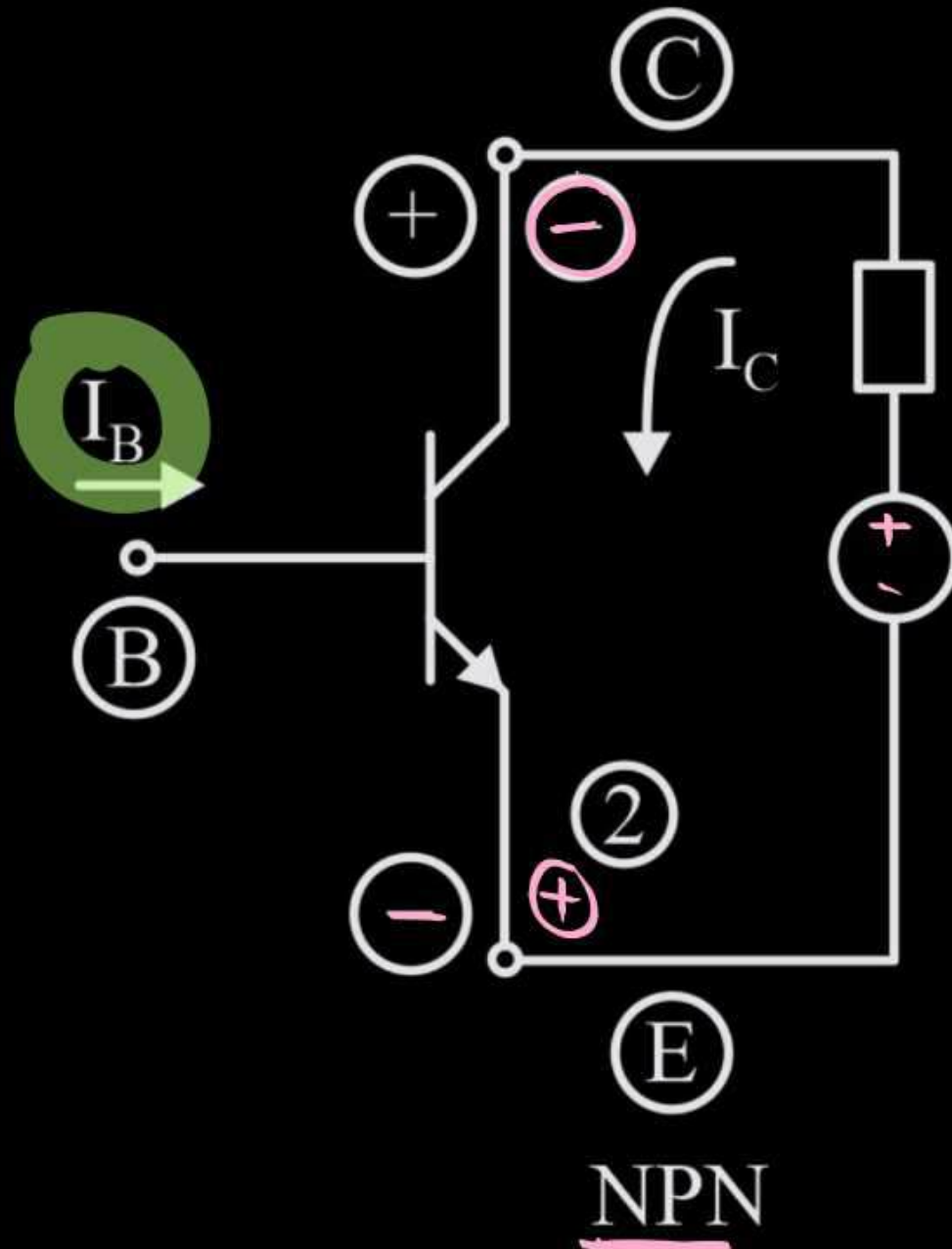
$$= \frac{100}{100 \pi \cdot 31.83 \times 10^{-3}} \left[ 1 + \frac{1}{\sqrt{2}} \right]$$

$$i_{\max} = 17.07$$



# Transistor Family

## Bipolar Junction Transistor (BJT)



# Bipolar Junction Transistor

- BJT is a three terminal device in which collector (C) and Emitter (E) are the main terminals and Base (B) is control terminal.
- It is a **fully controlled device**. It can be turned ON as well as turned OFF through control terminal.
- It is a **unidirectional device** in which current flows only from collector to emitter. (NPN)
- It has unipolar voltage blocking capacity. It can block only forward voltage. When significant amount of reverse voltage is applied , it is damaged.

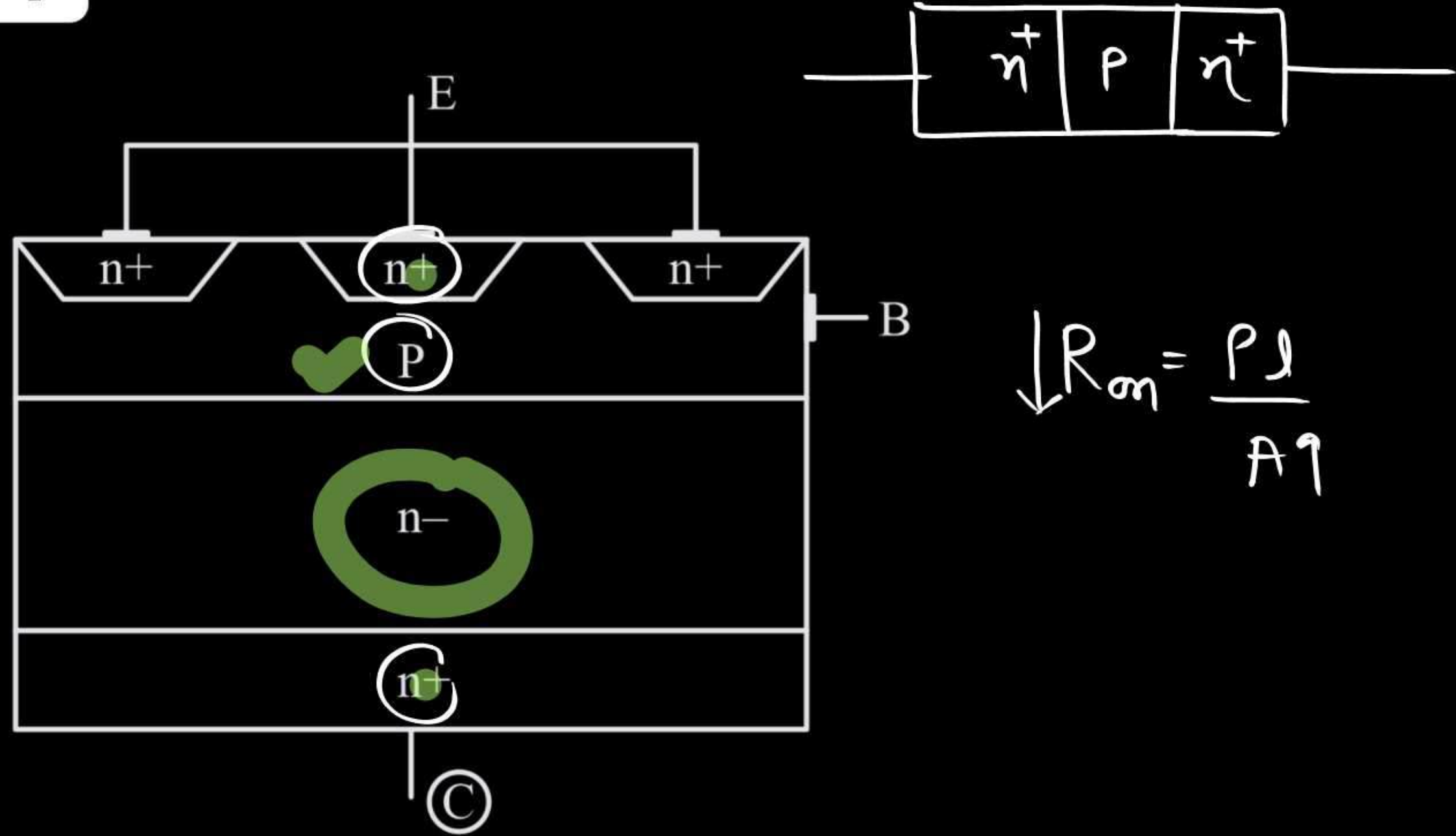
# Bipolar Junction Transistor

$T \uparrow = \text{Covalent bond break}$   
 $= \text{Minority } \uparrow = \text{charge } \uparrow$



- It is **Bipolar (Minority carrier)** device. In this device, conduction occurs due to electrons and holes both.
- It has negative **temperature coefficient of Resistance**.  $T \uparrow \Rightarrow R \downarrow$
- $T \uparrow \rightarrow R \downarrow$
- It also has **secondary breakdown**.
- It is a **current controlled device**, the control signal is  $I_B$
- It's **parallel operation is not possible** in normal way.

# Power BJT



## Construction – Power BJT

- In power BJT, we use alternate n and p type semiconductor layers in vertical configuration.
- Vertical configuration increases the **cross section area**, so  $R_{on}$  is reduced. Therefore, during ON condition, large amount of current can flow which increase its **current rating**.
- We introduce a lightly doped **drift region** between base and collector semiconductor layer, which increase the **voltage rating of power BJT**.

## Construction – Power BJT

- To increase the value of  $\beta = \frac{I_C}{I_B}$ , the base semiconductor layer has lower doping and its thickness is also less.
- We use multi emitter in power BJT to reduce the secondary breakdown phenomena which occurs due to current's crowding.



## 2 Minutes Summary

→ Diode ckt  $\begin{cases} \text{D.C} \\ \text{A.C} \end{cases}$

→ BJT  $\begin{cases} \text{Construction} \\ \text{Main point.} \end{cases}$



**THANK YOU**



# Electrical Engineering

## Power Electronics



Lecture No - 5

Power Semi conductor devices

By- Ajay Gupta Sir



# Recap of Previous class

- ✓ 1. Diode Circuit
- ✓ 2. BJT Introduction
- 3.



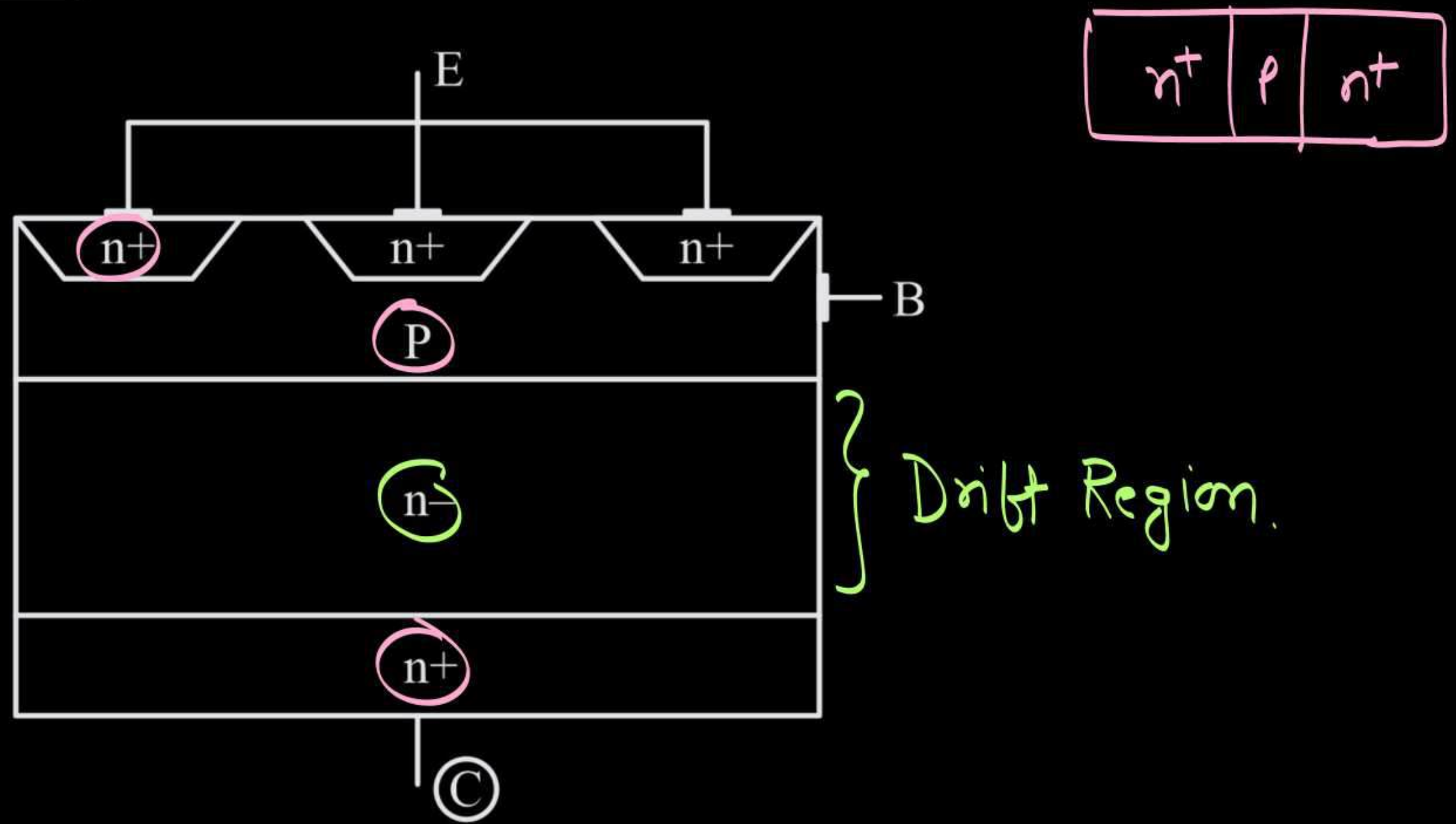
**Topic is  
To be  
covered**

✓ 1. Working of BJT

✓ 2. BJT as a switch

✓ 3. MOSFET

# Power BJT



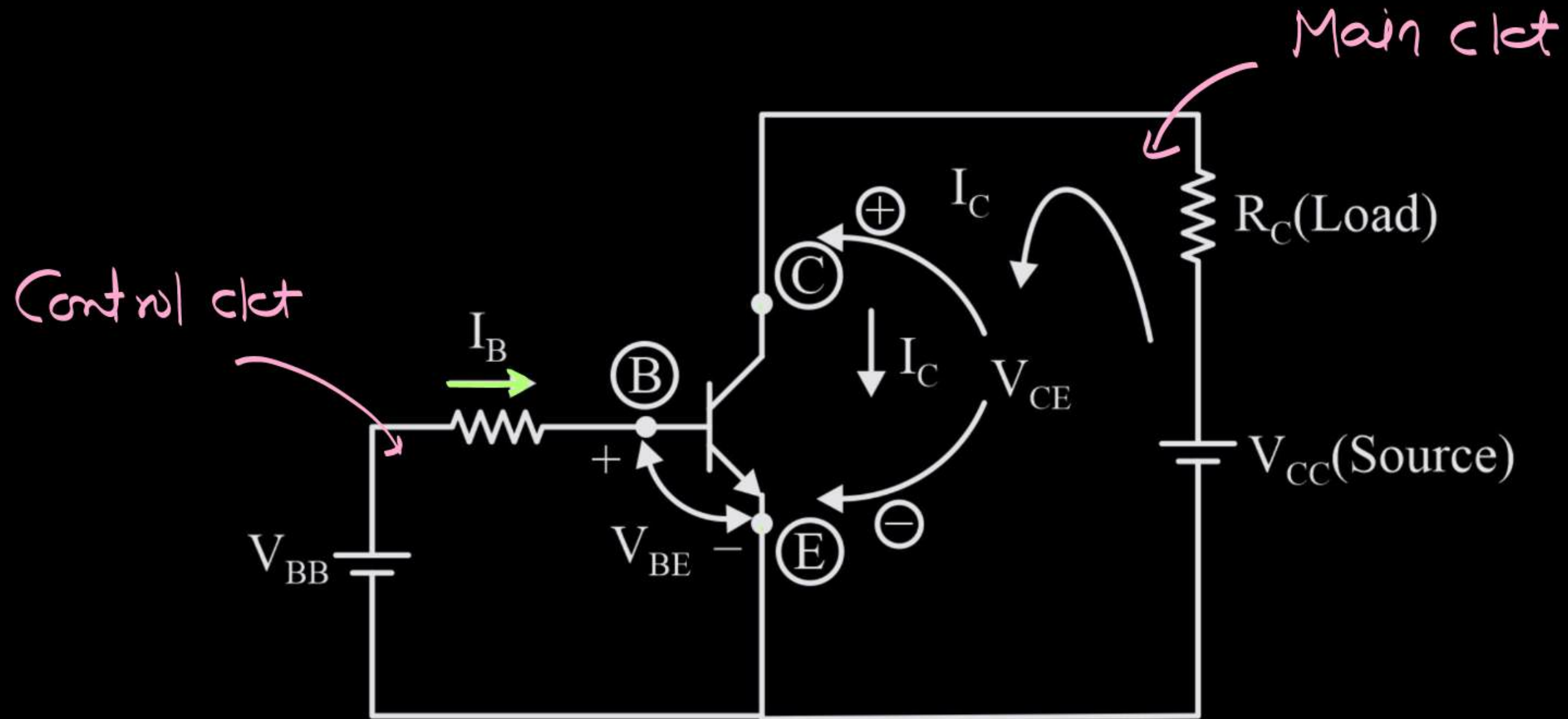
## Construction – Power BJT

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- Vertical configuration increases the cross section area, so  $R_{on}$  is reduced. Therefore, during ON condition, large amount of current can flow which increase its current rating.
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## Construction – Power BJT

- To increase the value of  $\beta = \frac{I_C}{I_B}$ , the base semiconductor layer has lower doping and its thickness is also less.
- We use multi emitter in power BJT to reduce the secondary breakdown phenomena which occurs due to current's crowding.

# Working Principle – Power BJT





## Working Principle – Power BJT

- Without biasing the BJT, it is in thermal equilibrium condition. So, depletion layer exists both in  $J_{CB}$  and  $J_{BE}$  (both junctions are RB). So, potential barrier exists, due to which no charges move between collector and emitter. At this time, BJT is operating in cut-off region. However small amount of leakage current can flow.
- When voltage between base and emitter terminal is applied, the width of depletion layer at junction  $J_{BE}$  starts reducing. So electrons start diffusing from emitter layer to base layer. Some of these electrons combine with the holes present in the base layer. The outer base circuit produce these holes continuously, due to which base current starts flowing.

# Working Principle – Power BJT

- But, majority of electrons move towards junction  $J_{CB}$  and due to drift phenomena, these electrons moves toward the collector layer. Finally, the positive collector terminal attract these negative electrons and that's why collector current starts flowing.

- In active region, junction  $J_{BE}$  is FB but Junction  $J_{CB}$  is RB.

$$\rightarrow \beta = \frac{I_C}{I_B} \quad I_C = \beta I_B$$

$$I_B \uparrow \Rightarrow I_C \uparrow = \beta I_B \uparrow \Rightarrow V_{CE} \downarrow = V_{CC} - I_C \uparrow R_C$$

$$V_{CE} = V_{CB} + V_{BE}$$

$$V_{CB} = V_{CE} - V_{BE}$$

$$V_{CB} = \ominus$$

$$\begin{array}{r} 7-5 \\ 6-4 \\ 5-3 \\ 4-2 \\ 3-1 \end{array} =$$

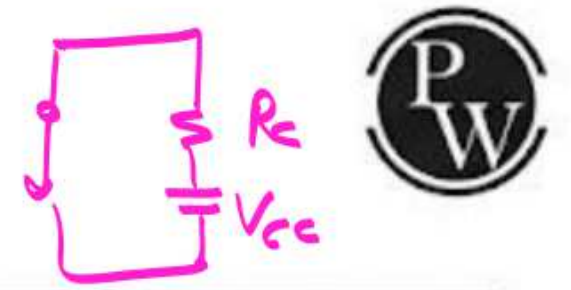
# Working Principle – Power BJT

- If we go on increasing  $I_B$ , the magnitude of  $I_C$  is increasing, so  $V_{CE}$  is reducing. If  $V_{CE} < V_{BE}$ , then  $V_{CB}$  becomes negative. So junction  $J_{CB}$  also becomes FB. Therefore, no depletion layer exists. At this time, BJT is in saturation region.
- In saturation region both junctions are FB.

IMP

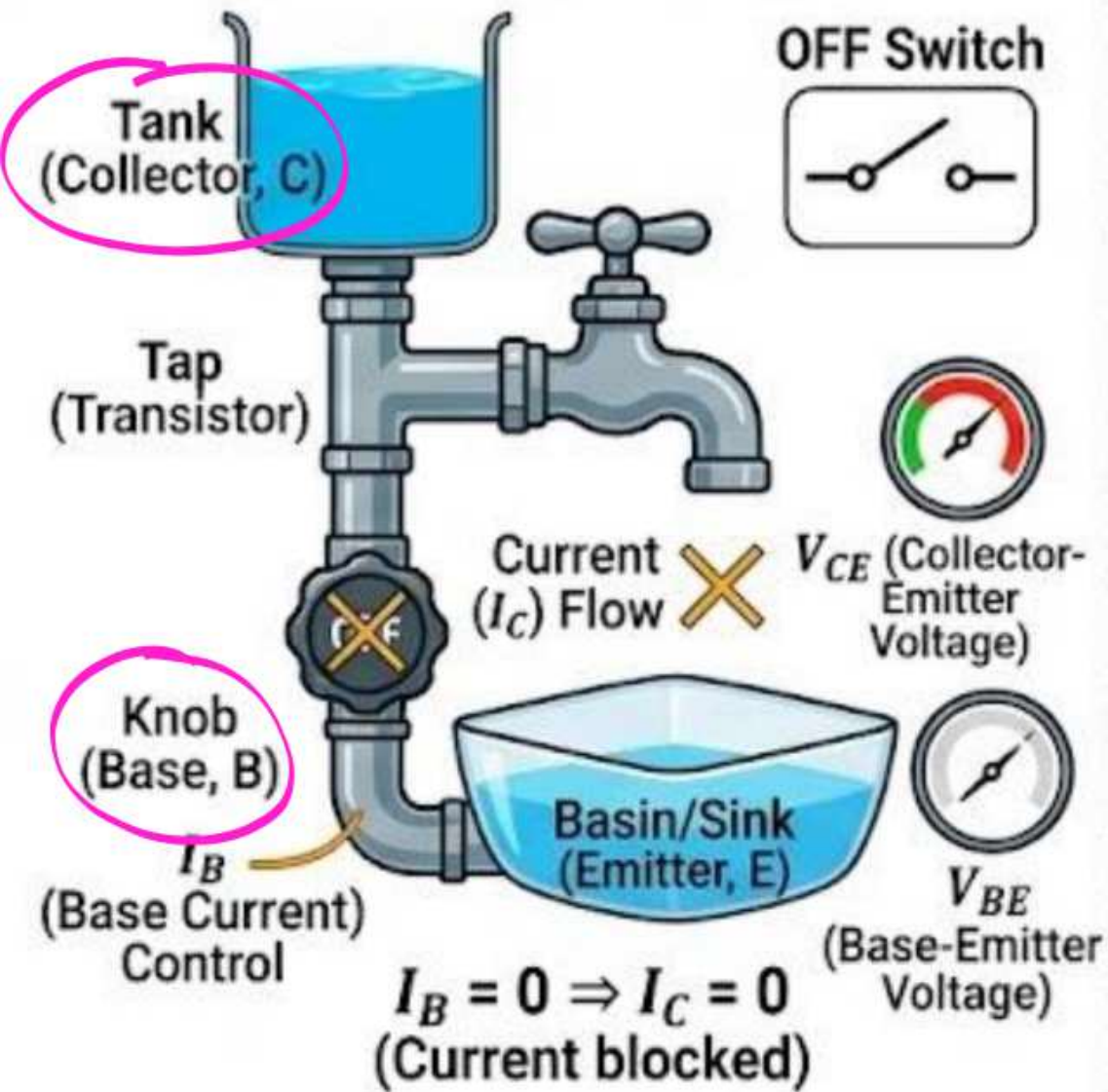
| Region          | $J_{CB}$ | $J_{BE}$ | Application  |
|-----------------|----------|----------|--------------|
| Cut-off         | → RB     | → RB     | → OFF Switch |
| Active (Linear) | → RB     | → FB     | ✓ Amplifier  |
| Saturation      | → FB     | → FB     | → ON Switch  |

# BJT Transistor-Water Tap Analogy: Visualizing Three Operational Regions



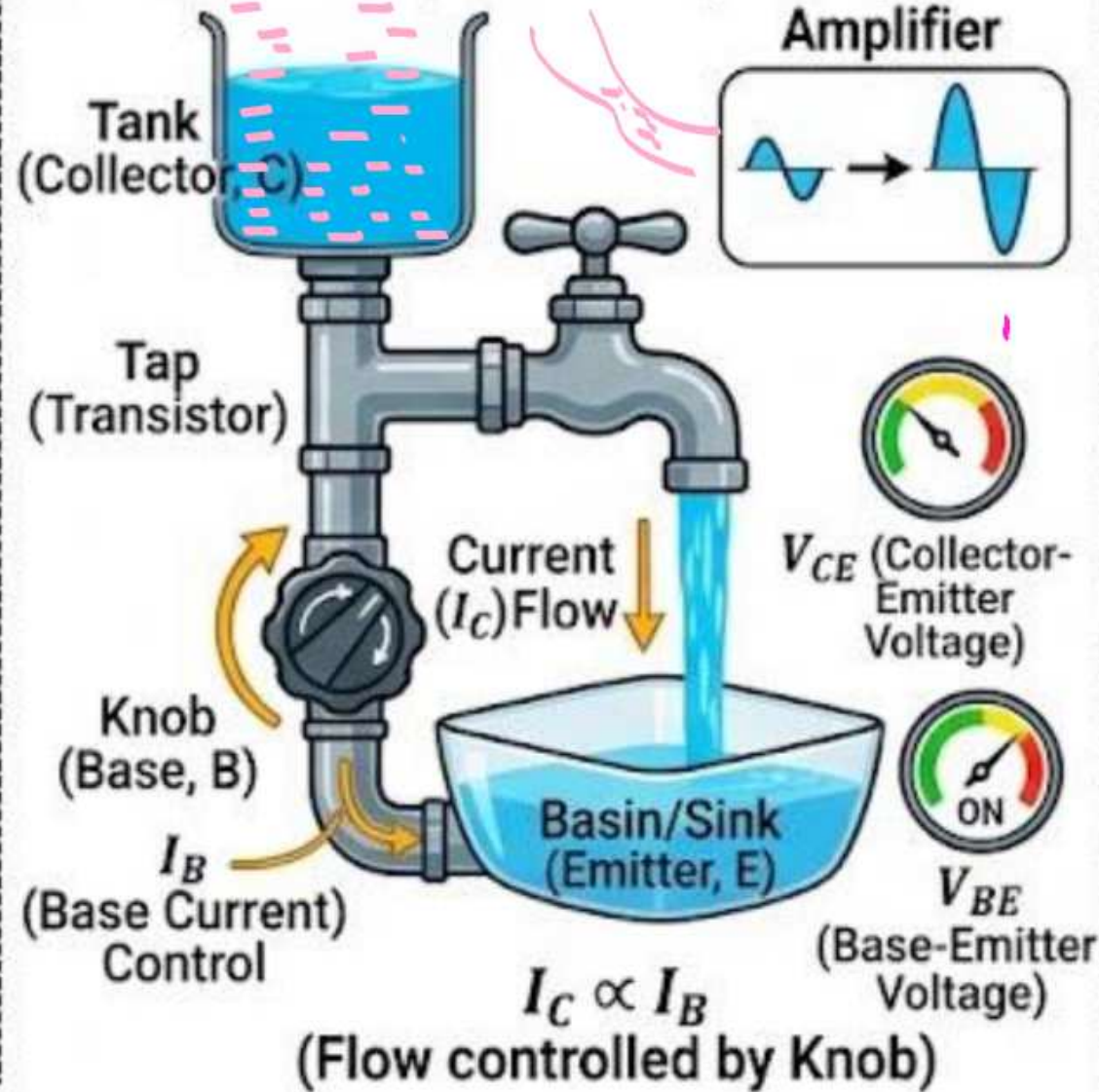
## Region 1: Cut-off

Nalka Band / OFF Switch



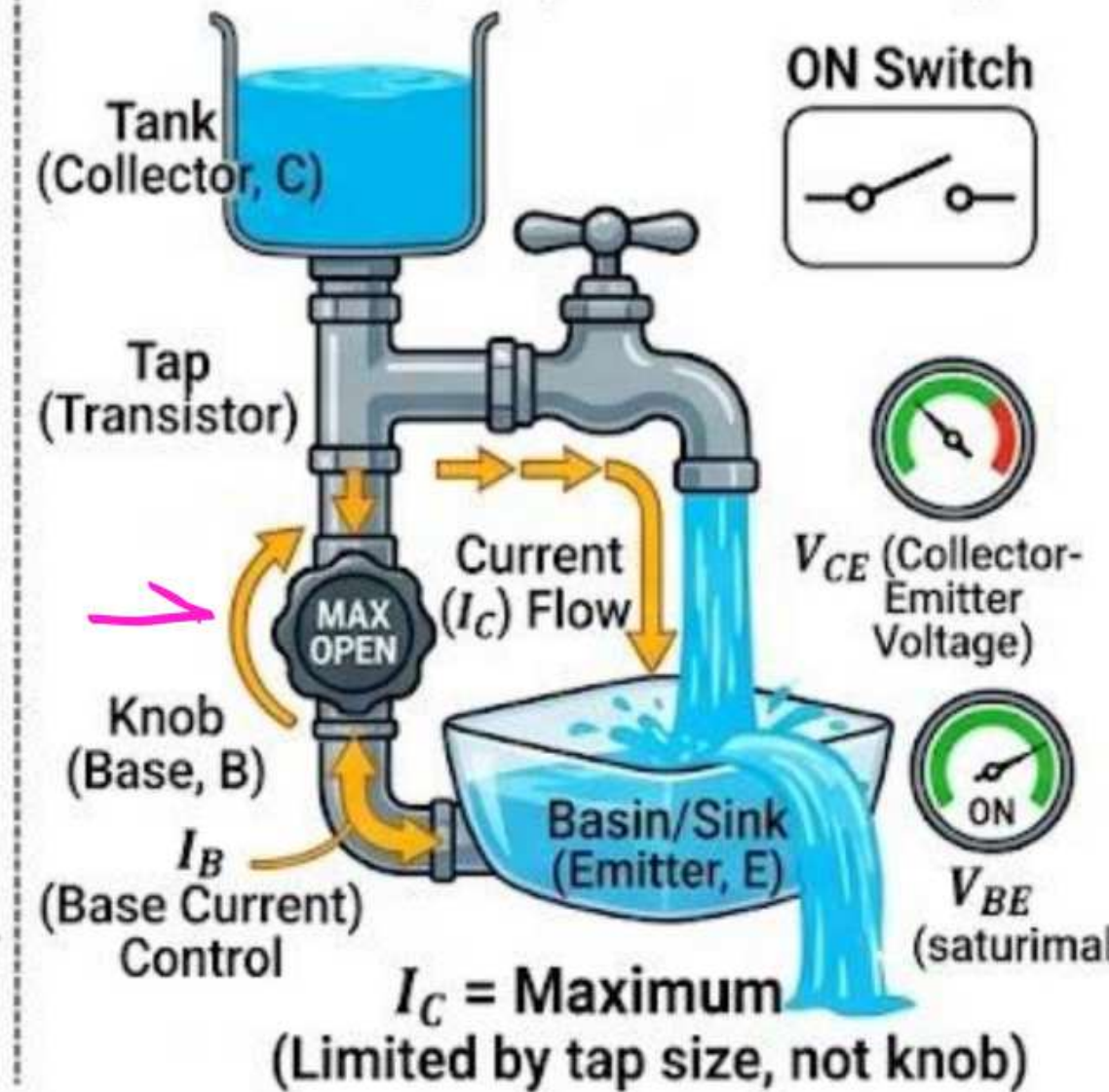
## Region 2: Active

Nalka Khula (Controlled) / Amplifier



## Region 3: Saturation

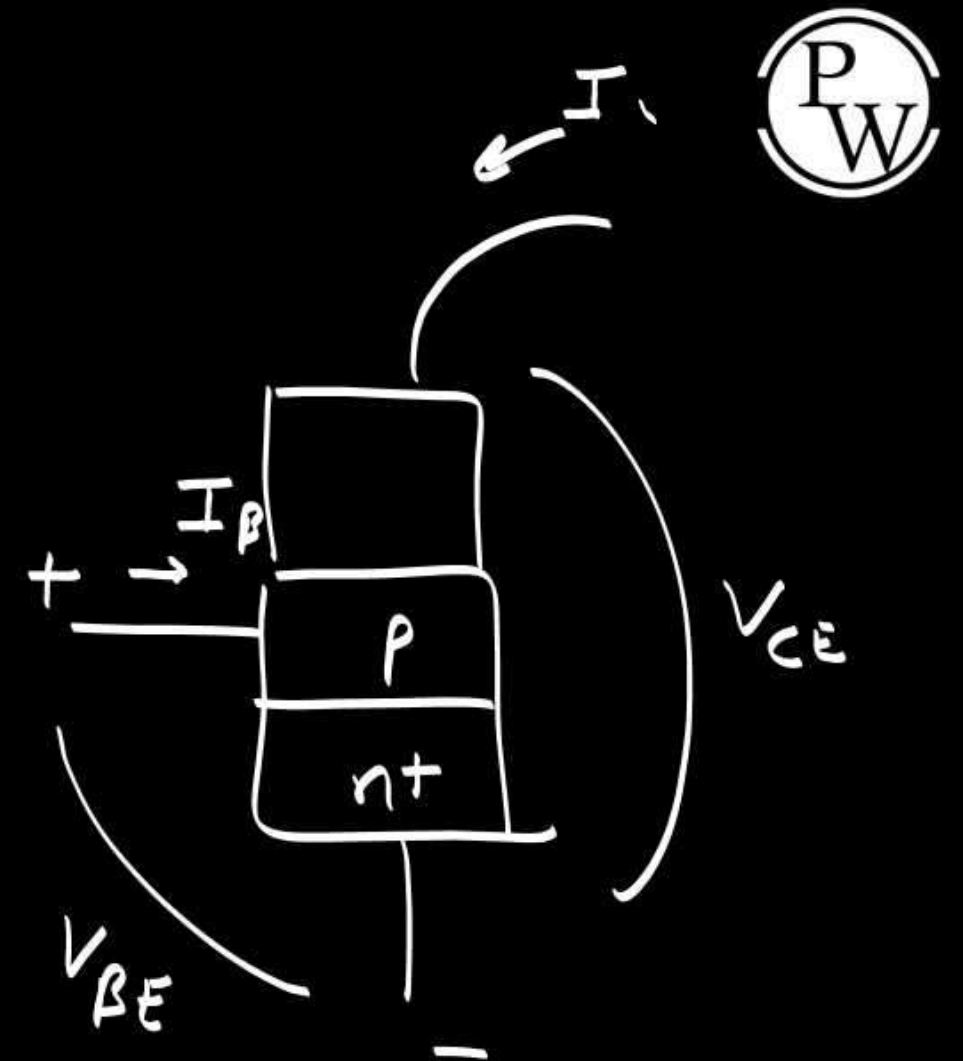
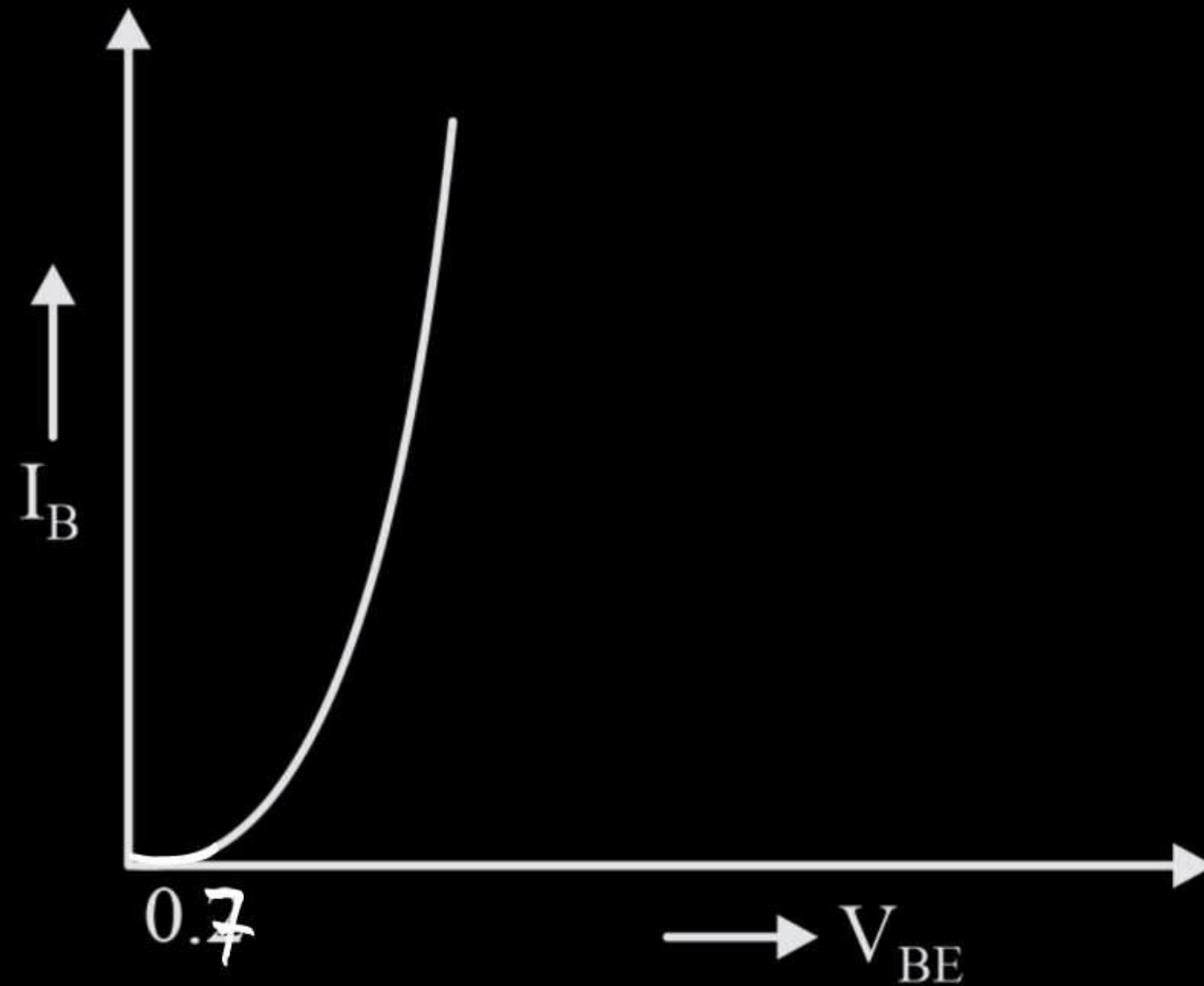
Nalka Full Open (Maximum Limit) /



| Region     | $V_{BE}$ | $I_B$ | Tap State   | $I_C$ | Function         |
|------------|----------|-------|-------------|-------|------------------|
| Cut-off    | On       | Vigh  | Controlled, | $I_C$ | Current open     |
| Saturation | $V_{BE}$ | $I_B$ | ON          | $I_C$ | Maximal, flowing |

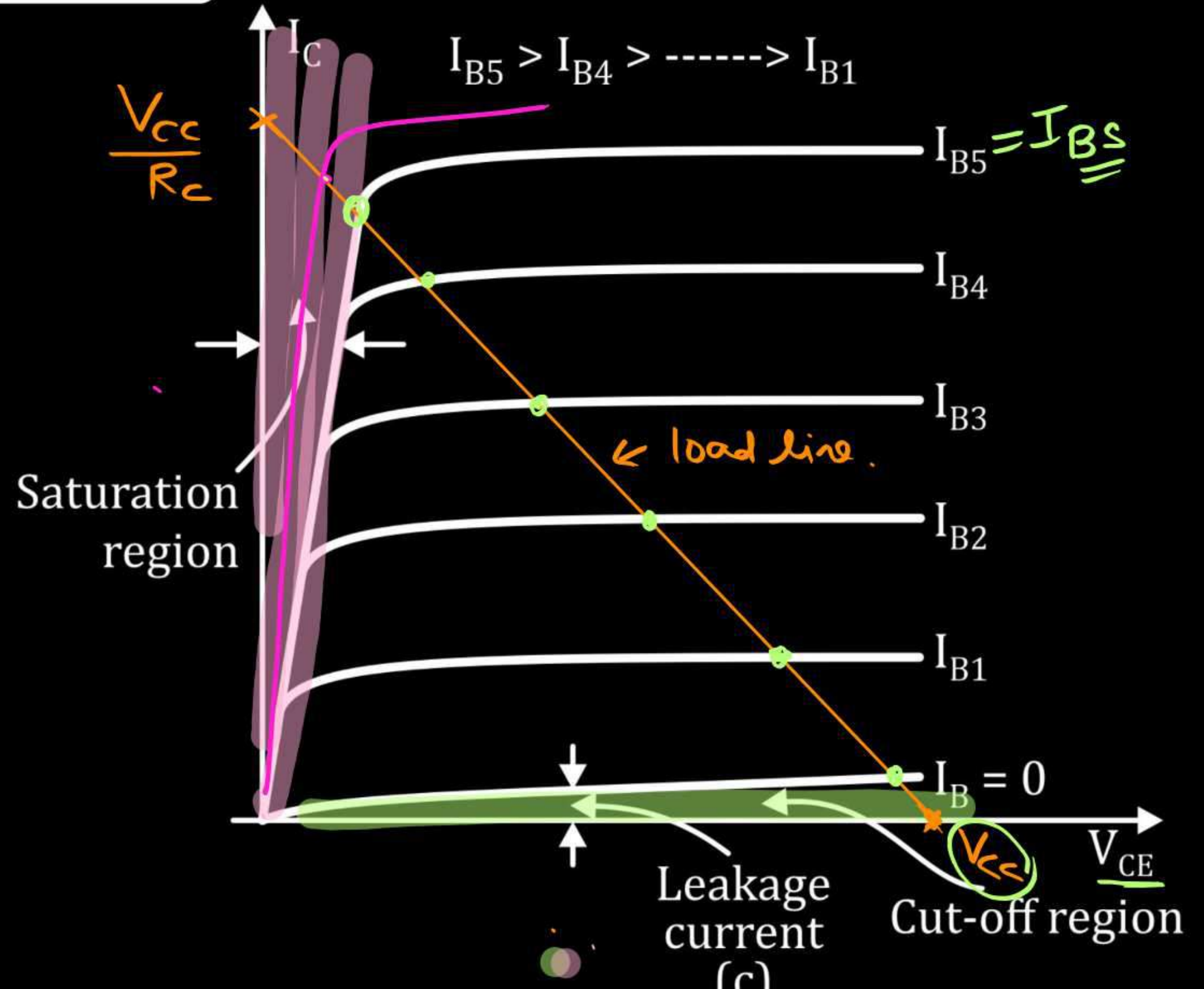
# Characteristics of BJT

## 1. Input characteristic



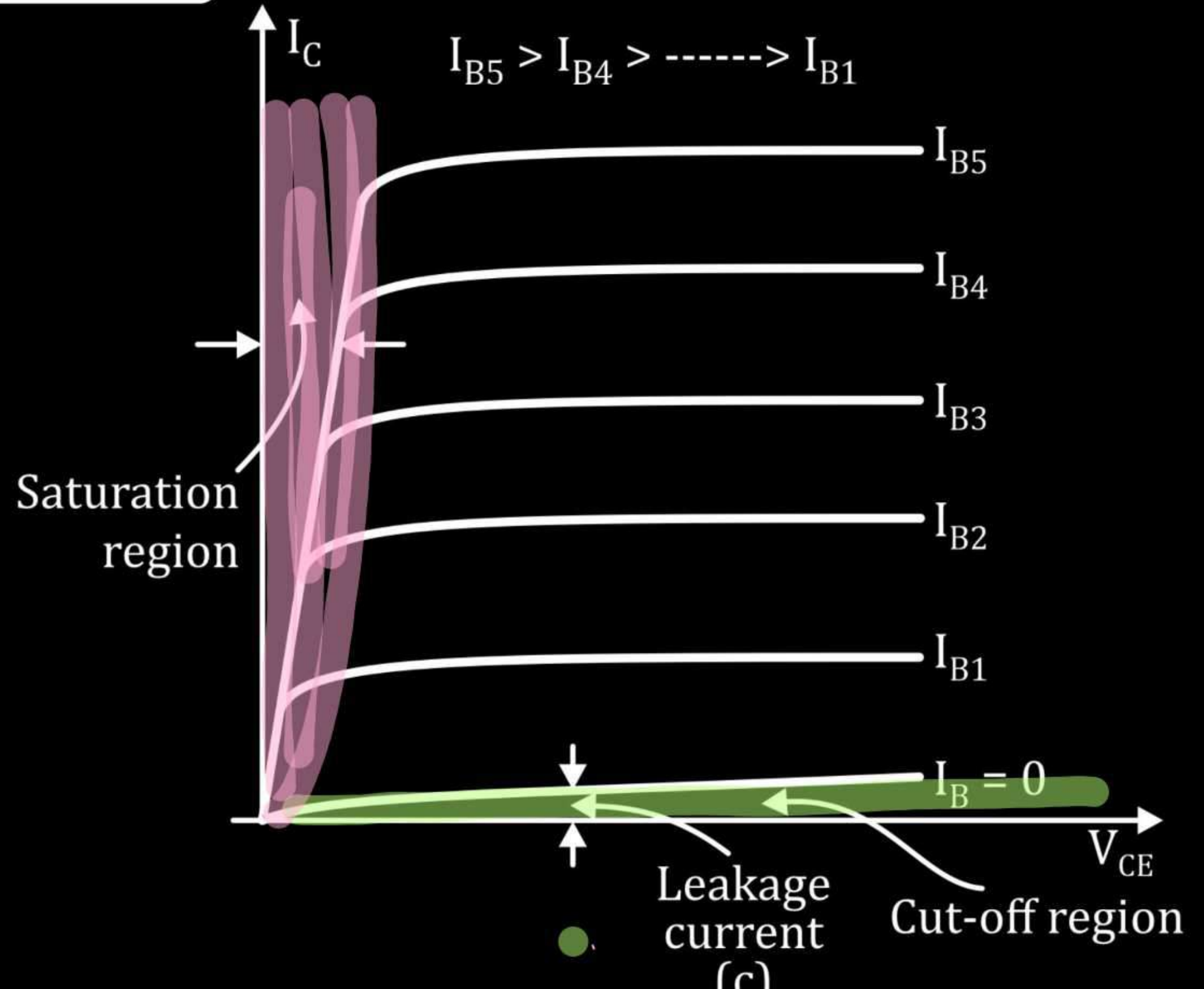
# Characteristics of BJT

## 2. Output characteristic



# Characteristics of BJT

## 2. Output characteristic



To find out operating point, we will write down eq<sup>n</sup> of load.

$$V_{CC} - I_C R_C - V_{CE} = 0$$

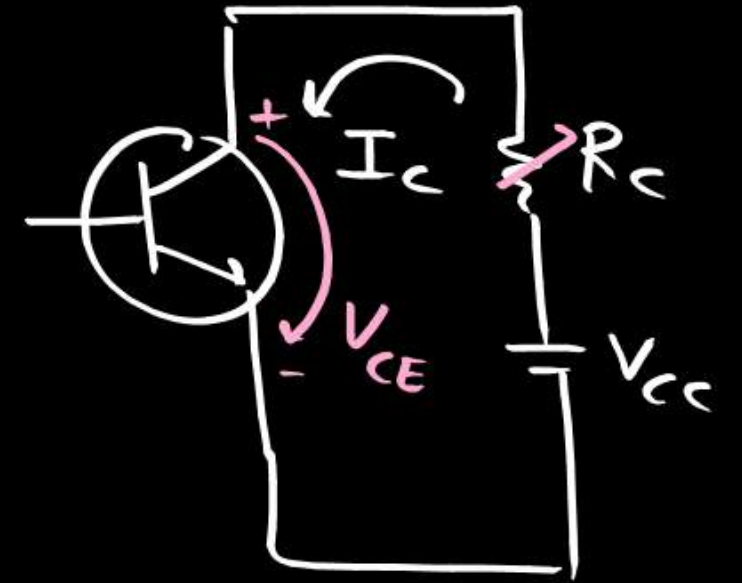
$$V_{CC} = V_{CE} + I_C R_C$$

At x axis

$$I_C = 0$$

$$V_{CC} = V_{CE}$$

$$V_{CE} = V_{CC} - I_C R_C$$



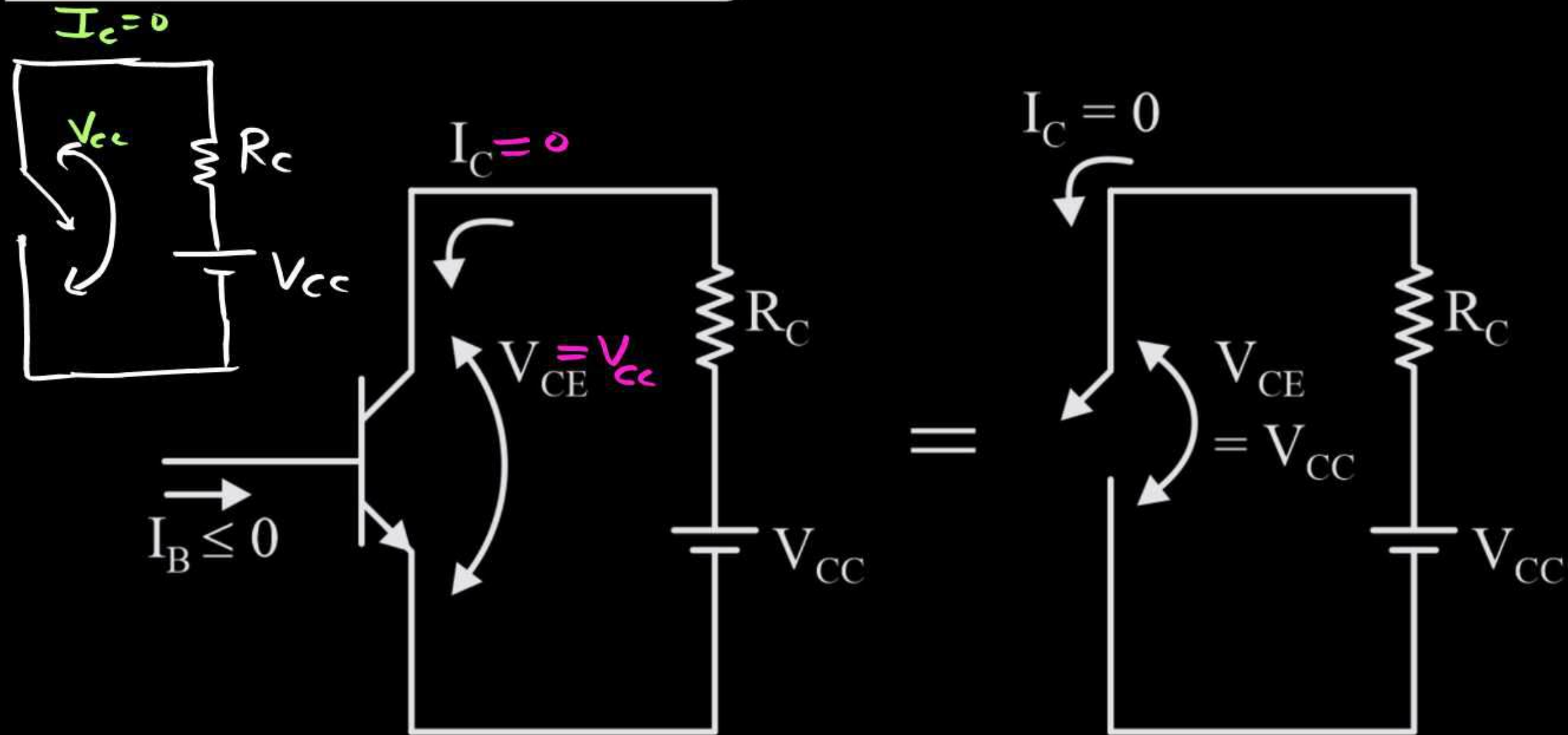
At y axis

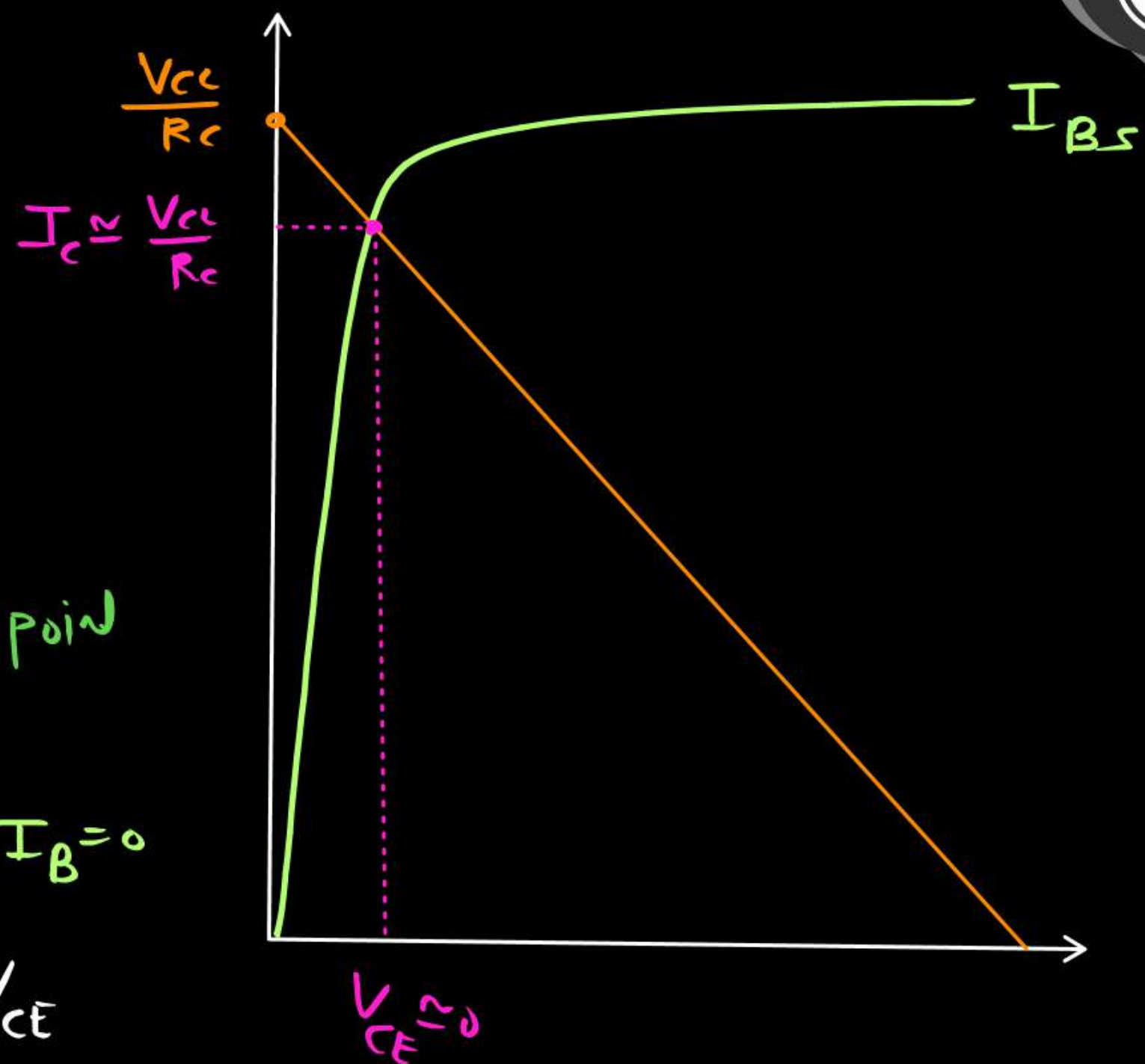
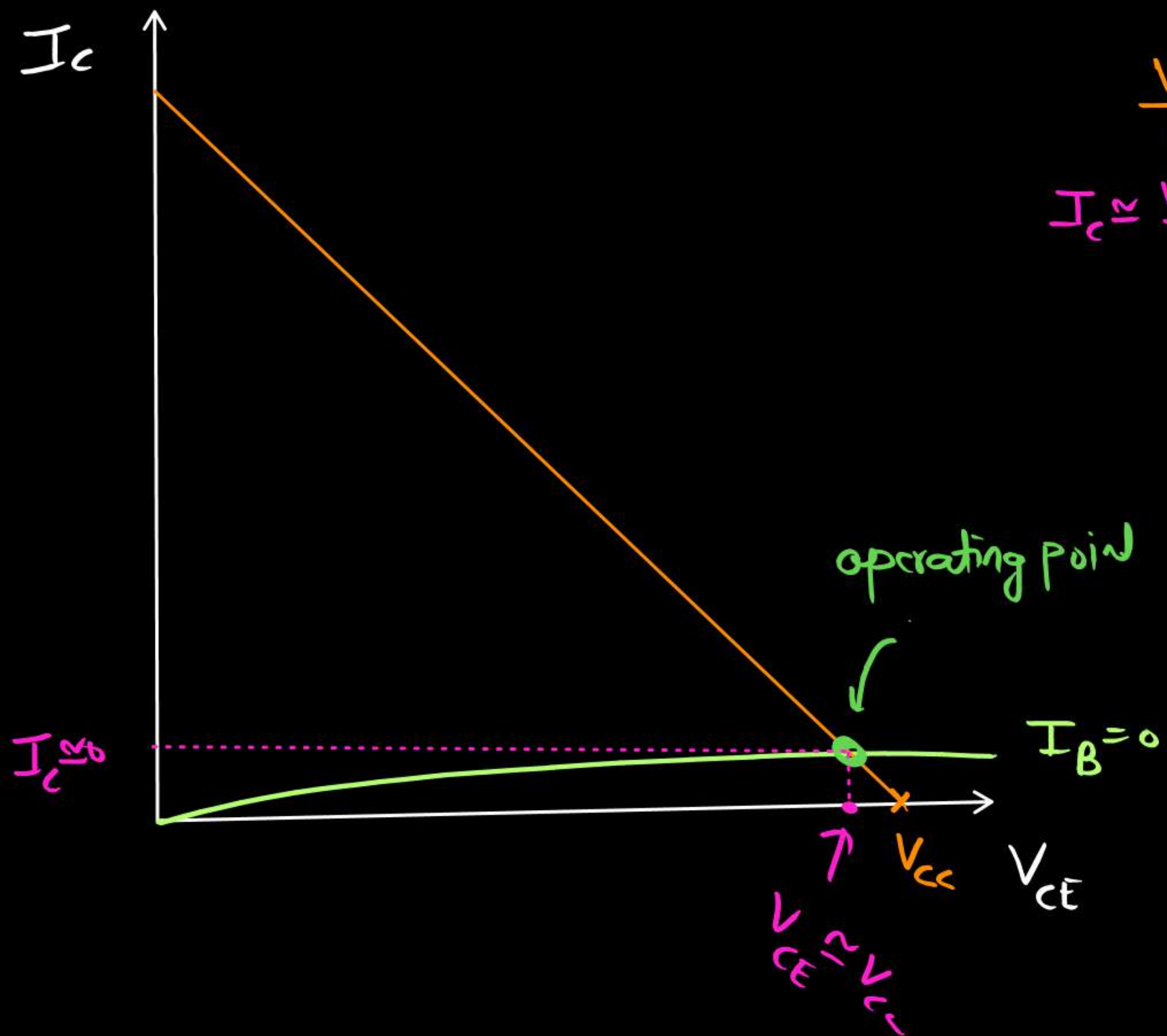
$$V_{CE} = 0$$

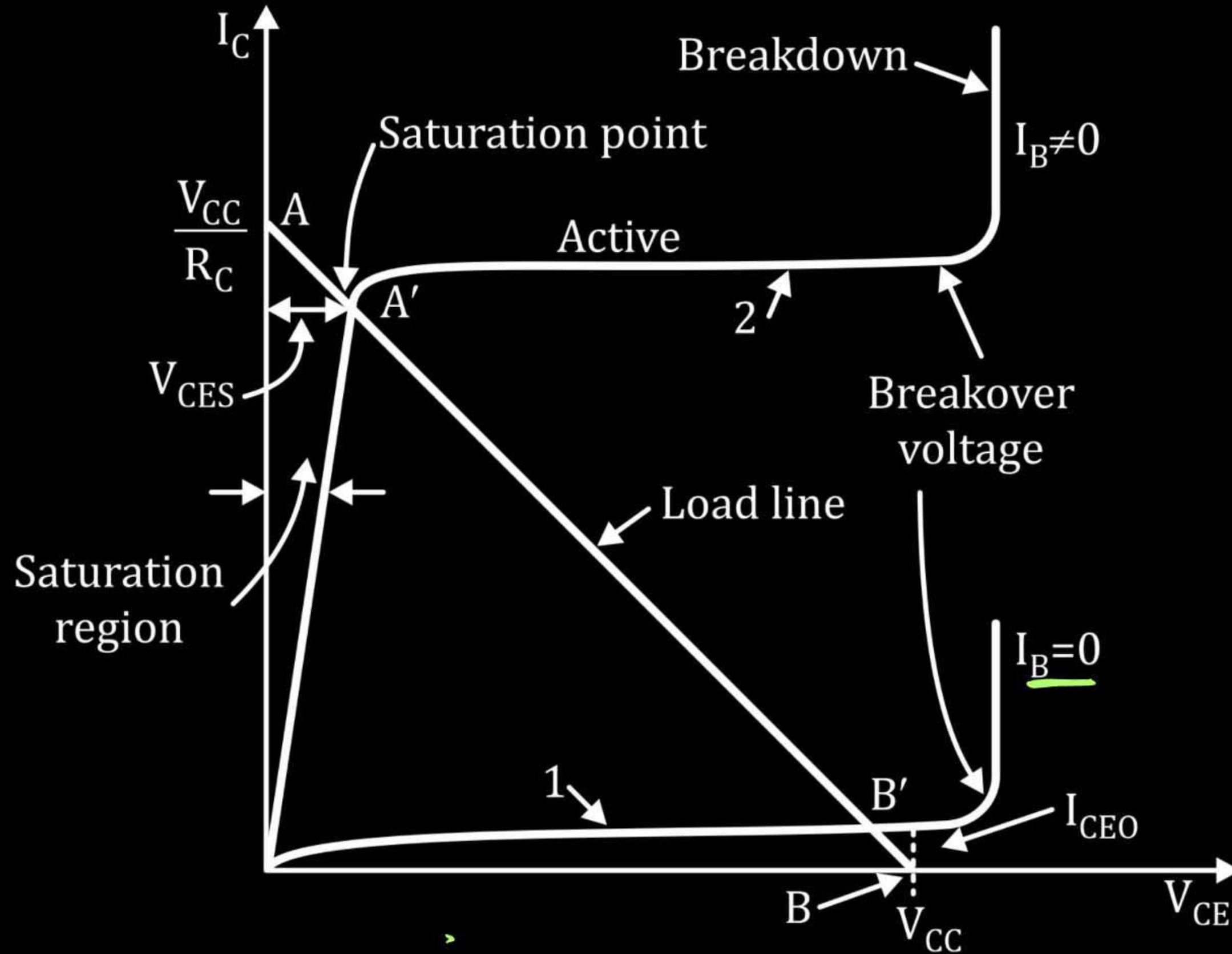
$$V_{CC} = 0 + I_c R_c$$

$$I_c = \frac{V_{CC}}{R_c}$$

# BJT as a Switch

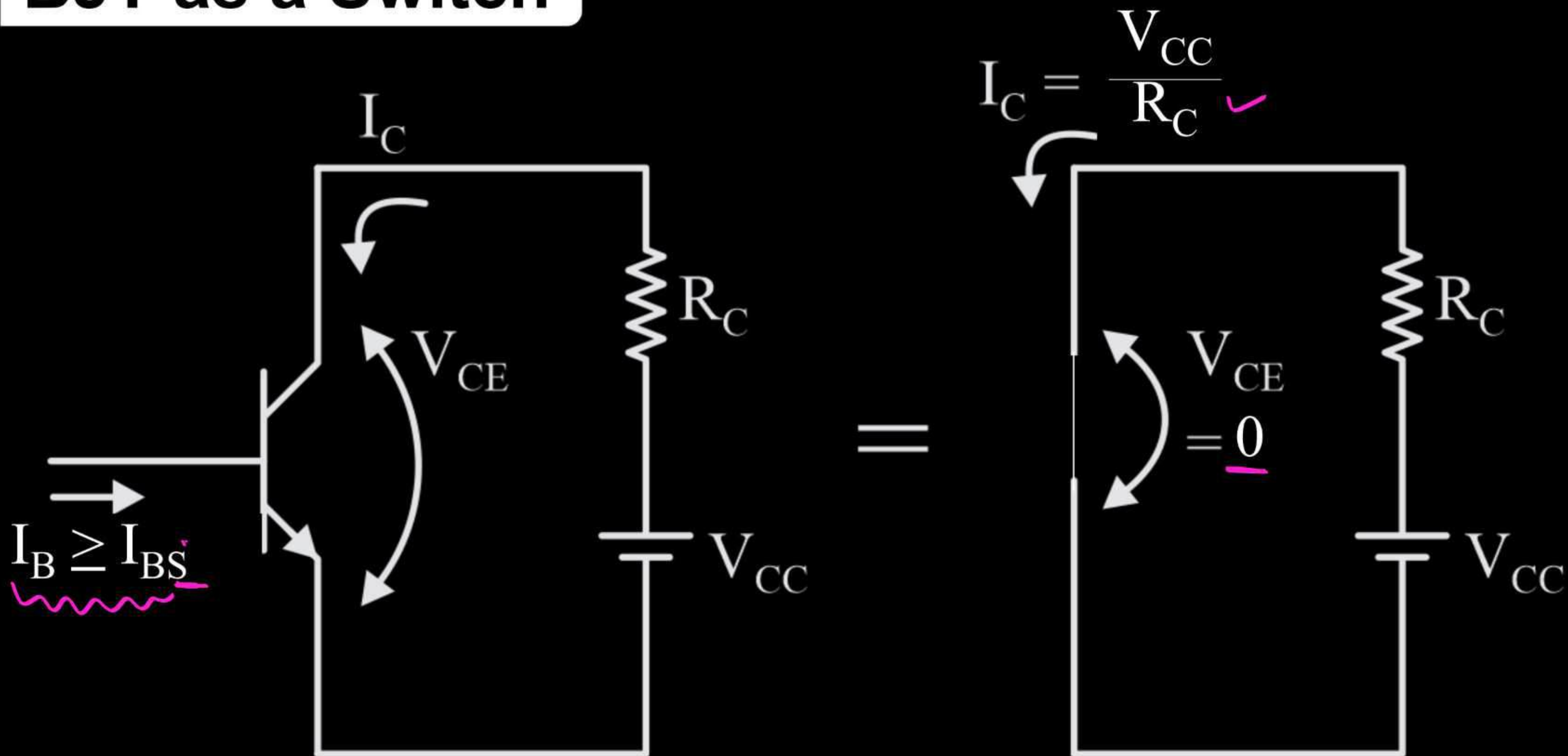






(a)

# BJT as a Switch



# BJT as a Switch

- $I_{BS}$  is the minimum base current required to drive the BJT into saturation region.

$$I_{BS} = 20 \text{ mA}$$

$$I_{BS} = 15 \text{ mA}$$

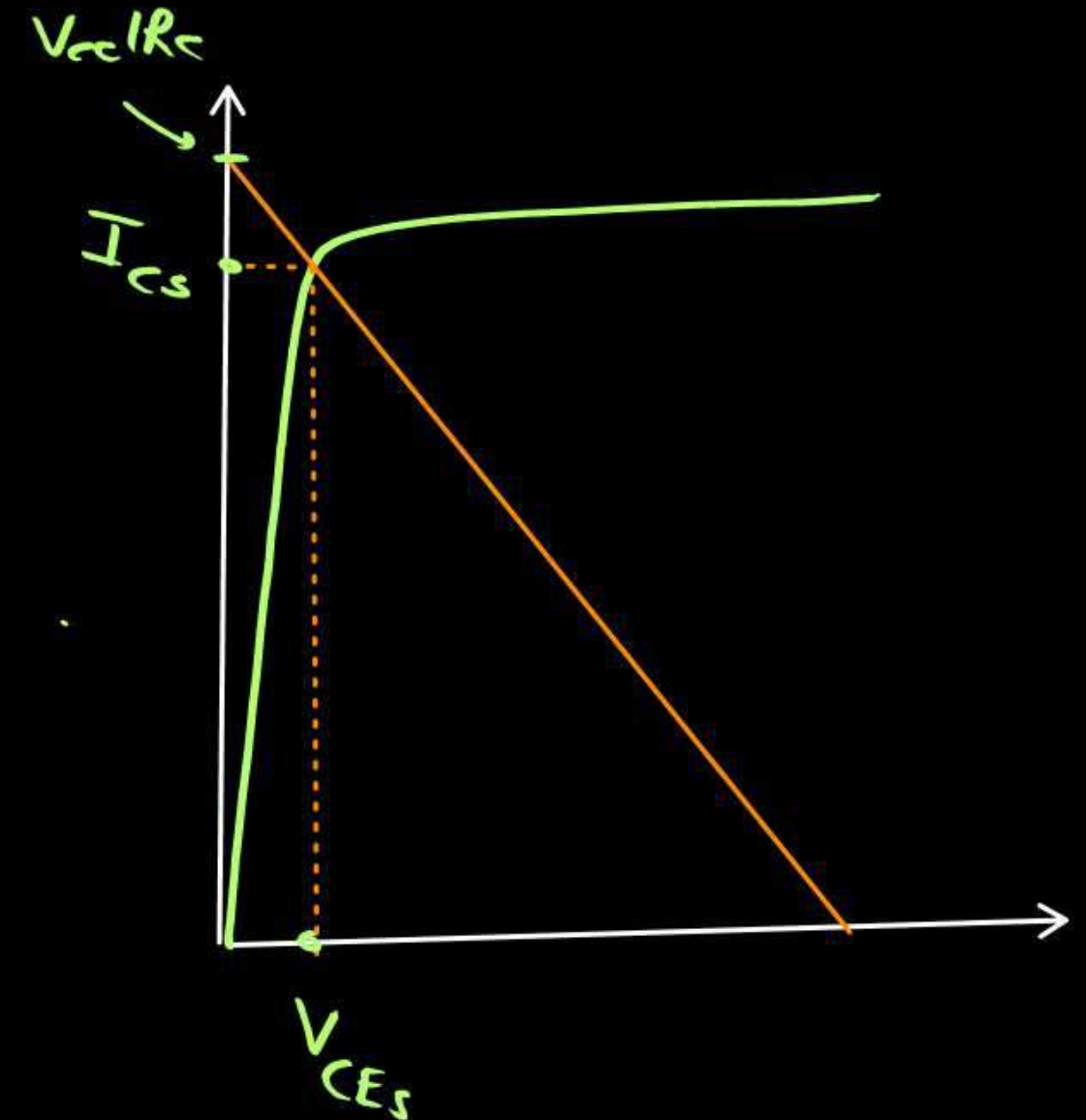
- In saturation region,  $I_C = I_{CS}$

$$V_{CE} = V_{CES}$$

$$\rightarrow V_{CC} = V_{CE} + I_C R_C$$

$$V_{CC} = V_{CES} + I_{CS} R_C$$

$$\rightarrow I_{CS} = \frac{V_{CC} - V_{CES}}{R_C}$$



# BJT as a Switch

- $\beta = \frac{I_C}{I_B} = \frac{I_{CS}}{I_{BS}}$

$$I_{BS} = \frac{I_{CS}}{\beta}$$

$I_B > I_{BS} \rightarrow$  BJT is in saturation region

$I_B < I_{BS} \rightarrow$  Active region

- ODF (Over drive factor) =  $\frac{I_B}{I_{BS}}$

$$I_B = 40$$

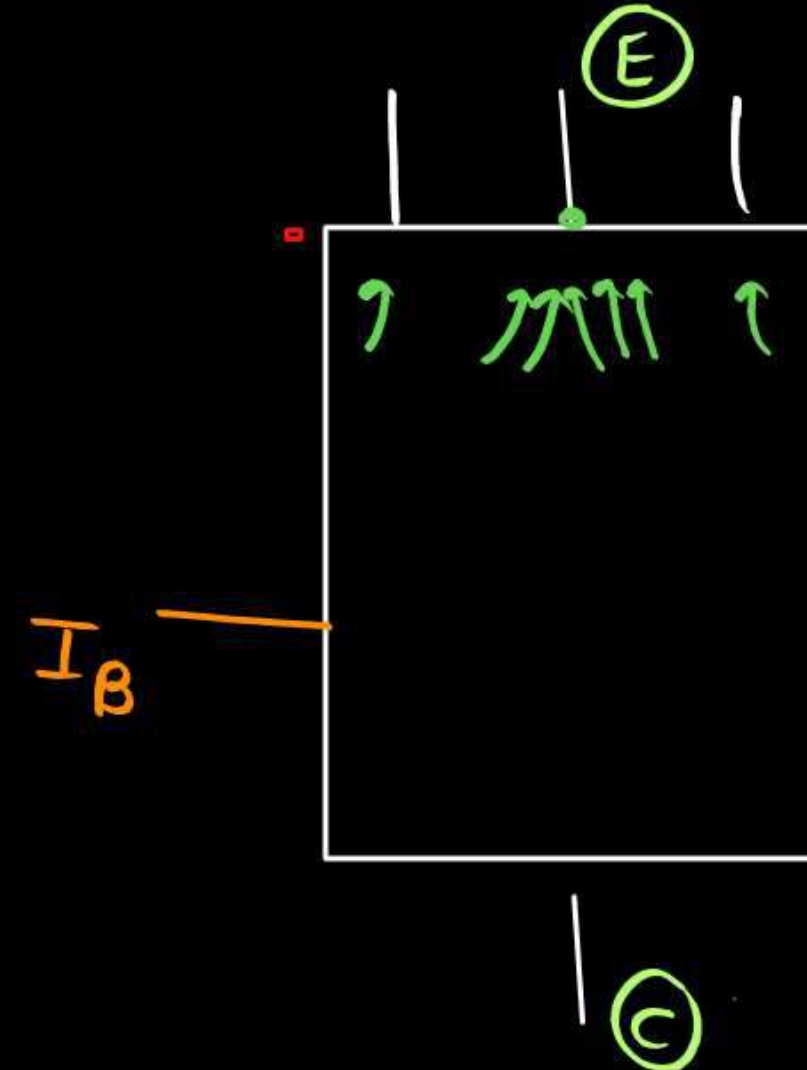
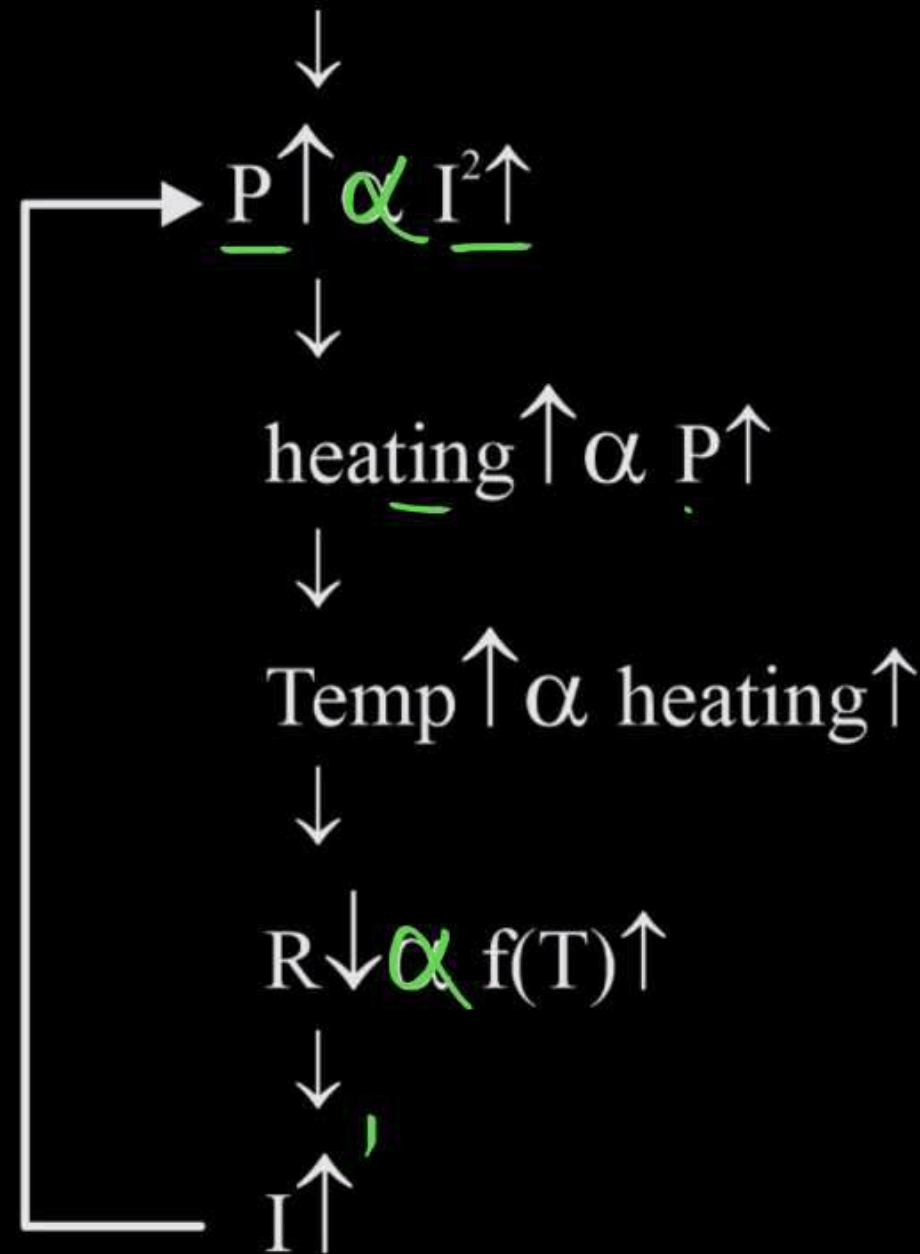
$$I_{BS} = 20$$

$$I_E = I_C + I_B$$

# Secondary Breakdown

- Due to large cross section area, current in a local region may be high (current density is not uniform).

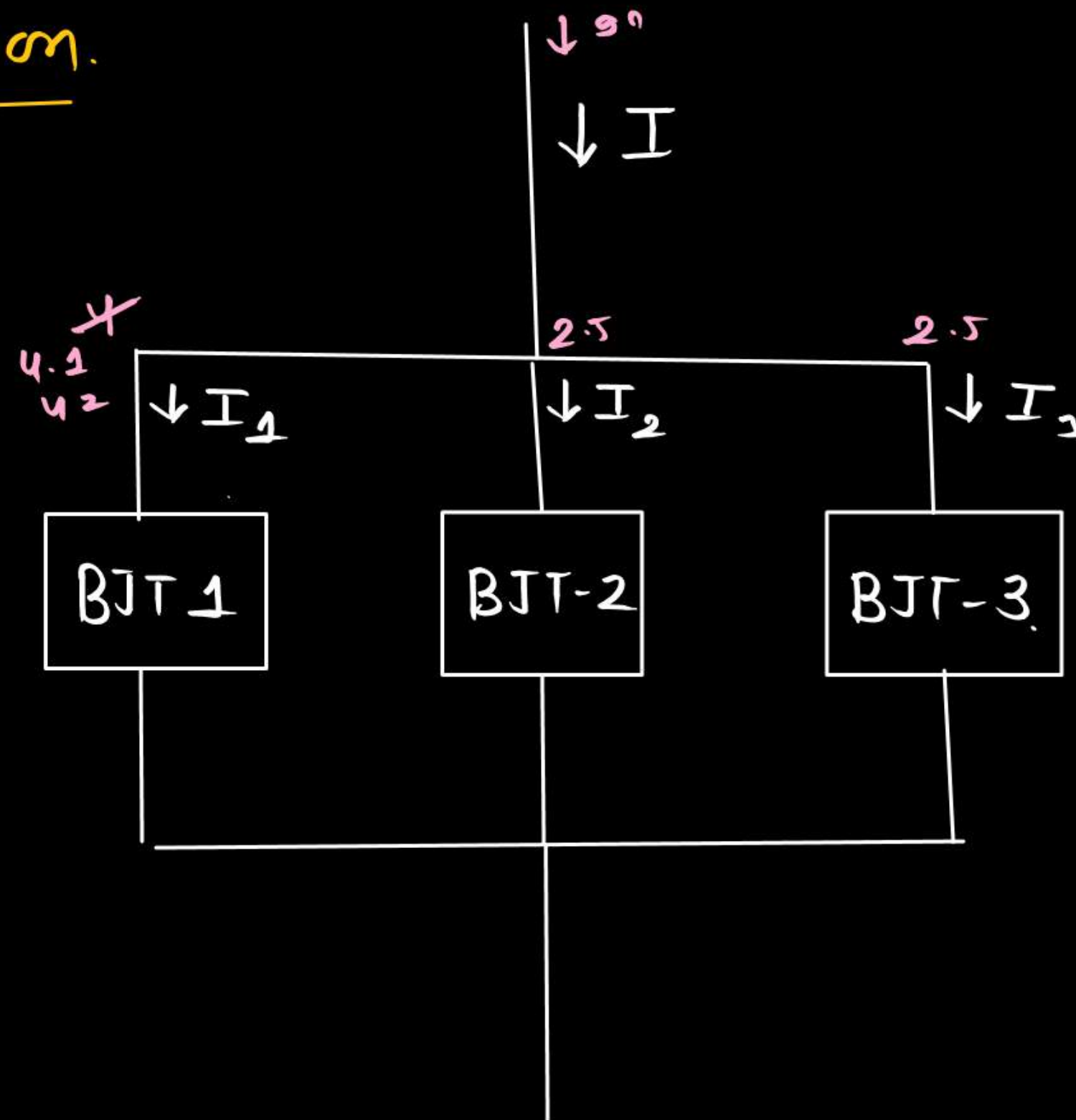
$$T \uparrow = R \downarrow$$



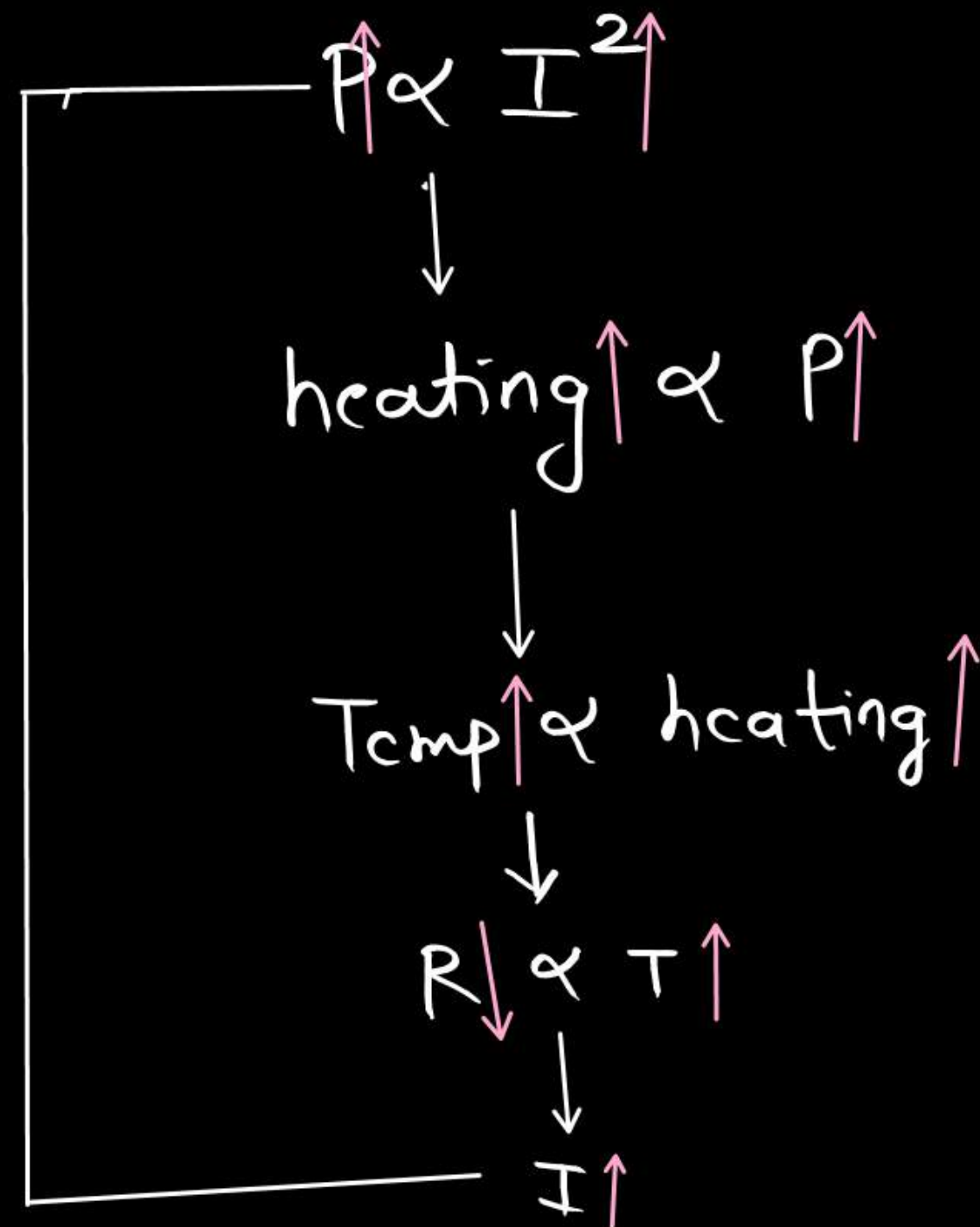
## Secondary Breakdown

- This is a cumulative process which increase the temperature of *local* region beyond critical value and device is damaged. This is called Secondary Breakdown (Thermal Runaway).

# Parallel operation.



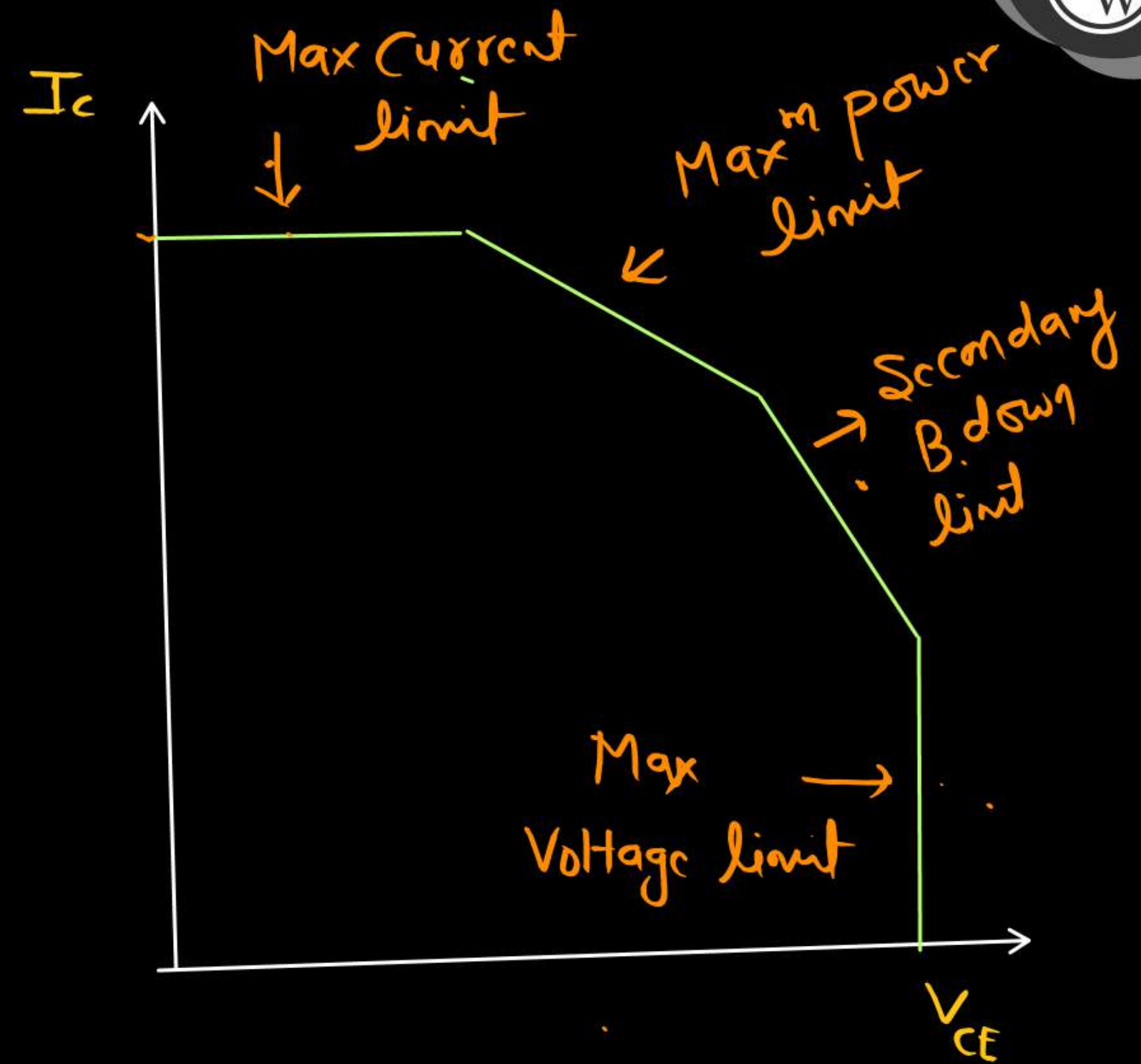
Due to any reason, current in one BJT increased.



When current is become more than its current rating. that BJT will be damaged.

→ So parallel operation of BJT is not possible

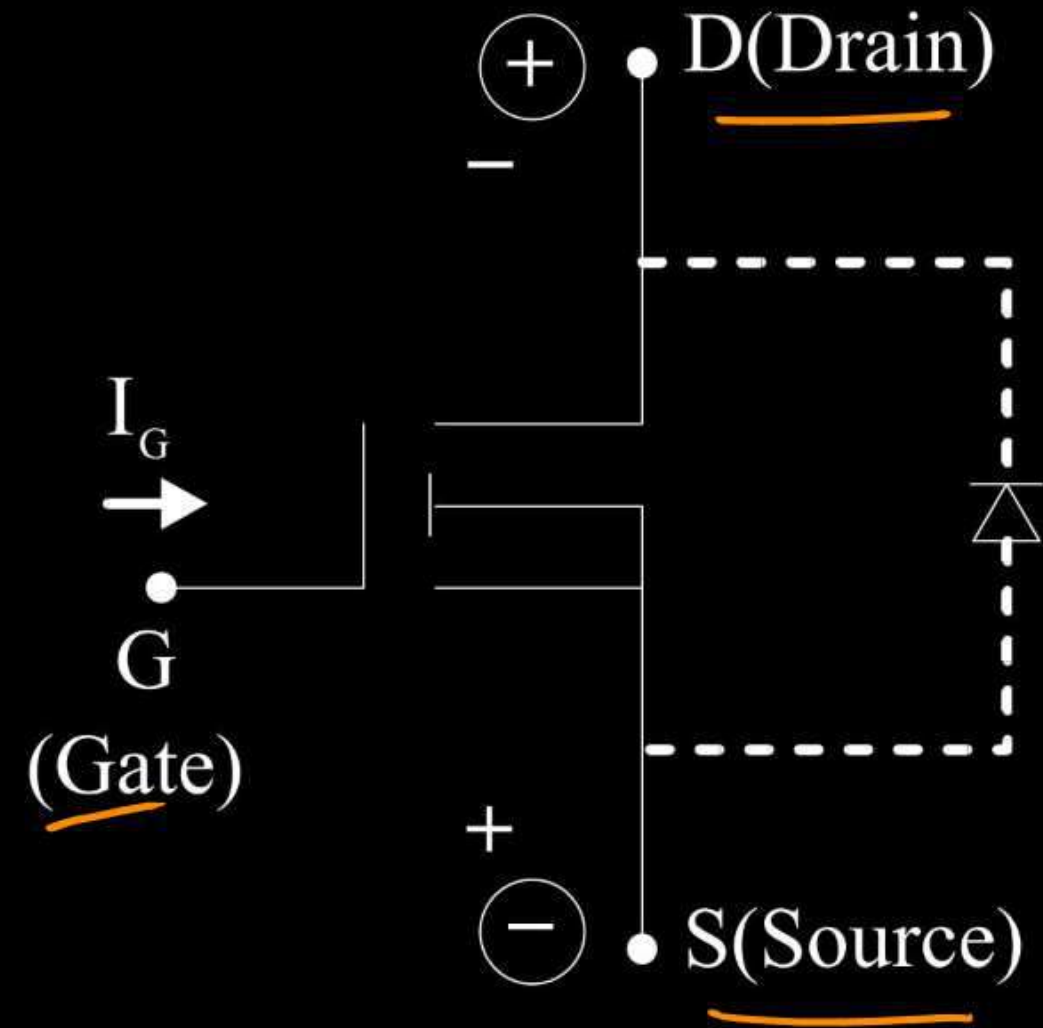
# Safe operating Area



# PMOSFET



Power Metal oxide semiconductor  
field effect transistor



# PMOSFET

1. It is a three-terminal device in which D and S are the main terminals and gate is the control terminal.
- IMP 2. It is a unipolar (Majority carrier) device in which conduction occurs due to flow of electrons only.
- IMP 3. It is a bidirectional device.
4. It has unipolar voltage blocking capacity. It can block only forward voltage.
5. It is fully controlled device.
6. It is a voltage-controlled device control signal is  $V_{gs}$ .

$I_g \downarrow$

# PMOSFET

7. It is a unipolar device. Due to absence of **minority carrier** (storage charge), its turn off time is very low. It may be turned off in **nano sec.**
8. This device is used when **fast switching frequency** is required (1 – 10 MHz).
9. It has **positive temperature coefficient** of resistance.
10. No **secondary breakdown** occurs.
11. MOSFET can be **operated in parallel**.
12. It has less **switching loss** as its turn off time is low.

# PMOSFET

13. Due to high resistance of drift region, its conduction losses are high.
14. It has high input impedance (due to  $\text{SiO}_2$ ), due to which  $I_G$  is reduced, which reduces gate power loss.

$$V_{gs} -$$



## 2 Minutes Summary

→ Pow BJT

→ BJT As a Switch

→ Characteristic of BJT.

A dark blue, 3D-style banner with a folded effect, featuring the text 'THANK YOU' in white, bold, sans-serif capital letters.

**THANK YOU**



# Electrical Engineering

## Power Electronics



Lecture No -6

Power semiconductor devices

By- Ajay Gupta Sir



# Recap of Previous class

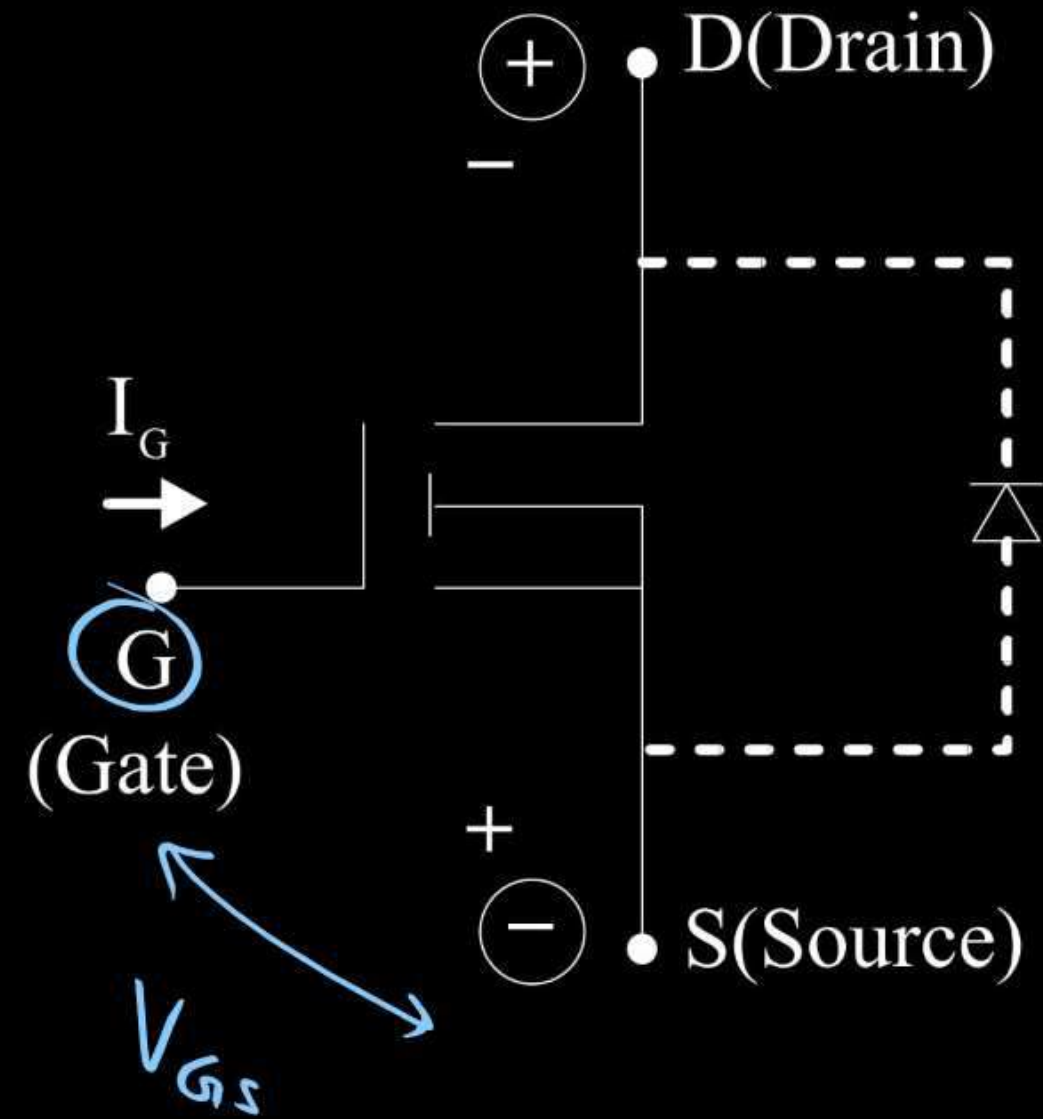
1. Working principle of BJT
2. Characteristic of BJT
3. BJT as a switch
4. Secondary breakdown and SOA

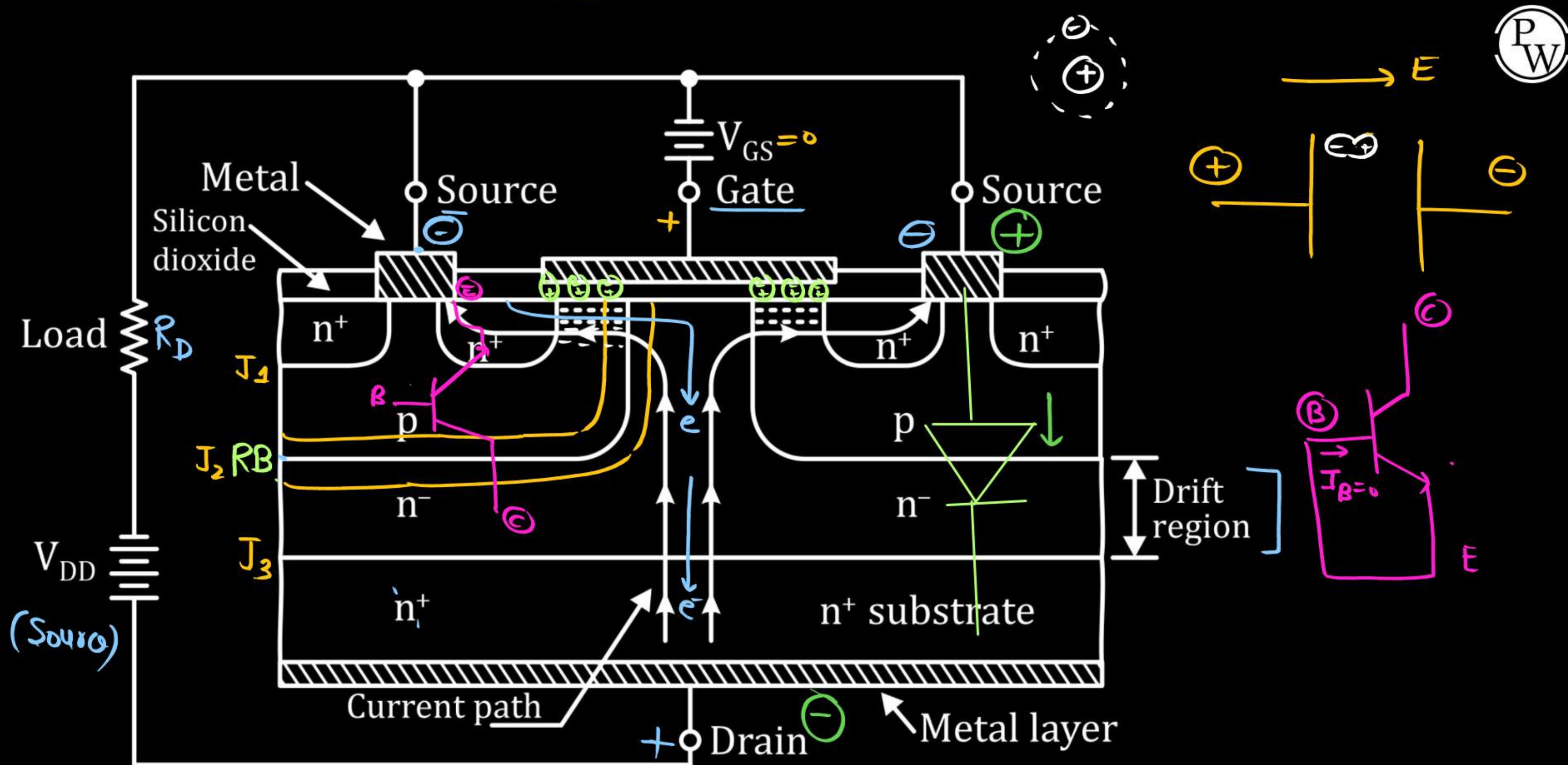


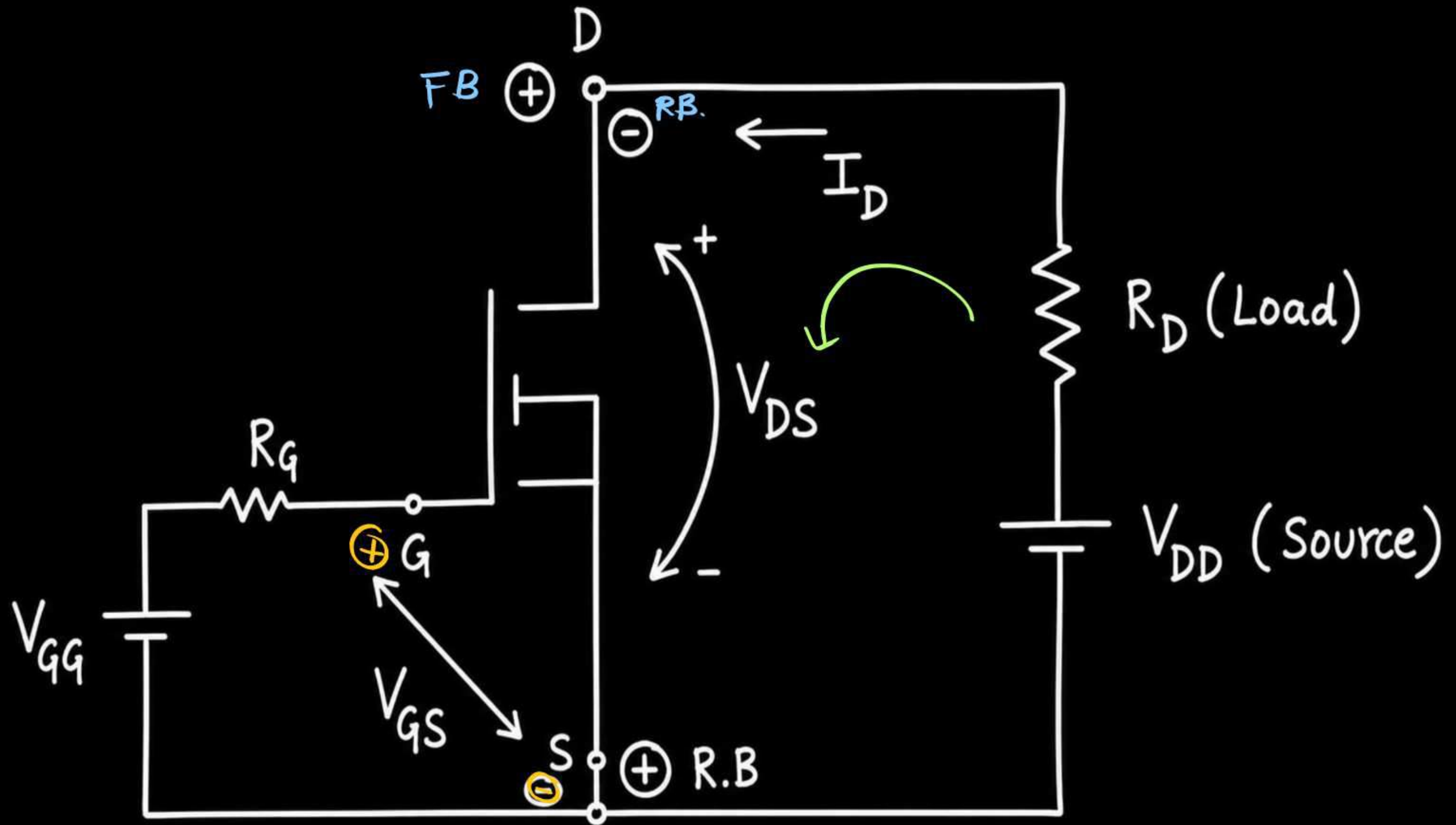
**Topic is  
to be  
covered**

1. Working principle of Mosfet
2. Characteristic of Mosfet
3. Mosfet as a switch
4. Working principle of IGBT
5. Characteristic of IGBT
6. IGBT as a switch

# PMOSFET







# Working of PMOSFET

1. If  $V_{GS} = 0$ , then junction  $J_2$  are in RB. So, a depletion layer (barrier potential) exists. Due to the barrier potential, charge cannot move between drain and source terminal.
2. If  $V_{GS}$  is applied, there is a polarisation of dielectric material ( $\text{SiO}_2$ ). The positive ions of dielectric attract the electrons, so it creates n channel (Inversion layer) in P semiconductor region.
3. This n channel short circuits the  $n^+$  and  $n^-$  semiconductor layer, so electrons start moving through n channel. This negative electrons are attracted by positive drain terminal .

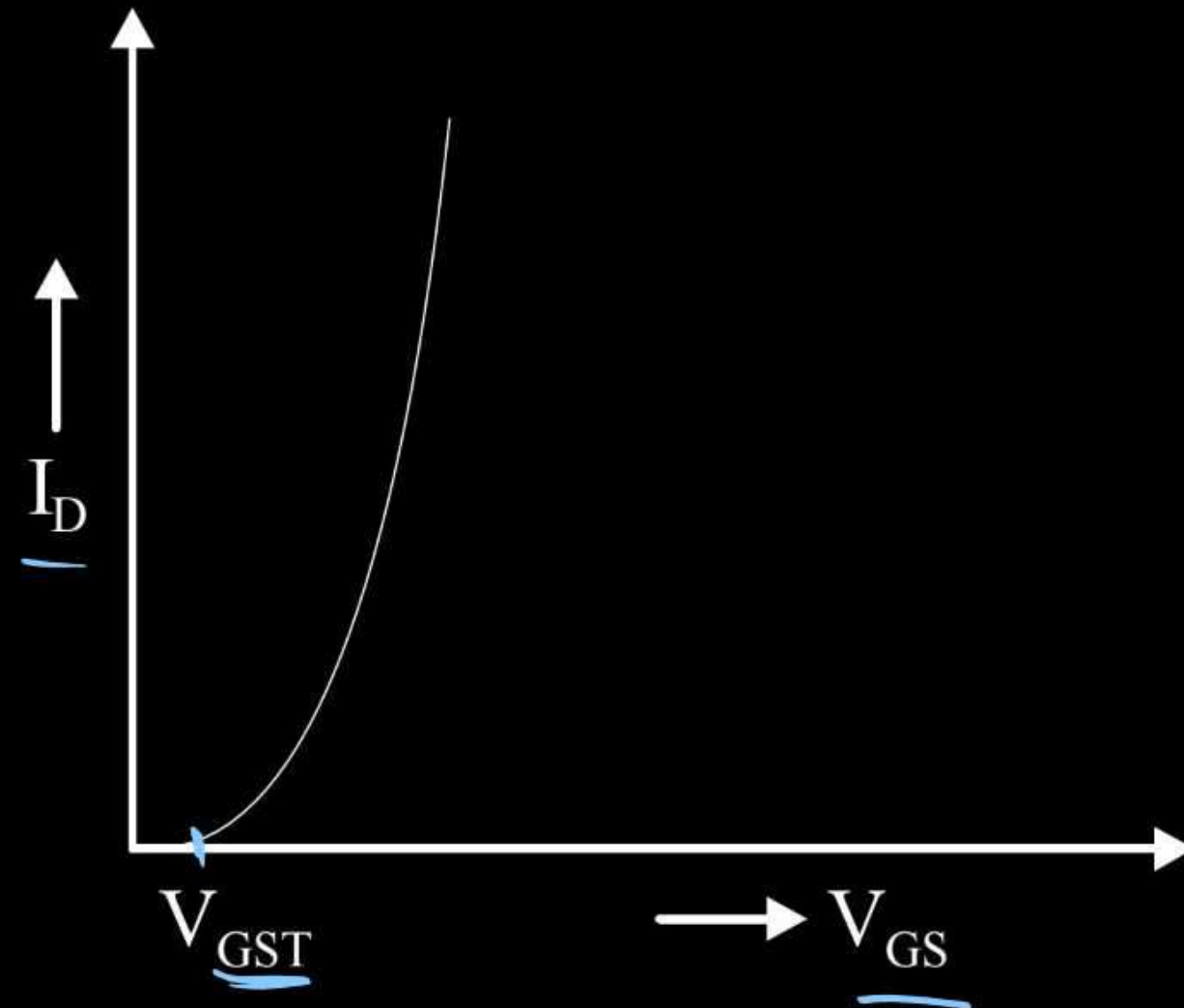
## Working of PMOSFET

4. So drain current  $I_D$  starts flowing.
5. Current is flowing only due to **flow of electrons**.
6. There is a parasitic BJT in MOSFET, but it is in cut off region. So, no current can flow due to this BJT.
7. There is a **parasitic diode between source and Drain** terminal. Due to this diode, it conduct in reverse direction and its reverse blocking capacity is zero.

# Characteristic of PMOSFET

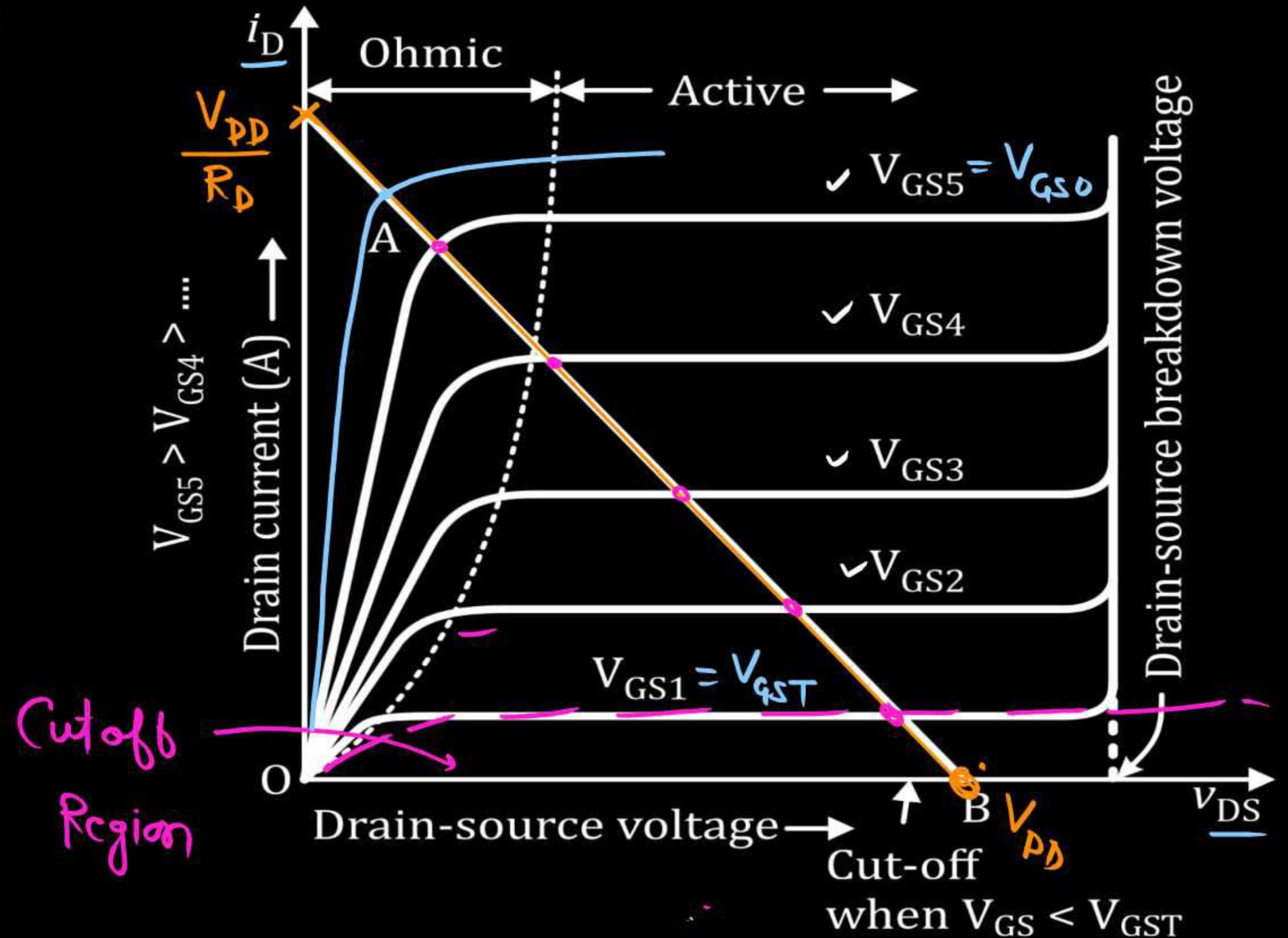
## 1. Transfer characteristic

$V_{GST}$  = Threshold voltage between gate and source that is required to form n channel.



# Characteristic of PMOSFET

## 2. Output characteristic



To find out load line equation, write down KVL in PW  
load ckt

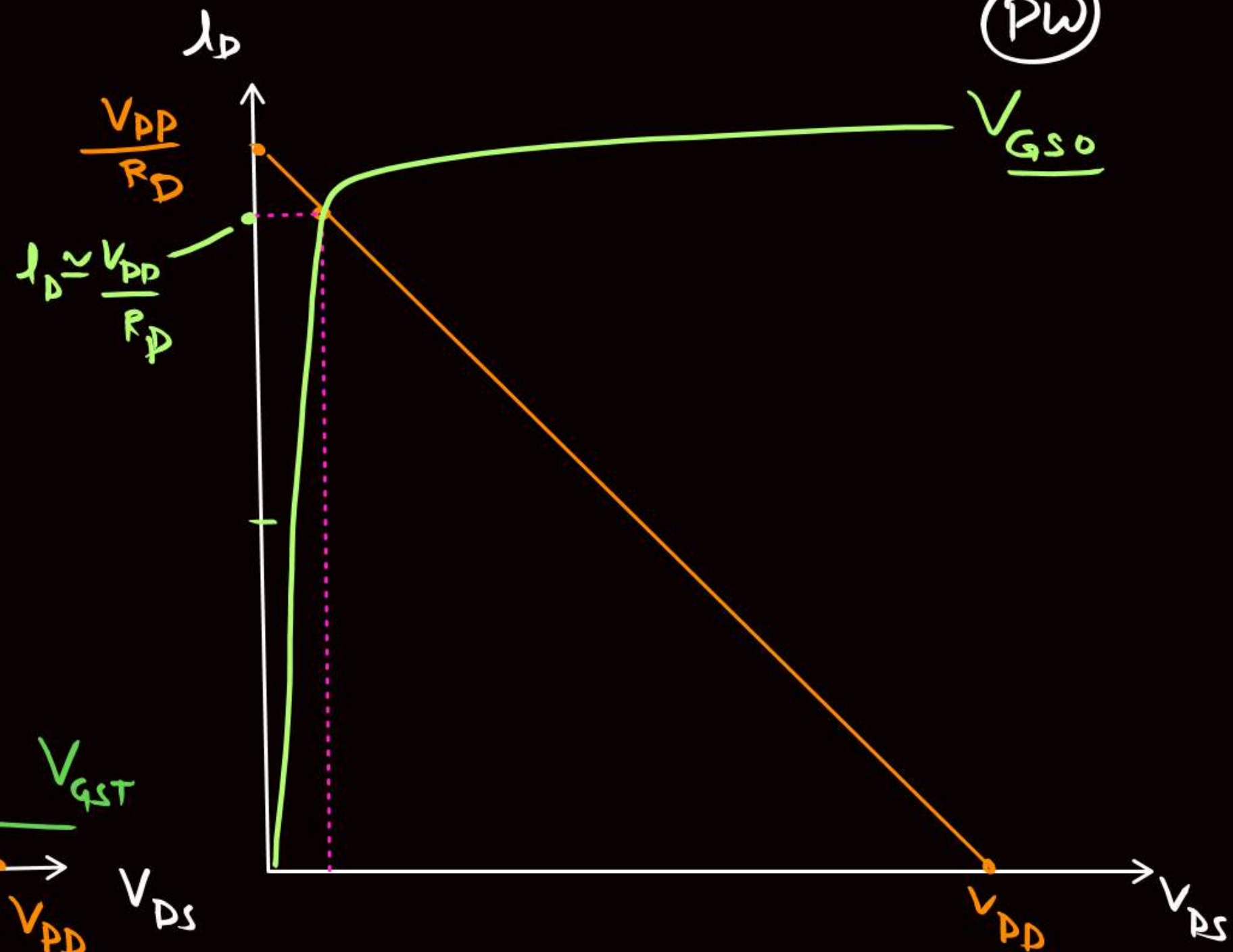
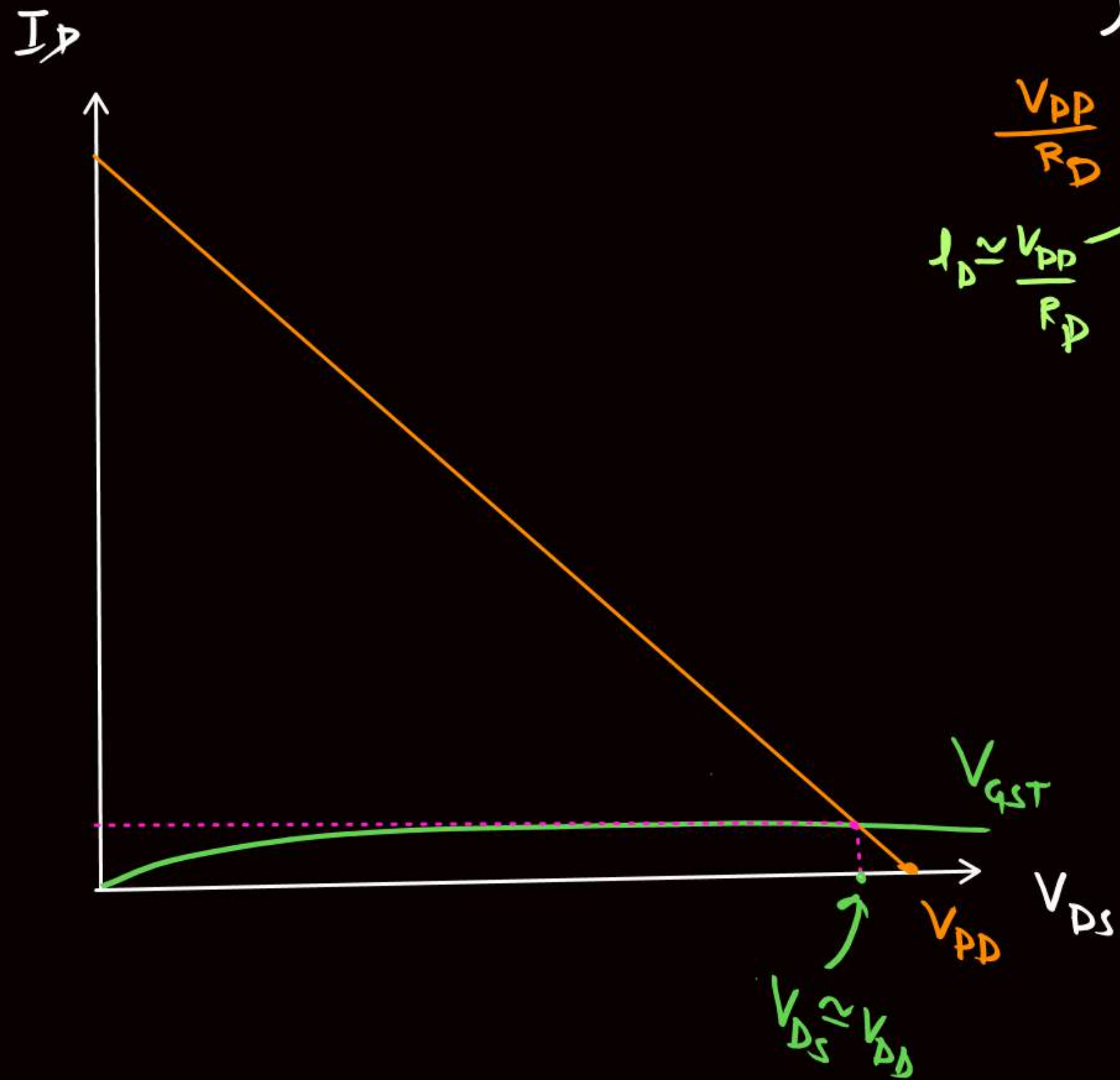
$$V_{DD} - I_D R_D - V_{DS} = 0$$

at x axis

$$\begin{aligned} & I_D = 0 \\ & V_{DD} - 0 - V_{DS} = 0 \Rightarrow \boxed{V_{DS} = V_{DD}} \end{aligned}$$

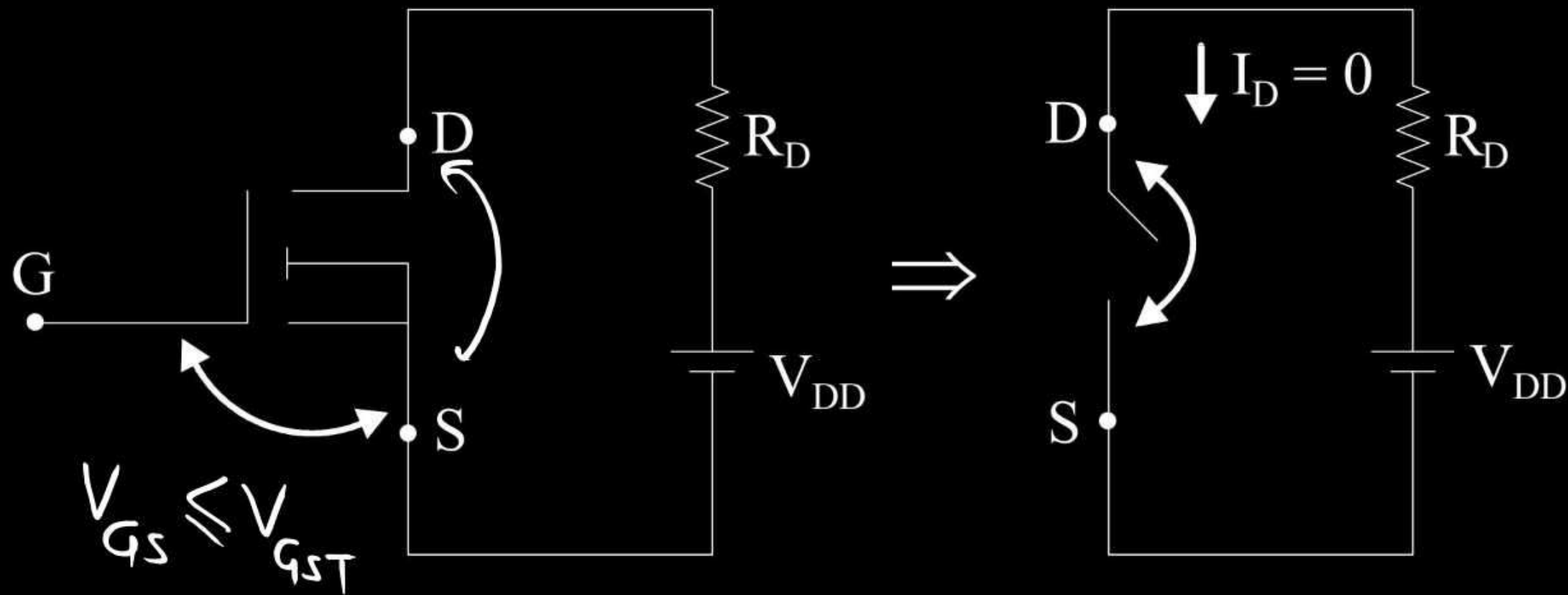
at y axis

$$\begin{aligned} & V_{DS} = 0 \\ & V_{DD} - I_D R_D = 0 \\ & \boxed{I_D = \frac{V_{DD}}{R_D}} \end{aligned}$$



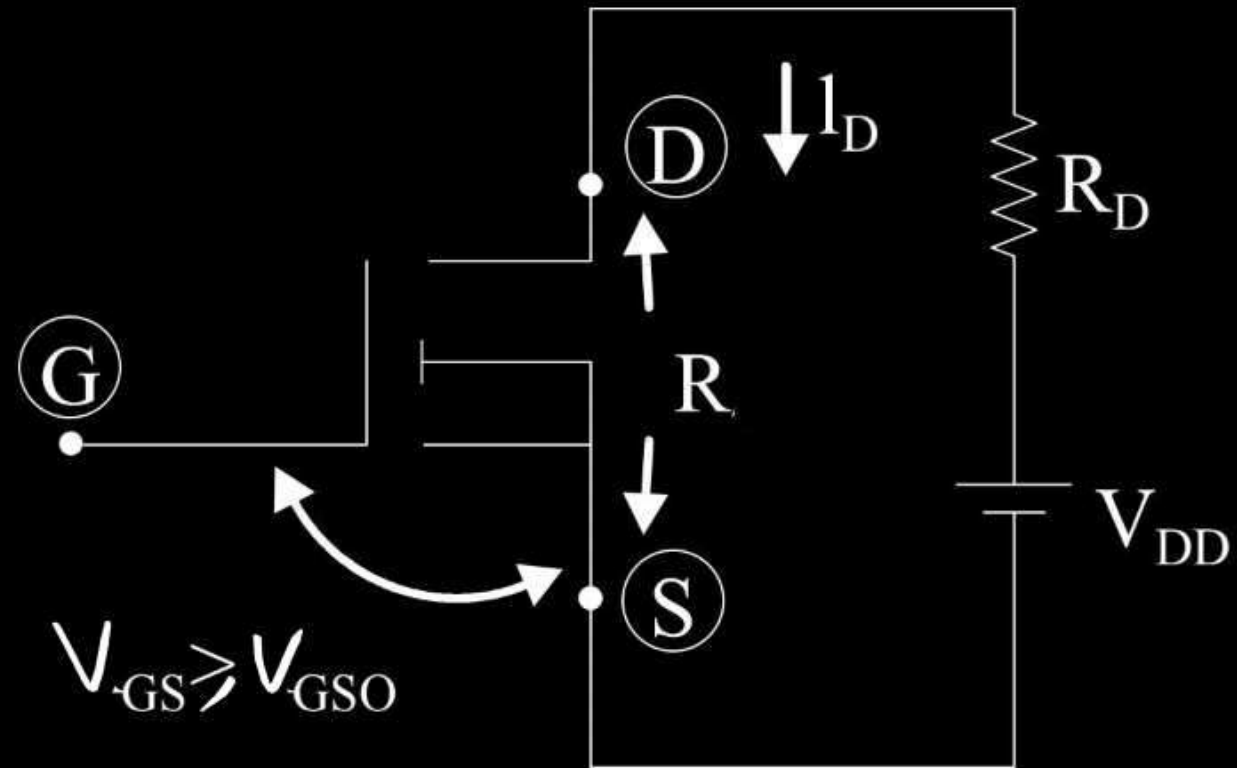
(PW)

# MOSFET as a Switch

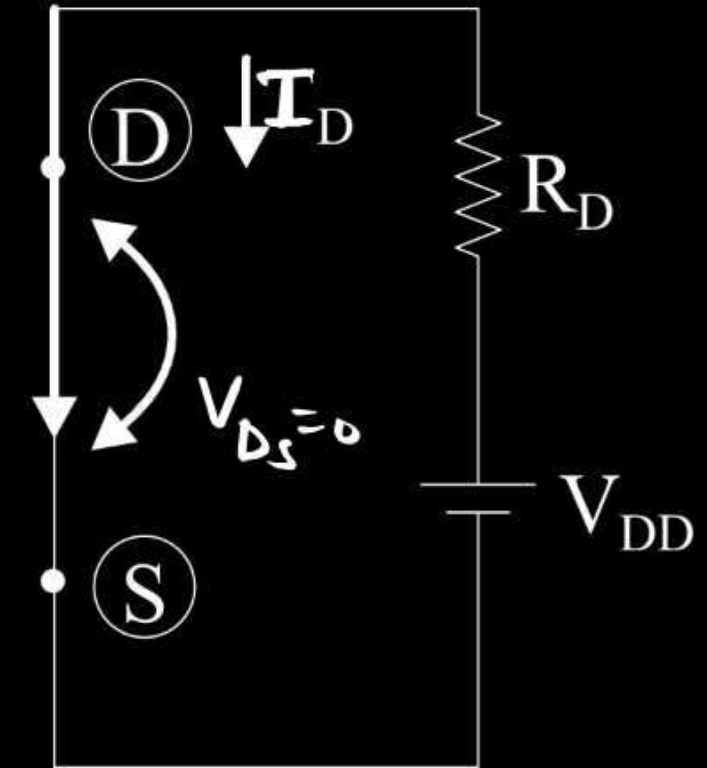


# MOSFET as a Switch

$$V_{t1} / R_{t1}$$



$\approx$



# SAME TRACK... DIFFERENT SPEEDS

## Switching Speed Race of Power Devices

Smaller  
the switching time,  
Faster the device!



**Fastest!**

(lowest switching time  
in ns range)



**1st**

**Second Fastest!**

(switching time  
in  $\mu$ s range)

**2nd**

**Slowest!**

(switching time  
in tens of  $\mu$ s range)

**3rd**

FAST  
DEVICES  
BRING  
BIG  
POSSIBILITIES

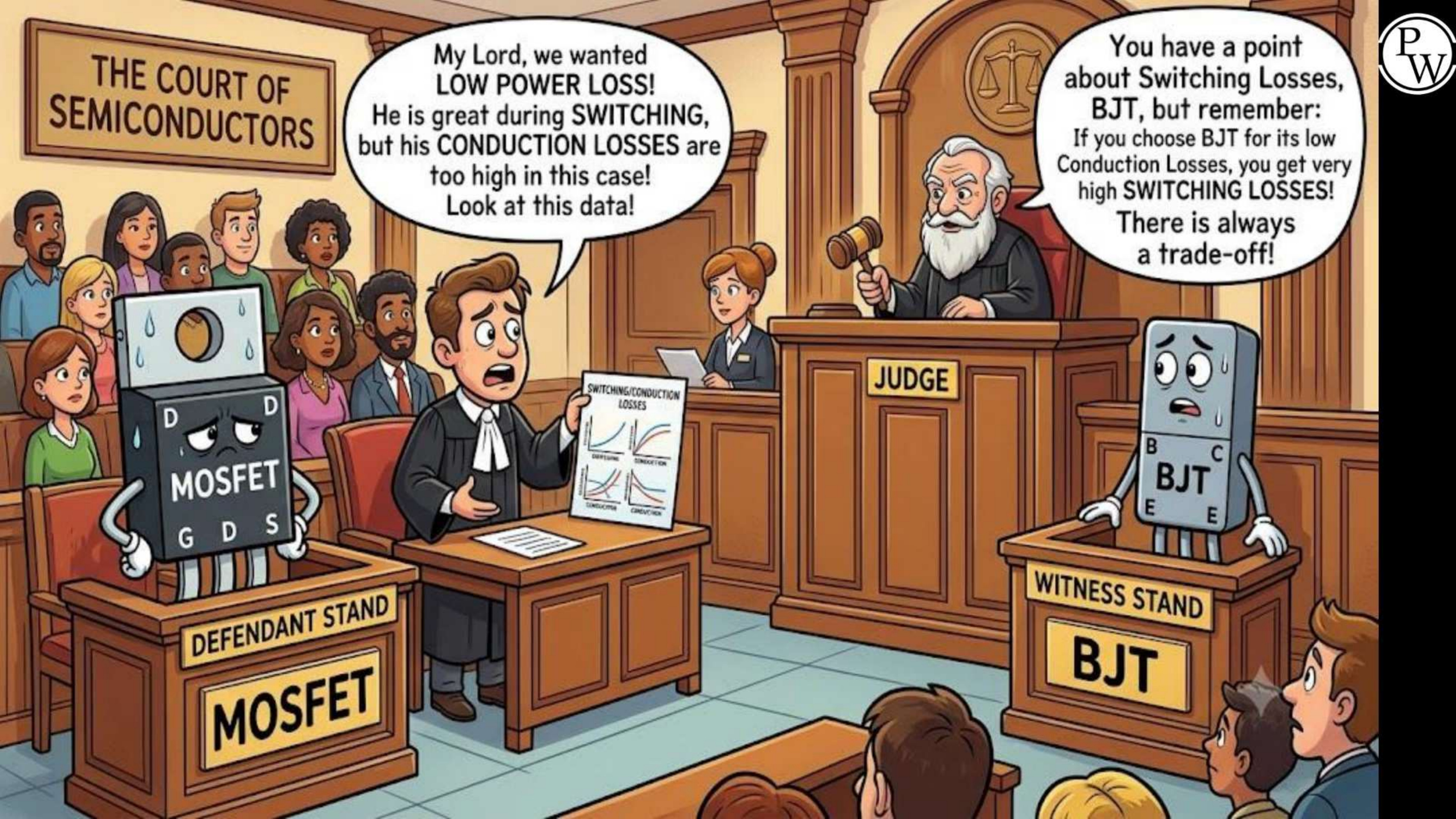
### Key Takeaway:

- **MOSFET** – Fastest switching
- **IGBT** – Second fastest
- **BJT** – Slowest switching

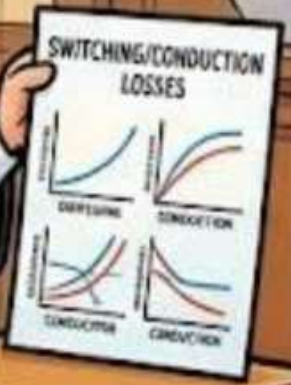
# THE COURT OF SEMICONDUCTORS

My Lord, we wanted **LOW POWER LOSS!**  
He is great during **SWITCHING**,  
but his **CONDUCTION LOSSES** are  
too high in this case!  
Look at this data!

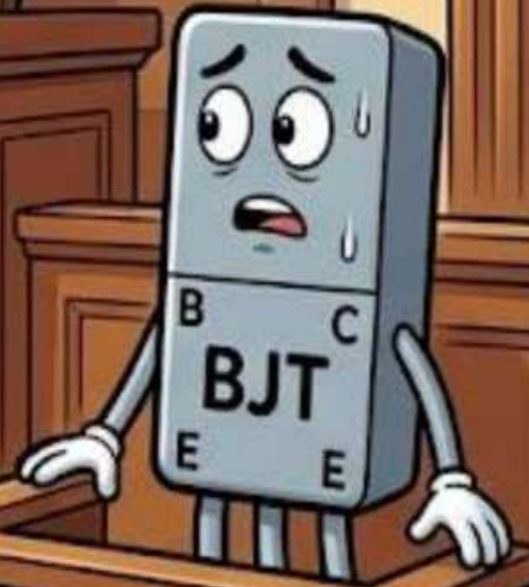
You have a point  
about **Switching Losses**,  
**BJT**, but remember:  
If you choose BJT for its low  
Conduction Losses, you get very  
high **SWITCHING LOSSES!**  
There is always  
a trade-off!



DEFENDANT STAND  
**MOSFET**



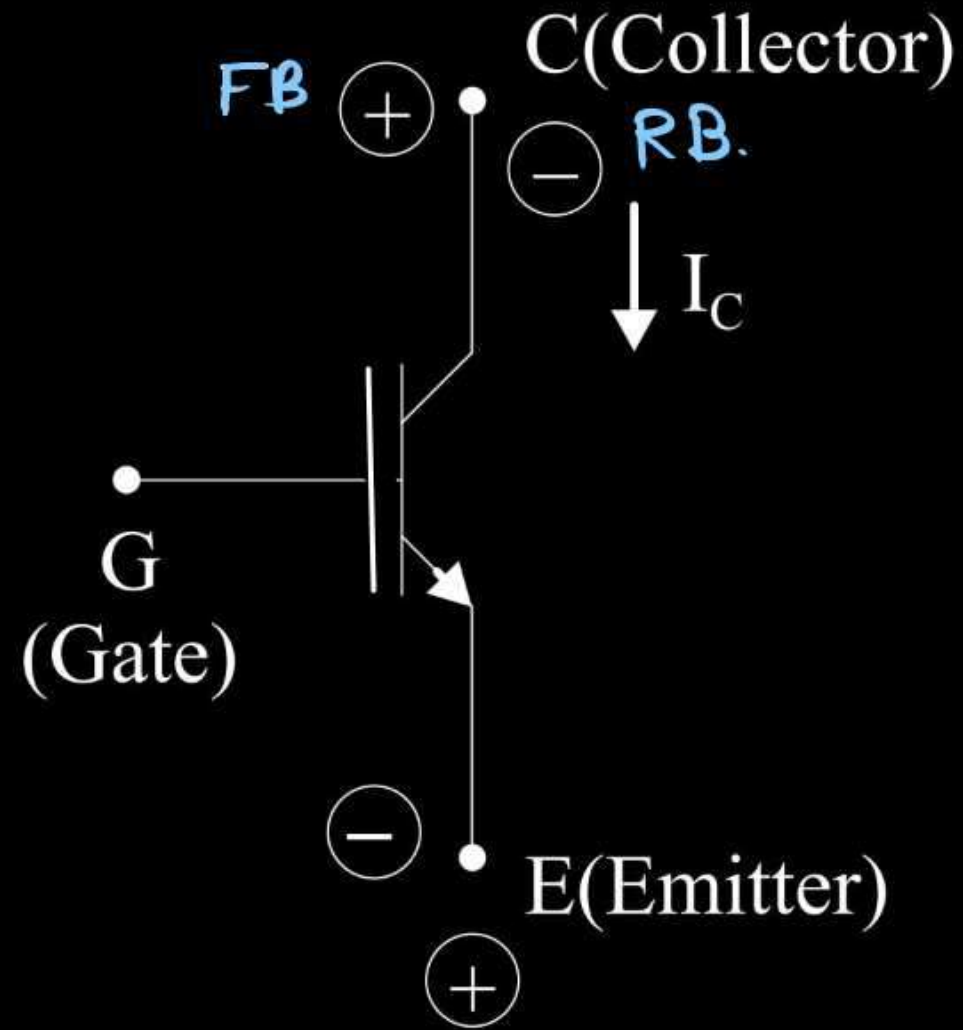
**JUDGE**



WITNESS STAND  
**BJT**



# IGBT (Insulated Gate Bipolar Transistor)



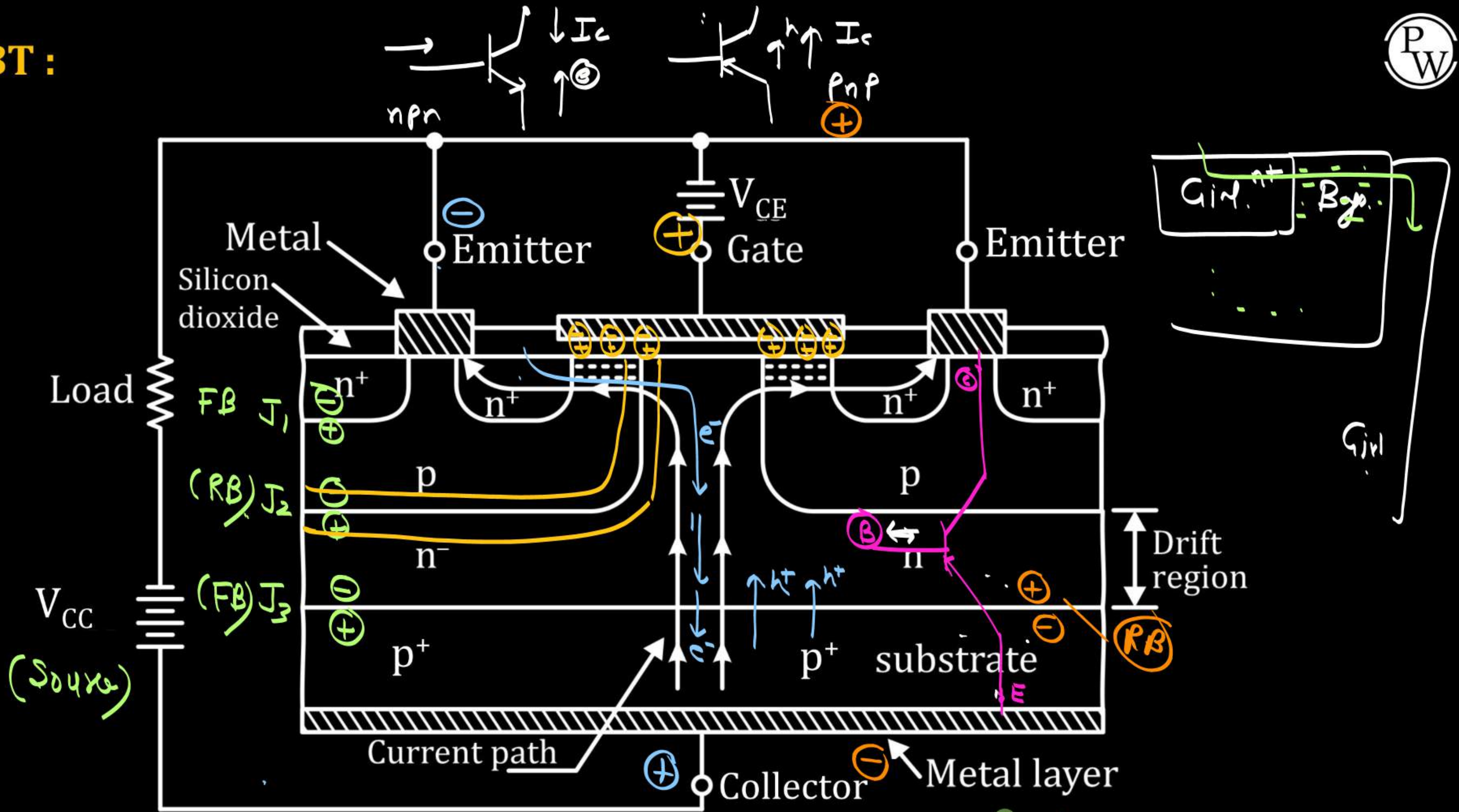
# IGBT (Insulated Gate Bipolar Transistor)

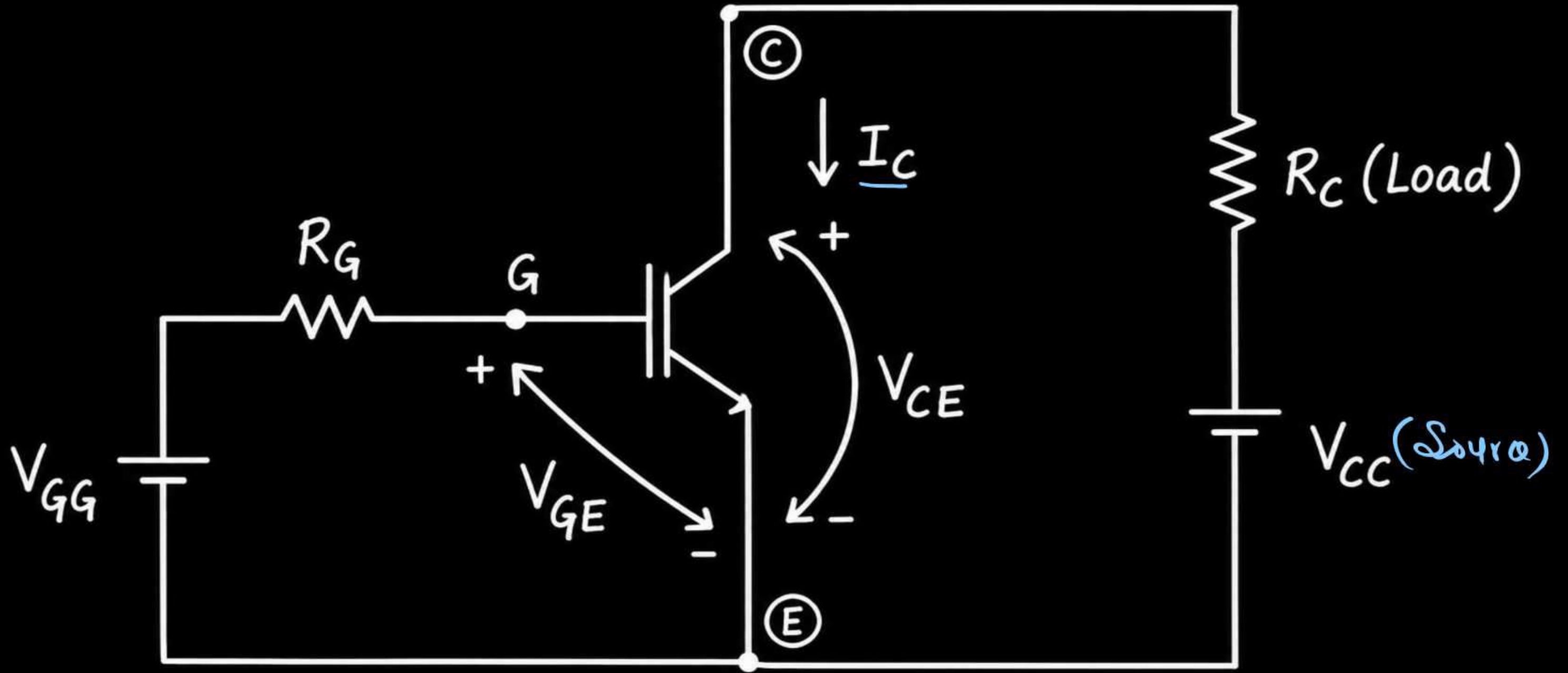
1. IGBT is a 3 terminal device in which C and E are the main terminals and G is the control terminal.
2. It is a fully controlled device. It can be turned on and turned off by control terminal.
3. It is a voltage controlled device. The control signal is  $V_{GE}$ .
- IMP 4. It is a unidirectional device, current can flow only from collector to emitter.
5. It has bipolar voltage blocking capacity.

# IGBT (Insulated Gate Bipolar Transistor)

6. It is a bipolar (Minority carrier) device, but current mainly flows due to electrons.
7. It has positive temperature coefficient of resistance.
8. No secondary breakdown.
9. It can be connected in parallel.
- ~~IMP~~ 10. It is a hybrid device of BJT and MOSFET.
11. It has high input impedance due to  $\text{SiO}_2$ .

# IGBT:





# Working of IGBT

1. When  $V_{GE} = 0$ , then junctions <sup>J<sub>2</sub></sup> are in RB, so depletion layer exists and due to this, a barrier potential is created. So no charge can move between collector and emitter terminal. So,  $I_C = 0$ .
2. When we apply the  $V_{GE}$ , it creates n channel (Inversion layer) in semiconductor region which will short circuit the  $n^+$  and  $n^-$  layers.
3. So electrons can move to  $n^-$  (Drift region) through the n channel.
4. This electrons attract positive holes from  $p^+$  substrates.

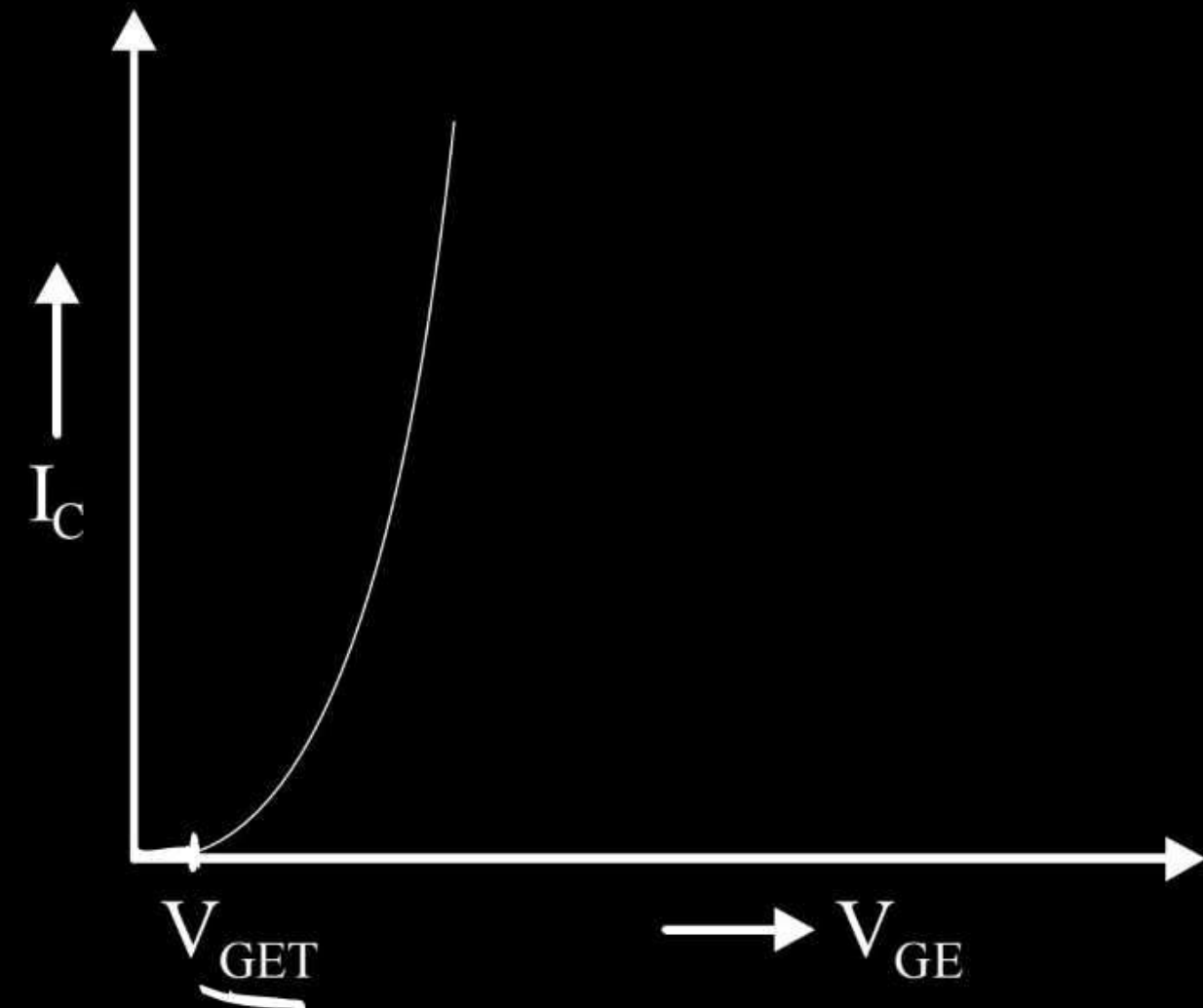
## Working of IGBT

5. So, at any instant of current flowing, the drift region has large no. of electrons and large no. of holes which increase conductivity of drift region (Decrease its resistance). It is called Conductivity Modulation.
6. In IGBT, the current due to holes is flowing through parasitic pnp BJT. Since, this BJT is in active region (not in saturation region), so magnitude of current due to holes is very low.

# Characteristic of IGBT

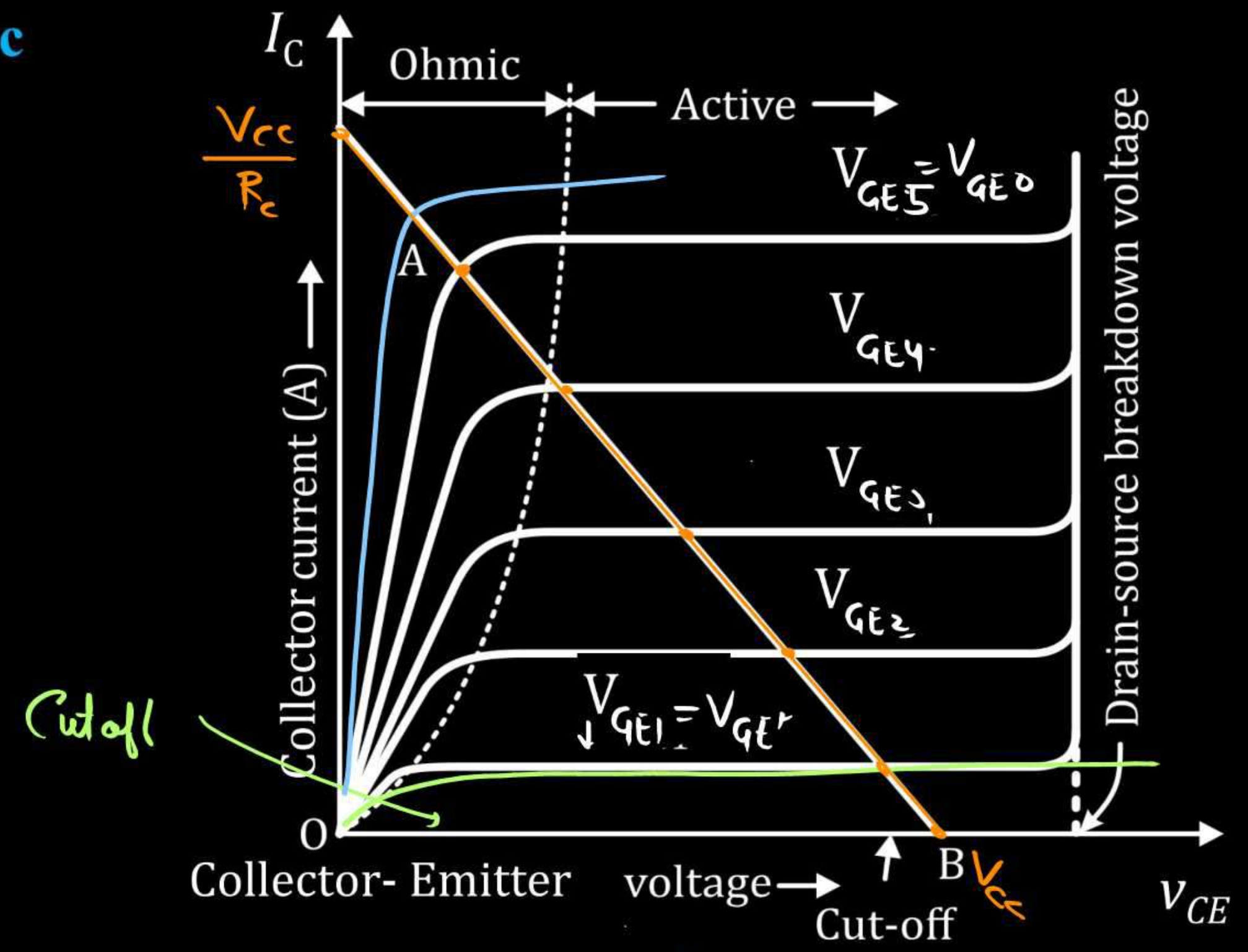
## 1. Transfer characteristic

- $V_{GET}$  = Threshold voltage. It is the minimum voltage that is required to form n channel



# Characteristic of IGBT

## 2. Output characteristic



Load line

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$V_{CC} = V_{CE} + I_C R_C$$

At x axis

$$I_C = 0$$

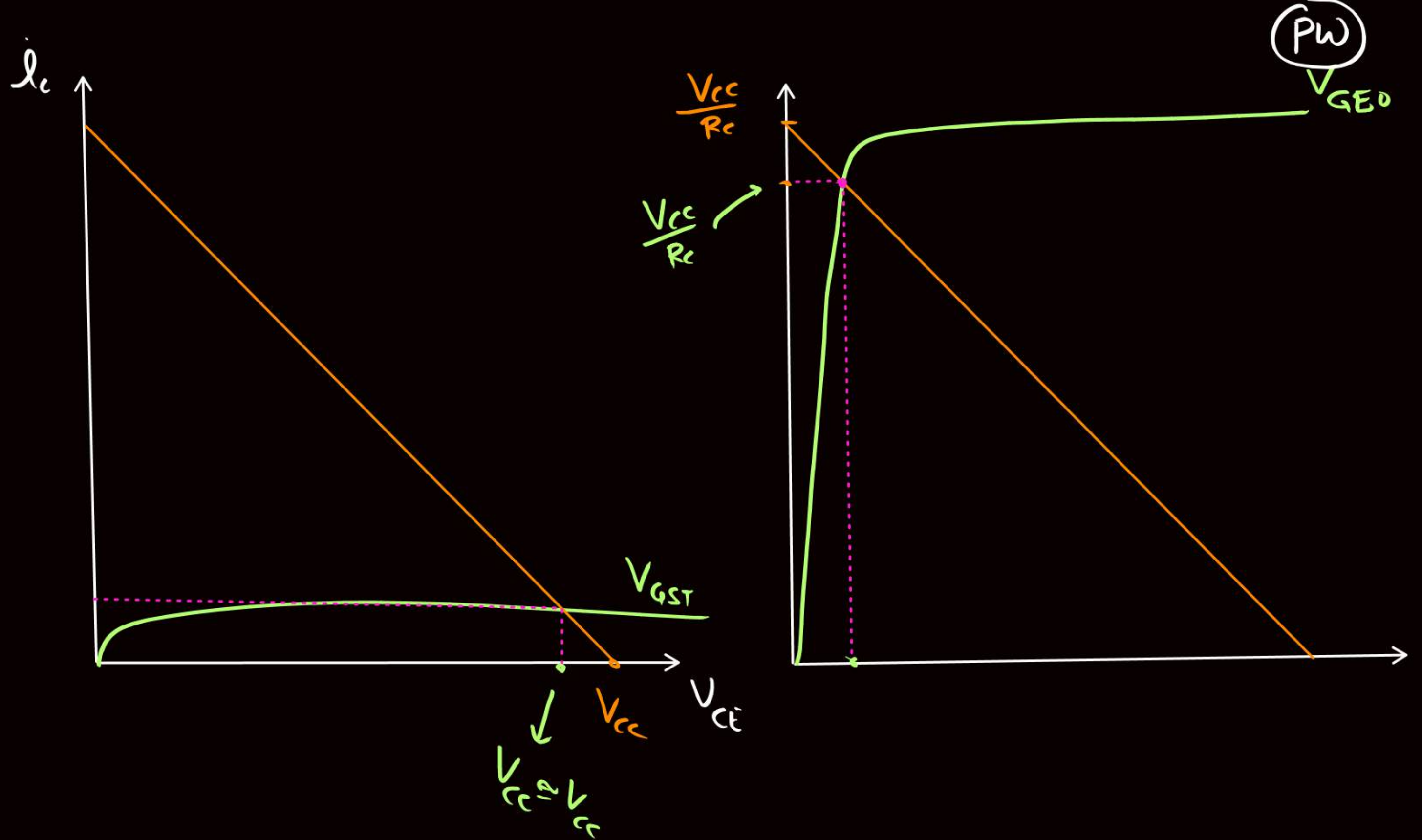
$$V_{CC} = V_{CE}$$

at y axis

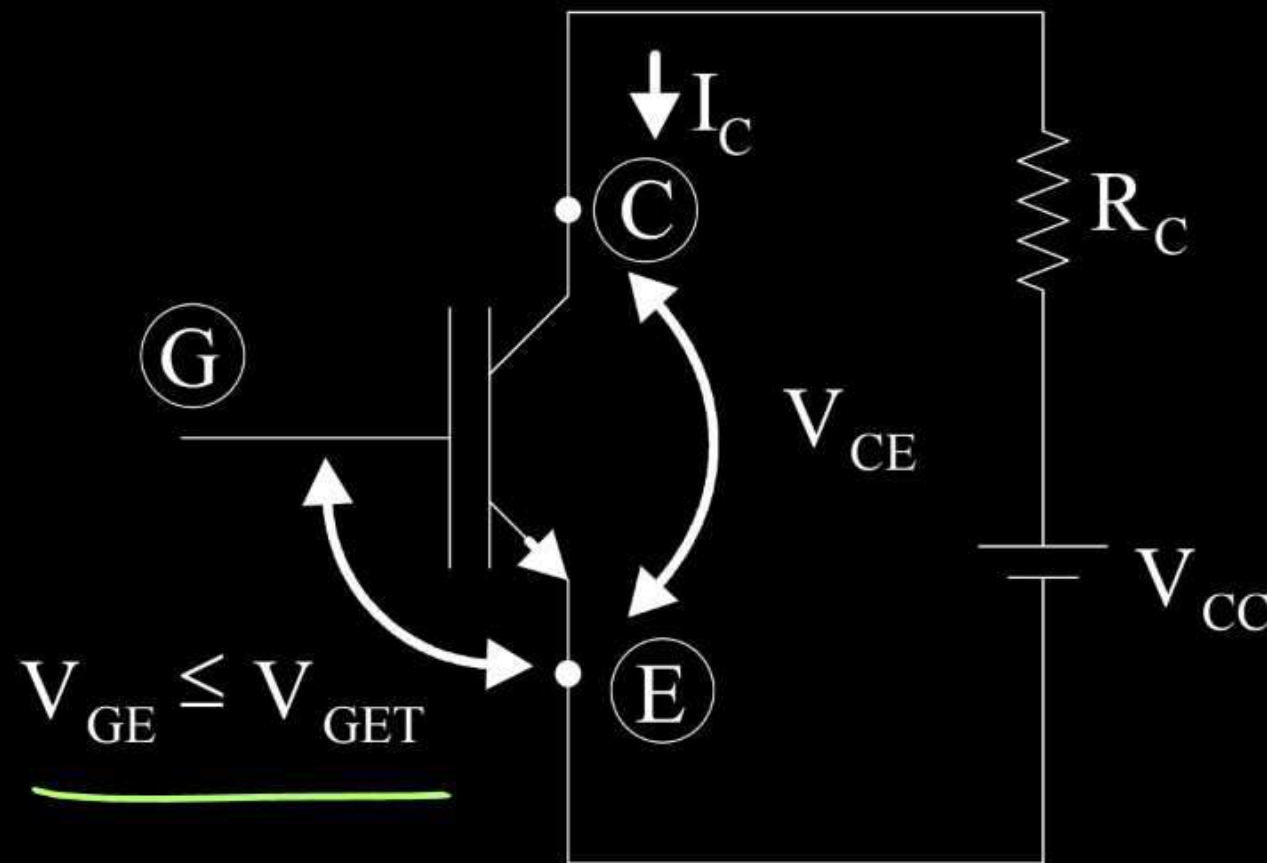
$$V_{CE} = 0$$

$$V_{CC} = I_C R_C$$

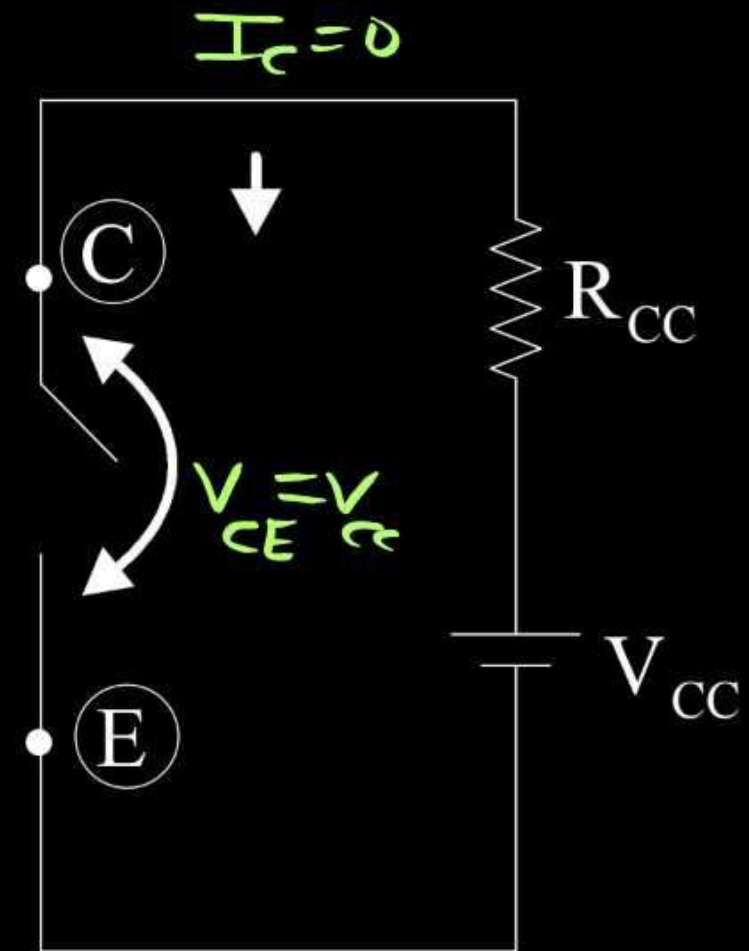
$$I_C = \frac{V_{CC}}{R_C}$$



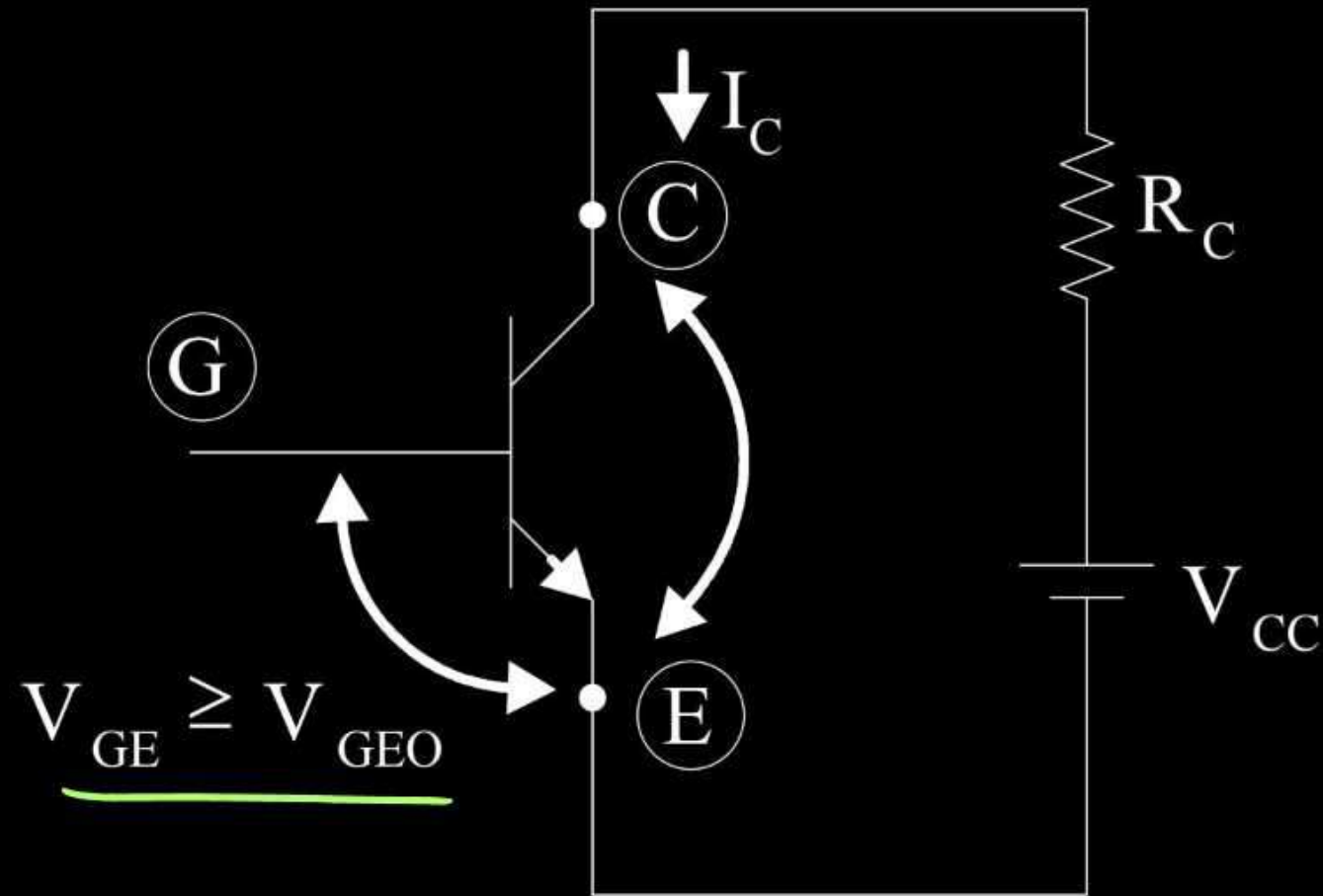
# IGBT as a Switch



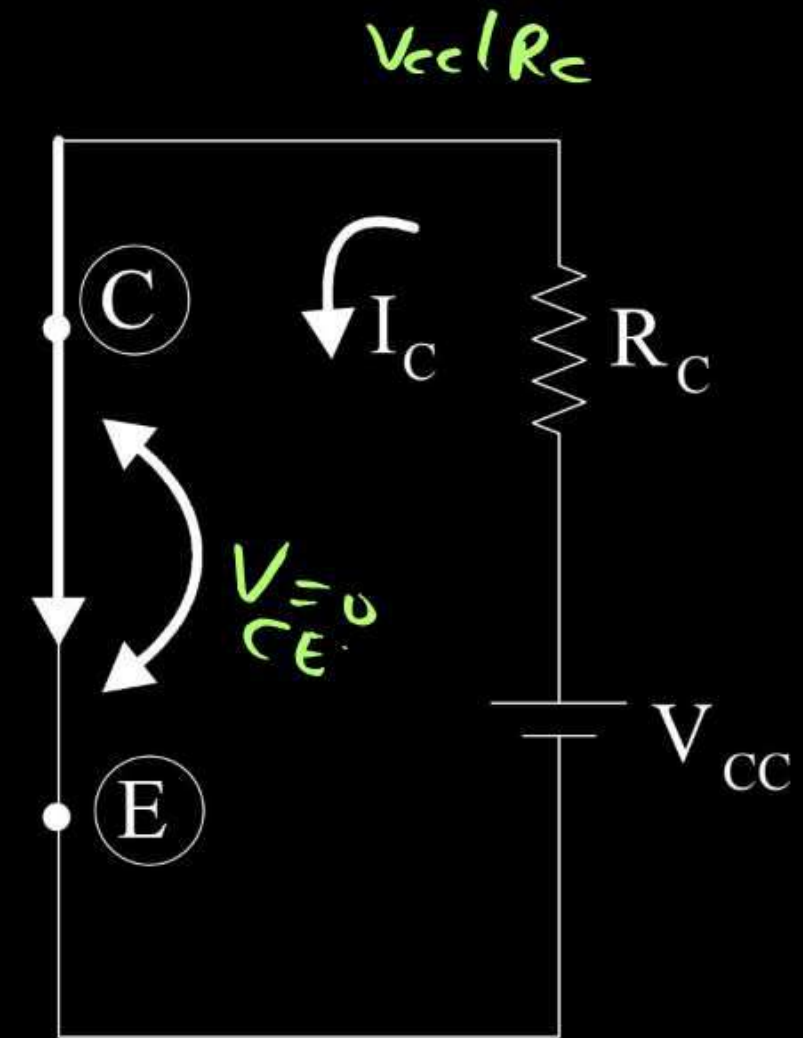
$\Rightarrow$



# IGBT as a Switch

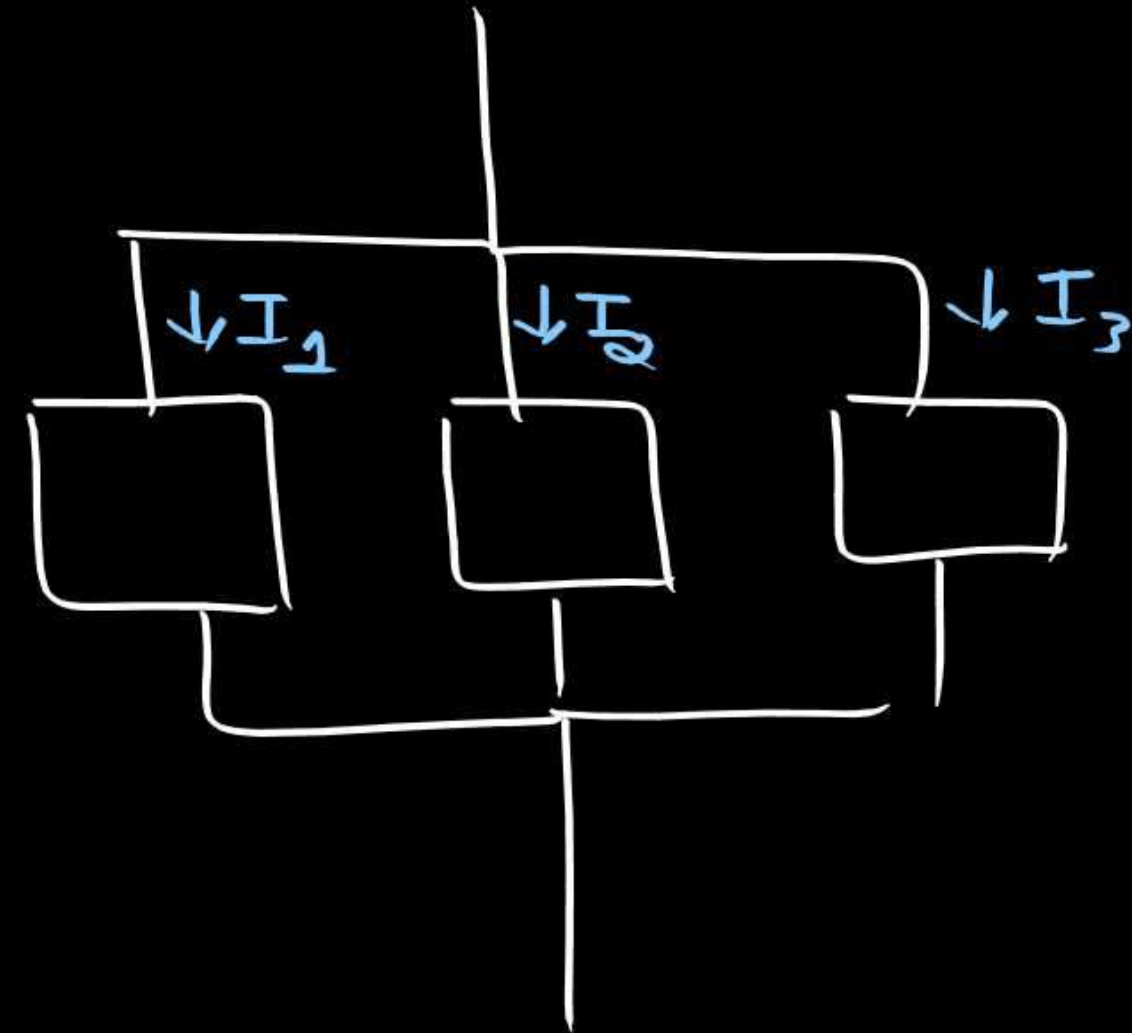


$\Rightarrow$

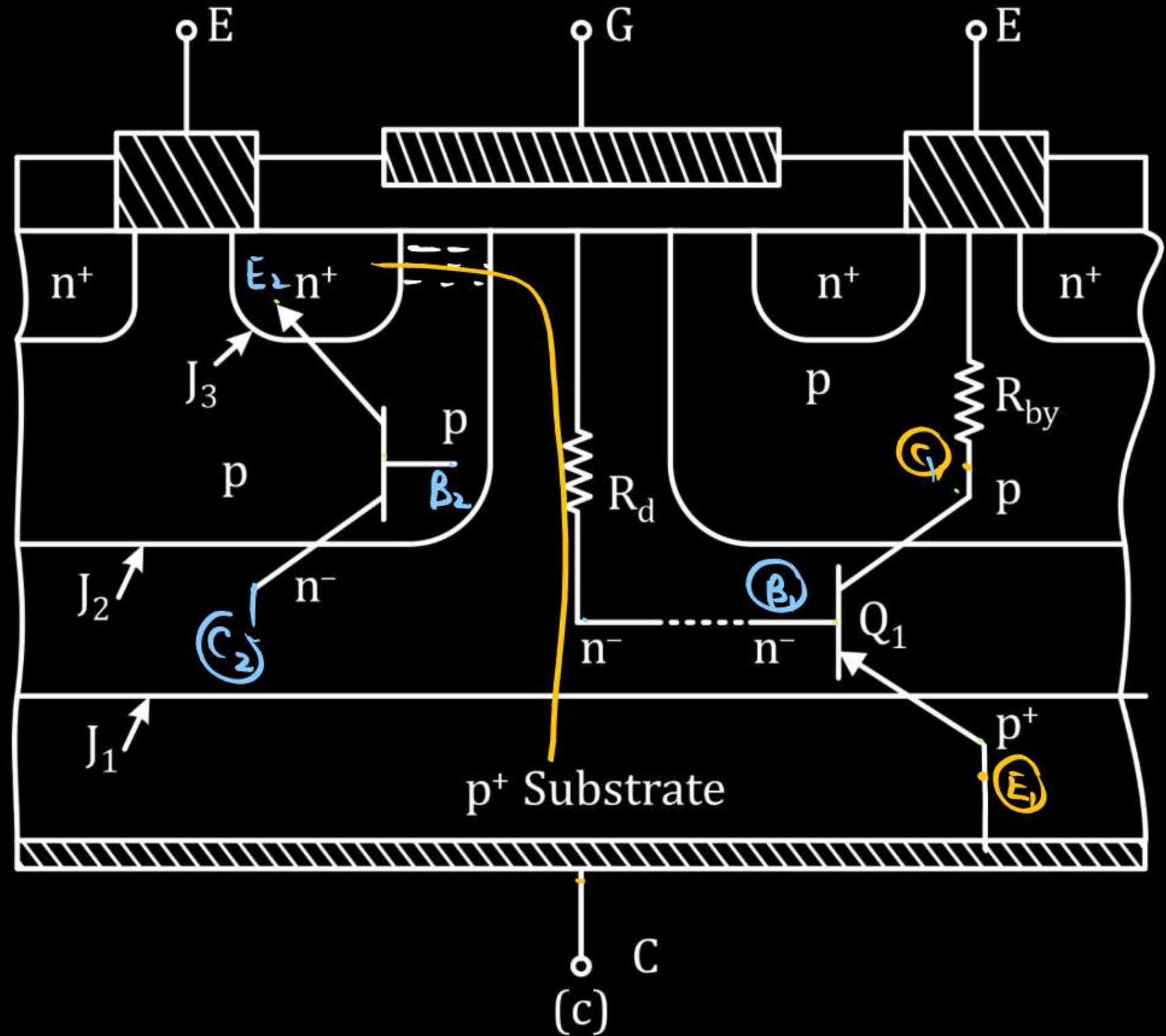


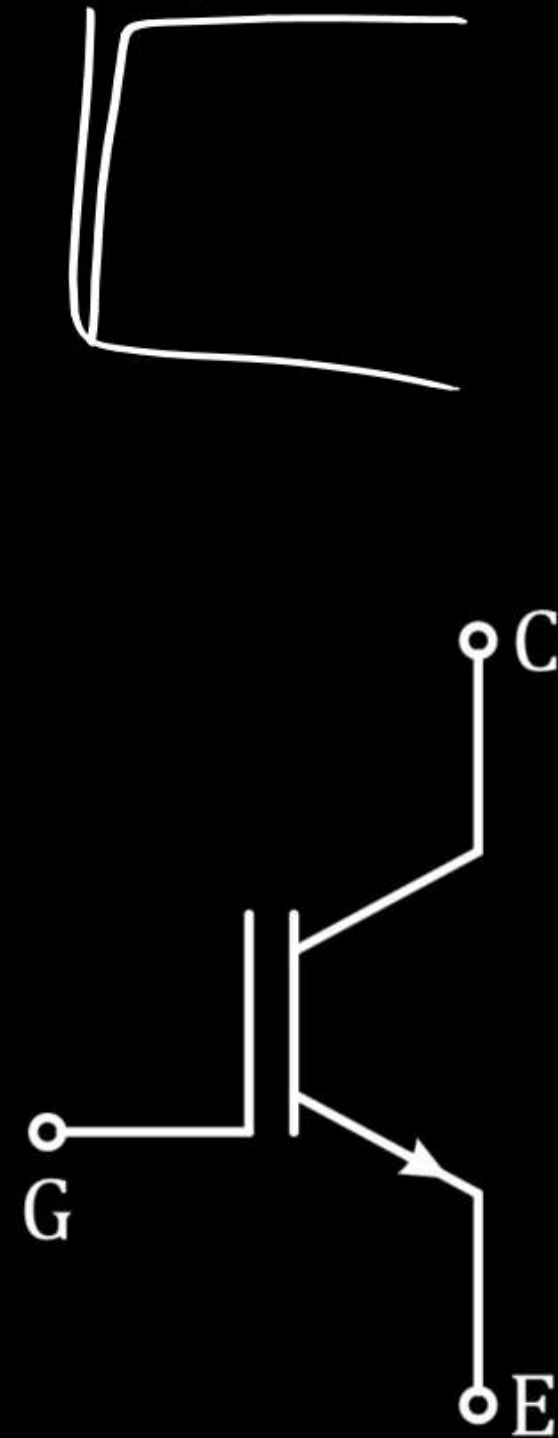
- ✓ 1 IGBT = 2BJT + 1 MOSFET
- 1 IGBT = SCR + 1 MOSFET

$I_1 \uparrow$   
 $\downarrow$   
 $P_1 \uparrow$   
 $\downarrow$   
 $T_{emp} \uparrow$   
 $\downarrow$   
 $R \uparrow$   
 $\downarrow$   
 $I \downarrow$



# Latch-up in IGBT





(e)

Suppose if Load Current Increases.

$$I_L \uparrow = I_e + I_h \uparrow$$



$$V_{BE2} \uparrow = I_h \uparrow R_{by}$$



$$I_{B2} \uparrow$$



$$I_{C2} \uparrow = \beta I_{B2} \uparrow$$

$$I_{B1} \uparrow = I_{C2} \uparrow + I_e$$



$$I_{C1} \uparrow = \beta I_{B1} \uparrow$$



$$I_{B2} \uparrow$$



So Both BJT is driving each other into saturation region  
and Main current start flowing through BJT

## BJT

1. Current controlled
2. Control signal  $I_B$
3. Unidirectional
4. Unipolar Voltage Blocking
5. Bipolar

## MOSFET

1. Voltage controlled
2. Control signal  $V_{GS}$
3. Bidirectional
4. Unipolar voltage Blocking
5. Unipolar

## IGBT

1. Voltage Controlled.
2. Control signal  $V_{GE}$
3. Unidirectional.
4. Bipolar voltage Blocking
5. Bipolar, But Mainly  
Current flow due to electrons

## BJT

- 6. Negative Temp Coefficient  $T \uparrow \Rightarrow R \downarrow$
- 7. Secondary B. down occurs
- 8. Parallel operation is not possible

## MOSFET

- 6. Positive Temp Coefficient  $T \uparrow \Rightarrow R \uparrow$
- 7. No Secondary B. down
- 8. Parallel operation is possible

## IGBT

- 6. Positive temp Coefficient  $T \uparrow \Rightarrow R \uparrow$
- 7. No Secondary B. down
- 8. Parallel operation is possible



## BJT

9. Slowest device
10. Highest Switching loss
11. Lowest Switching Frequency
12. Lowest Cond<sup>n</sup> loss
13. Highest Rating

## MOSFET

9. Fastest device
10. lowest Switching loss
11. Highest Switching freq.
12. Highest Cond<sup>n</sup> loss
13. Lowest Rating

## IGBT

9. Moderate
10. Moderate
11. Moderate
12. Moderate
13. Medium



## 2 Minutes Summary



→ Mosfet

→ IGBT.

A dark blue, 3D-style banner with the words 'THANK YOU' in white, bold, sans-serif capital letters. The banner is tilted and has a folded appearance.

**THANK YOU**



# PRACTICE SHEET-1

EE

## POWER ELECTRONICS

### Power Semiconductor Devices

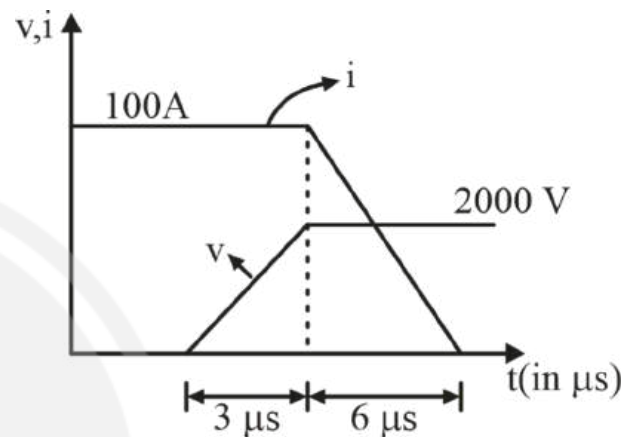
**Q1** The reverse recovery time of a diode is  $3\ \mu\text{s}$  and rate of fall  $\left(\frac{di}{dt}\right)$  is  $30\ \text{A}/\mu\text{s}$ . The stored charge of the diode is

- (A)  $45\ \mu\text{C}$  (B)  $135\ \mu\text{C}$   
(C)  $270\ \mu\text{C}$  (D)  $540\ \mu\text{C}$

**Q2** The reverse recovery time of a diode is  $t_{rr} = 3\ \mu\text{s}$  and the rate of fall of the diode current is  $di/dt = 30\ \text{A}/\mu\text{s}$ . The storage charge  $Q_{RR}$  and the peak inverse current  $I_{RR}$  will be respectively

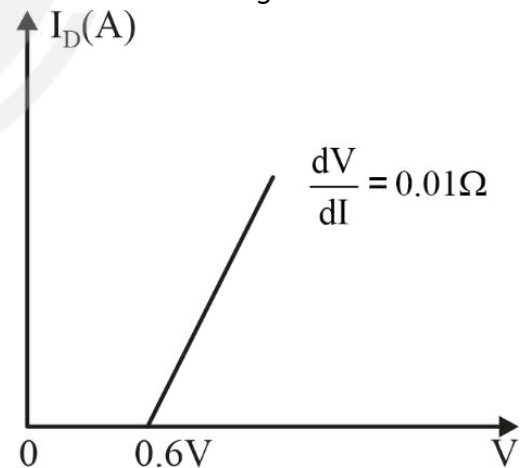
- (A)  $135\ \mu\text{C}$  and  $90\ \text{A}$   
(B)  $270\ \mu\text{C}$  and  $90\ \text{A}$   
(C)  $270\ \mu\text{C}$  and  $60\ \text{A}$   
(D)  $135\ \mu\text{C}$  and  $60\ \text{A}$

**Q3** Graph of voltage across a power semiconductor device and current through the device versus time is shown below. The switching transition is \_\_\_\_\_ process and energy lost during the transition is \_\_\_\_\_ J.



- (A) Turn off, 0.9 (B) Turn on, 0.9  
(C) Turn off, 1.8 (D) Turn on, 1.8

**Q4** I-V characteristics of a power semiconductor device is shown in the figure.



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If the diode carries a steady state DC current of 200 A when forward biased, the conduction power loss is \_\_\_\_\_ watts.

- (A) 480 (B) 120  
(C) 520 (D) 400

**Q5** Which of the following is not required for power diodes?

- (A) High speed operation  
(B) Fast commutation  
(C) Small Recovery time  
(D) Low on-stage voltage drop

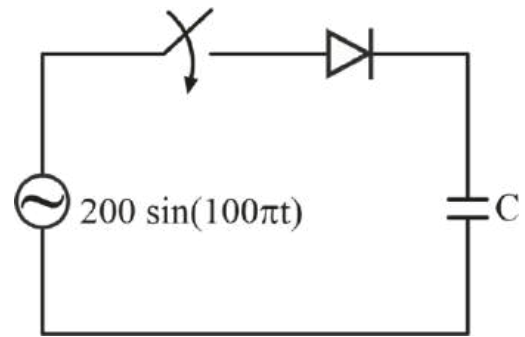
**Q6** When a power diode is turned off, its anode current falls at the rate of 20 A/msec. If the reverse recovery time of the diode is 20 msec, the value of stored charge removed during reverse recovery of diode will be

- (A) 0.4 C (B) 4 C  
(C) 4 mC (D) 4000 C

**Q7** Which of the following type of diode is preferred for inverters and choppers?

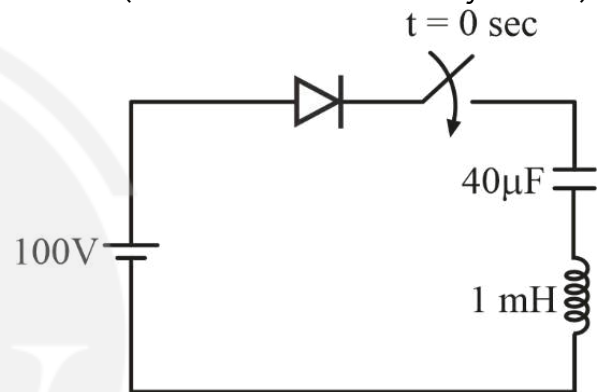
- (A) General purpose diodes  
(B) Fast recovery diodes  
(C) Schottky diodes  
(D) Metal-semiconductor diodes

**Q8** For the circuit shown in figure, if the switch S is closed at  $t = 0$  sec, the diode will conduct for



- (A) 15 m sec (B) 20 m sec  
(C) 10 m sec (D) 5 m sec

**Q9** For the circuit shown below, the value of peak current is (Assume the circuit is initially relaxed)



- (A) 80 A (B) 50 A  
(C) 0 A (D) 20 A

**Q10** In the previous question, the frequency of current is

- (A) 795.78 Hz (B) 0 Hz  
(C) 5 kHz (D) 10 kHz

**Q11** The most suitable device for high frequency inversion in SMPS is

- (A) BJT (B) IGBT  
(C) MOSFET (D) GTO

**Q12** Turn-on and turn-off times of transistor depend on



- (A) static characteristic  
 (B) junction capacitances  
 (C) current gain  
 (D) None of the above

**Q13** Consider the following statements about IGBT

1. It has high input impedance
2. It has low ON state voltage drop.
3. Its switching speed is higher than that of the MOSFET.
4. It is a voltage-controlled device.

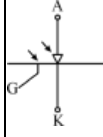
Which of the above statements are correct?

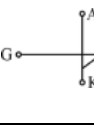
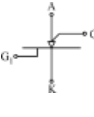
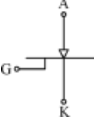
- (A) 1, 2 and 3 only  
 (B) 2, 3 and 4 only  
 (C) 1, 2 and 4 only  
 (D) 1, 2, 3 and 4

**Q14** In a Bipolar Junction Transistor (BJT) due to current flow to small portion of the base, hot spots are produced causing localized excessive heating and damaging the transistor. This switching limit is called

- (A) Forward-Biased Safe Operating Area (FBSOA)  
 (B) Reverse-Biased Safe Operating Area (RBSOA)  
 (C) Power Derating  
 (D) Second Breakdown (SB)

**Q15** Match **List-I** (Thyristors) with **List-II** (Symbols) and select the correct answer:

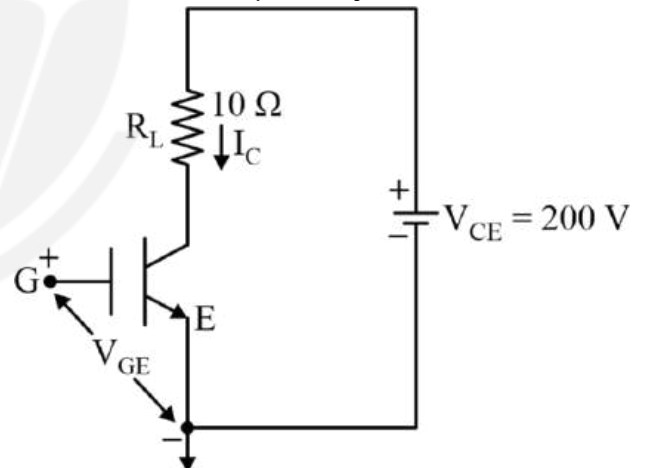
| List-I                                  | List-II                                                                                   |
|-----------------------------------------|-------------------------------------------------------------------------------------------|
| A<br>Silicon-controlled rectifier (SCR) | 1.<br> |

|                                      |                                                                                           |
|--------------------------------------|-------------------------------------------------------------------------------------------|
| B<br>Silicon-controlled switch (SCS) | 2.<br> |
| C<br>Silicon-unilateral switch (SUS) | 3.<br> |
| D<br>Light-activated SCR (LASCR)     | 4.<br> |

- (A) A→3, B→4, C→1, D→2  
 (B) A→4, B→3, C→1, D→2  
 (C) A→3, B→4, C→2, D→1  
 (D) A→4, B→3, C→2, D→1

**Q16** The IGBT (Insulated GATE Bipolar Transistor) used in the circuit has the following data:  $t_{ON} = 3 \mu s$ ,  $t_{OFF} = 1.2 \mu s$ , Duty cycle ( $D$ ) = 0.7,  $V_{CE(sat)} = 2V$  and  $f_s = 1 \text{ kHz}$ .

What are the switching Power losses during turn-on and turn-off, respectively?



- (A) 1.98 W and 1.7 W  
 (B) 2.2 W and 1.7 W  
 (C) 1.98 W and 0.792 W  
 (D) 2.2 W and 0.792 W



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**Q17** When cathode of a thyristor is made more positive than its anode

- (A) all the junctions are reverse biased
- (B) outer junctions are reverse biased and central one is forward biased
- (C) outer junctions are forward biased and central one is reverse biased
- (D) all the junctions are forward biased

**Q18** The sharing of the voltages between thyristors operating in series is influenced by the

- (A)  $di/dt$  capabilities
- (B)  $dv/dt$  capabilities
- (C) junction temperatures
- (D) static v-i characteristics and leakage currents

**Q19** R-C snubber is used in parallel with the thyristor to

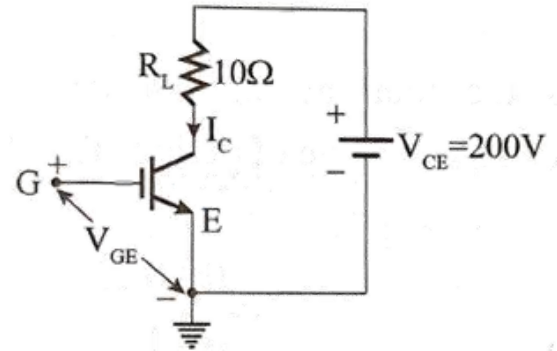
- (A) reduce  $dv/dt$  across it
- (B) reduce  $di/dt$  through it
- (C) limit current through the thyristor
- (D) ensure its conduction after gate signal is removed

**Q20** A Gate Turn Off (GTO) thyristor has capacity to

- (A) Amplify the gate-current
- (B) Turn-off when positive current pulse is given at the gate
- (C) Turn-off when a gate-pulse is given at the gate even though it is reverse biased
- (D) Turn-off when a negative current pulse is given at the gate

**Q21** The IGBT (Insulated Gate Bipolar Transistor) used in the circuit has the following data:  $t_{ON} = 3$  ms,  $t_{OFF} = 1.2$  ms, Duty cycle (D) = 0.7,  $V_{CE(sat)} = 2$  V

and  $f_s = 1$  kHz. What are the switching power losses during turn-on and turn-off, respectively?



- (A) 1.98 W and 1.7 W
- (B) 2.2 W and 1.7 W
- (C) 1.98 W and 0.792 W
- (D) 2.2 W and 0.792 W

**Q22** The  $i_g$ - $v_g$  characteristics of a thyristor is a straight line passing through origin with a gradient of  $2.5 \times 10^3$ . If  $P_g = 0.015$  watt, the value of gate voltage will be nearly

- (A) 5.0 V
- (B) 6.1 V
- (C) 7.5 V
- (D) 8.5 V

**Q23** For an SCR, the gate cathode characteristic has a straight line slope of 140. For trigger source voltage of 20 V and allowable gate power dissipation of 0.5 watts, what is the gate source resistance?

- (A) 200  $\Omega$
- (B) 255  $\Omega$
- (C) 195  $\Omega$
- (D) 185  $\Omega$

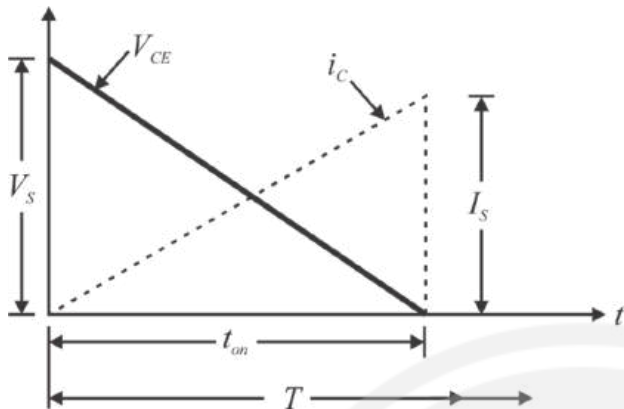
**Q24** The conduction loss versus device current characteristic of a power MOSFET is best approximated by

- (A) a parabola
- (B) a straight line
- (C) a rectangular hyperbola



(D) an exponentially decaying function

- Q25** For the switching waveform shown in the figure for a power transistor, the peak instantaneous power loss is



- (A)  $\frac{V_s I_s}{4}$  (B)  $\frac{V_s I_s}{6}$   
(C)  $\frac{V_s I_s}{3}$  (D)  $\frac{V_s I_s}{8}$

- Q26** In the previous question, if  $V_s = 100$  V,  $I_s = 10$  A, then peak instantaneous power loss in watts is

- (A) 500 (B) 166.67  
(C) 333.33 (D) 250

- Q27** For the switching waveform shown in question 25 for a power transistor, the average value of switch-on power loss at a switching frequency  $f$  is ( $f = 1/T$ )

- (A)  $\frac{V_s I_s}{4} \cdot t_{on} \cdot f$   
(B)  $\frac{V_s I_s}{6} \cdot t_{on} \cdot f$   
(C)  $\frac{V_s I_s}{3} \cdot t_{on} \cdot f$   
(D)  $\frac{V_s I_s}{8} \cdot t_{on} \cdot f$

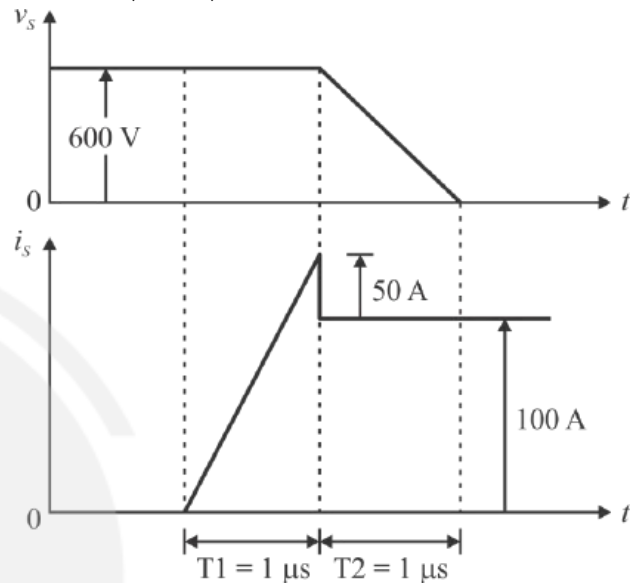
- Q28** In question 25, if  $V_s = 100$  V,  $I_s = 10$  A,  $t_{on} = 1.2$  ms and  $f = 10$  kHz, then average value of switch-on power loss is

- (A) 1 W (B) 4 W

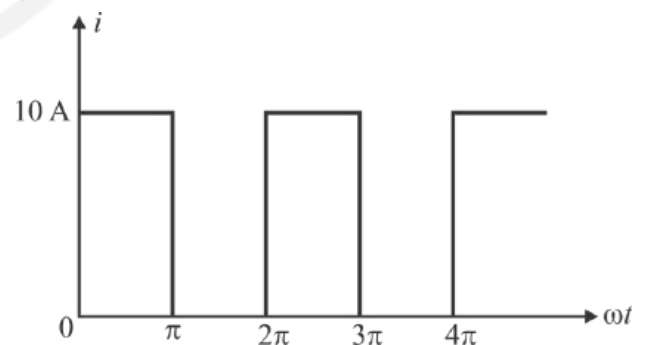
(C) 2 W

(D) 3 W

- Q29** The voltage ( $v_s$ ) across and the current ( $i_s$ ) through a semiconductor switch during a turn-ON transition are shown in the figure given below. The energy dissipated during the turn-ON transition, in mJ, is....



- Q30** A MOSFET rated for 15 A, carries a periodic current as shown in the figure given below. The on-state resistance of the MOSFET is 0.15 ohm. What is the average on-state loss in the MOSFET?



- (A) 3.75 W (B) 7.5 W



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## Answer Key

Q1 (B)  
Q2 (A)  
Q3 (A)  
Q4 (C)  
Q5 (B)  
Q6 (B)  
Q7 (B)  
Q8 (B)  
Q9 (D)  
Q10 (A)  
Q11 (C)  
Q12 (B)  
Q13 (C)  
Q14 (D)  
Q15 (D)

Q16 (C)  
Q17 (B)  
Q18 (D)  
Q19 (A)  
Q20 (D)  
Q21 (C)  
Q22 (B)  
Q23 (C)  
Q24 (C)  
Q25 (A)  
Q26 (D)  
Q27 (B)  
Q28 (C)  
Q29 75~75  
Q30 (B)



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## Hints & Solutions

**Q1 Text Solution:**

(B)

**Q2 Text Solution:**

(A)

**Q3 Text Solution:**

(A)

**Q4 Text Solution:**

(C)

**Q5 Text Solution:**

(B)

**Q6 Text Solution:**

(B)

**Q7 Text Solution:**

(B)

**Q8 Text Solution:**

(B)

**Q9 Text Solution:**

(D)

**Q10 Text Solution:**

(A)

**Q11 Text Solution:**

(C)

**Q12 Text Solution:**

(B)

**Q13 Text Solution:**

(C)

**Q14 Text Solution:**

(D)

**Q15 Text Solution:**

(D)

**Q16 Text Solution:**

(C)

**Q17 Text Solution:**

(B)

**Q18 Text Solution:**

(D)

**Q19 Text Solution:**

(A)

**Q20 Text Solution:**

(D)

**Q21 Text Solution:**

(C)

**Q22 Text Solution:**

(B)

**Q23 Text Solution:**

(C)

**Q24 Text Solution:**

(C)

**Q25 Text Solution:**

(A)

**Q26 Text Solution:**

(D)

**Q27 Text Solution:**

(B)

**Q28 Text Solution:**

(C)



[Android App](#)

| [iOS App](#)

| [PW Website](#)

**Q29 Text Solution:**  
75

**Q30 Text Solution:**  
(B)



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# Electrical Engineering



## Power Electronics

Practice Sheet – 1 Discussion



Power Semiconductor Devices

By – Ajay Gupta Sir

**Q.01** The reverse recovery time of a diode is  $3 \mu\text{s}$  and rate of fall  $\left(\frac{di}{dt}\right)$  is  $30 \frac{\text{A}}{\mu\text{s}}$ . The stored charge of the diode

- A**  $45 \mu\text{C}$
- B**  $135 \mu\text{C}$  ✓
- C**  $270 \mu\text{C}$
- D**  $540 \mu\text{C}$

$$t_{rr} = 3 \mu\text{s}$$

$$\frac{di}{dt} = 30 \frac{\text{A}}{\mu\text{s}}$$

$$t_{rr} = \sqrt{\frac{2Q_R}{di/dt}}$$

$$3 \times 10^{-6} = \sqrt{\frac{2Q_R \times 10^{-6}}{30}}$$

$$9 \times 10^{-12} = \frac{2Q_R \times 10^{-6}}{30}$$

$$Q_R = \frac{30 \times 9}{2} \times 10^{-6}$$

$$Q_R = 135 \times 10^{-6}$$

**Q.02** The reverse recovery time of a diode is  $t_{rr} = 3 \mu s$  and the rate of fall of the diode current is  $di/dt = 30 A/\mu s$ . The storage charge  $Q_{RR}$  and the peak inverse current  $I_{RM}$  will be respectively

- A** 135  $\mu C$  and 90 A ✓
- B** 270  $\mu C$  and 90 A
- C** 270  $\mu C$  and 60 A
- D** 135  $\mu C$  and 60 A

$$t_{rr} = 3 \mu s$$

$$\frac{di}{dt} = 30 \frac{A}{\mu s}$$

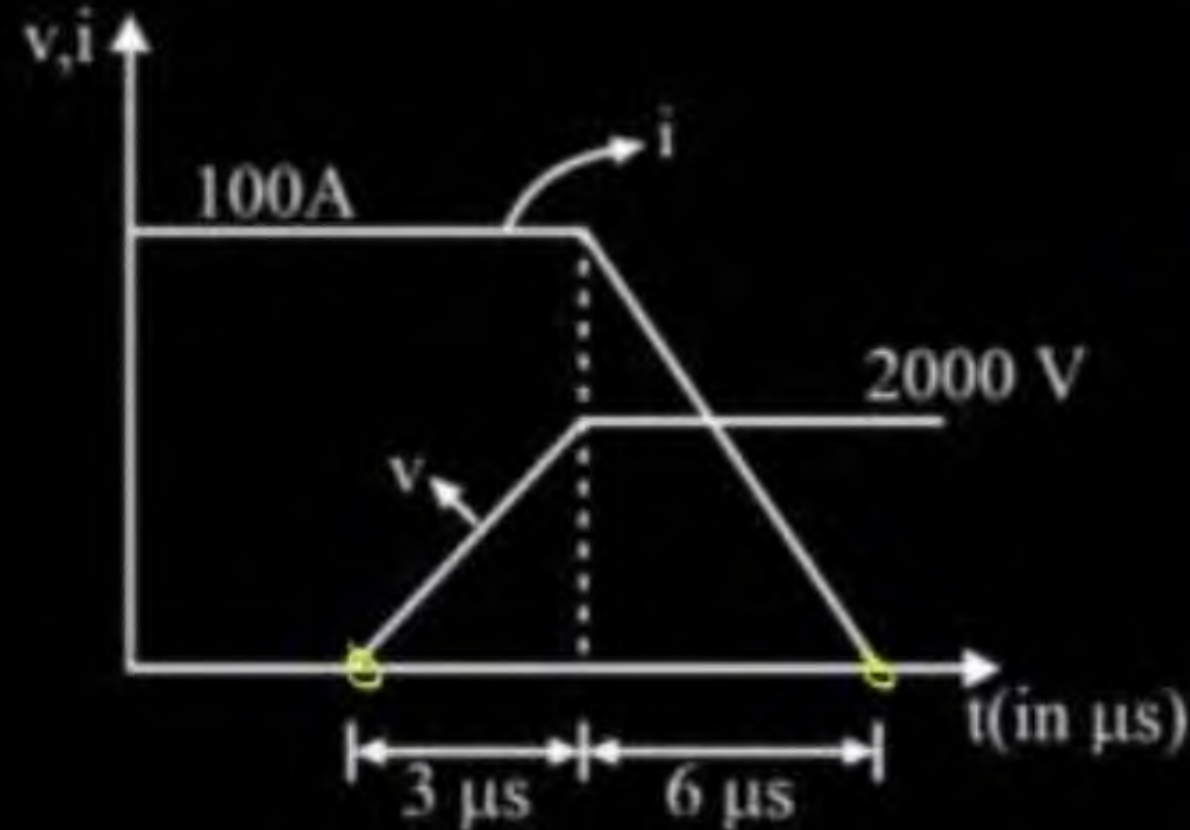
$$I_{RM} = t_{rr} \cdot \frac{di}{dt}$$

$$= 3 \times 30 = 90 \text{ A}$$

$$Q_R = \frac{1}{2} I_{RM} t_{rr} = \frac{1}{2} \times 90 \times 3 = 135 \mu C$$

**Q.03** Graph of voltage across a power semiconductor device and current through the device versus time is shown below. The switching transition is \_\_\_\_\_ process and energy lost during the transition is \_\_\_\_\_ J.

- A** Turn off, 0.9 ✓
- B** Turn on, 0.9 ✗
- C** Turn off, 1.8
- D** Turn on, 1.8 ✗



→ Current is Reducing and Voltage is increasing  
→ Turn off

$$E = \int_0^{3 \times 10^{-6}} 9.150 \, dt + \int_0^{6 \times 10^{-6}} 2000 \, i \, dt$$

$$= 150 \int_0^{3 \times 10^{-6}} v \, dt + 2000 \int_0^{6 \times 10^{-6}} i \, dt$$

$$= 150 \times \frac{1}{2} \times 3 \times 10^{-6} \times \overset{1000}{\cancel{2000}} + \overset{1000}{\cancel{2000}} \times \frac{1}{2} \times 150 \times 6 \times 10^{-6}$$

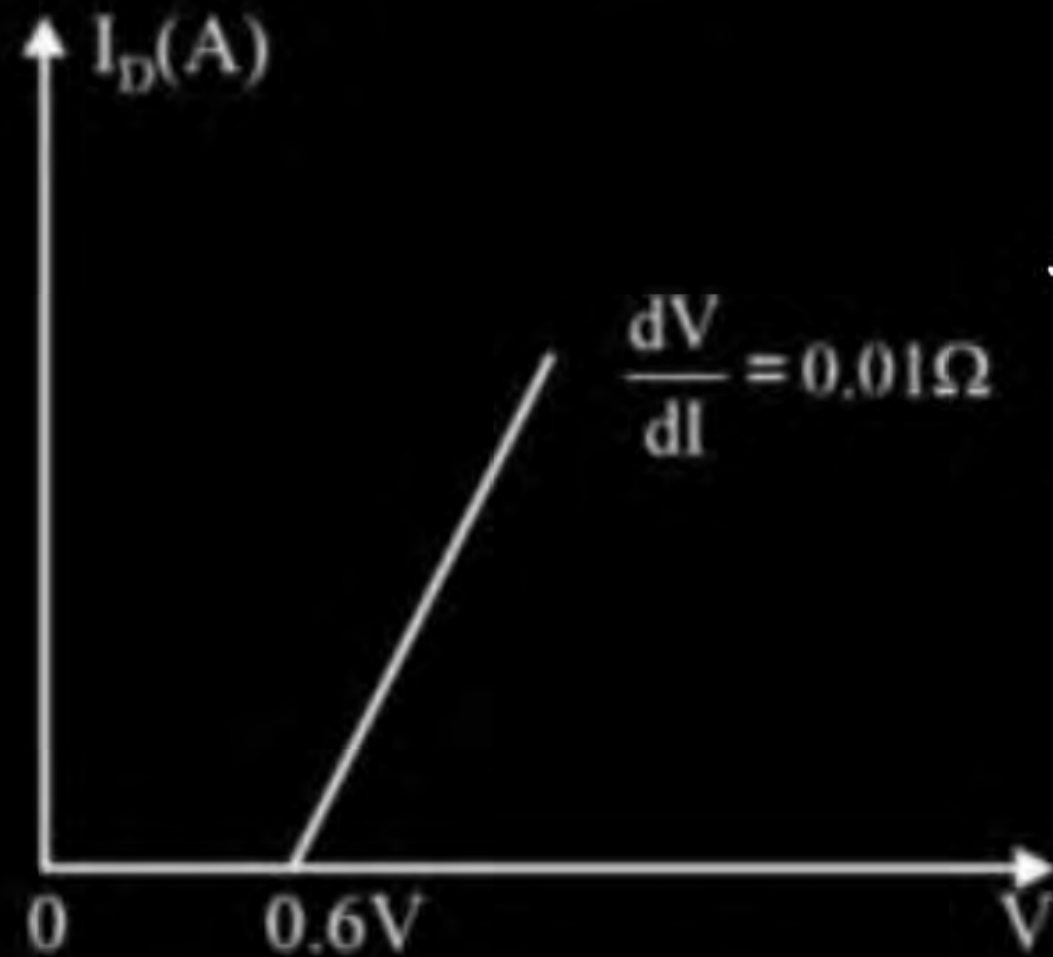
$$= 0.3 \times 10^{-6} + 0.6 \times 10^{-6}$$

$$= 0.9 \times 10^{-6}$$

**Q.04** I-V characteristics of a power semiconductor device is shown in the figure. 

If the diode carries a steady state DC current of 200 A when forward biased, the conduction power loss is \_\_\_\_\_ watts.

- A** 480
- B** 120
- C** 520 ✓
- D** 400



$$\begin{aligned} & \text{Circuit model: } 0.6 \text{ V source in series with } 0.01 \Omega \text{ resistor} \\ & 0.6 \times I_{avg} + I_{rms}^2 \times 0.01 \\ & 0.6 \times 200 + (200)^2 \times 0.01 \\ & = 520 \end{aligned}$$

$$y = mx + c$$

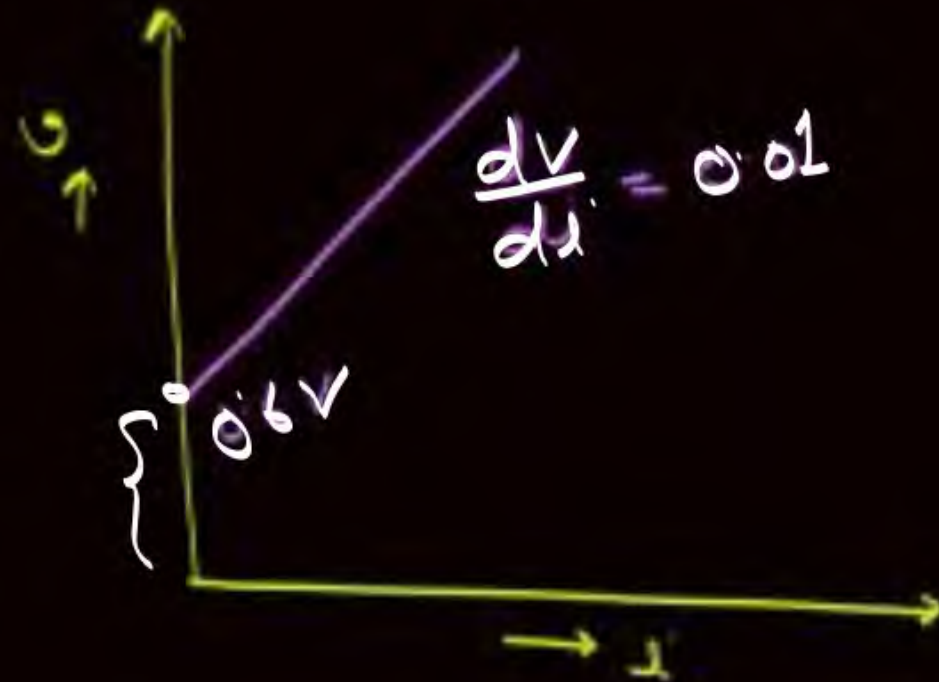
$$V = 0.01i + 0.6$$

The value of current  $i = 250$

$$V = 0.01 \times 250 + 0.6$$

$$V = 2 + 0.6 = 2.6$$

$$\begin{aligned} \text{loss} &= 2.6 \times 250 \\ &= 520 \end{aligned}$$



**Q.05** Which of the following is not required for power diodes?

- A** High speed operation
- B** Fast commutation ✓
- C** Small Recovery time
- D** Low on-stage voltage drop

**Q.06** When a power diode is turned off, its anode current falls at the rate of 20 A/msec. If the reverse recovery time of the diode is 20 msec, the value of stored charge removed during reverse recovery of diode will be

- A** 0.4 C
- B** 4 C ✓
- C** 4 mC
- D** 4000 C

$$\frac{di}{dt} = \frac{20 \text{ A}}{\text{msec}}$$

$$t_{rr} = 20 \text{ msec}$$

$$t_{rr} = \sqrt{\frac{2Q_R}{di/dt}}$$

$$\Rightarrow 20 \text{ msec} = \frac{di}{dt} \times (t_{rr})^2$$

$$Q_R = \frac{1}{2} \times \frac{di}{dt} \times (t_{rr})^2$$

$$= \frac{1}{2} \times \frac{20 \text{ A}}{\text{msec}} \times 20 \text{ msec} \times 20 \text{ msec}$$

$$= 4000 \text{ mC}$$

$$= 4 \text{ C}$$

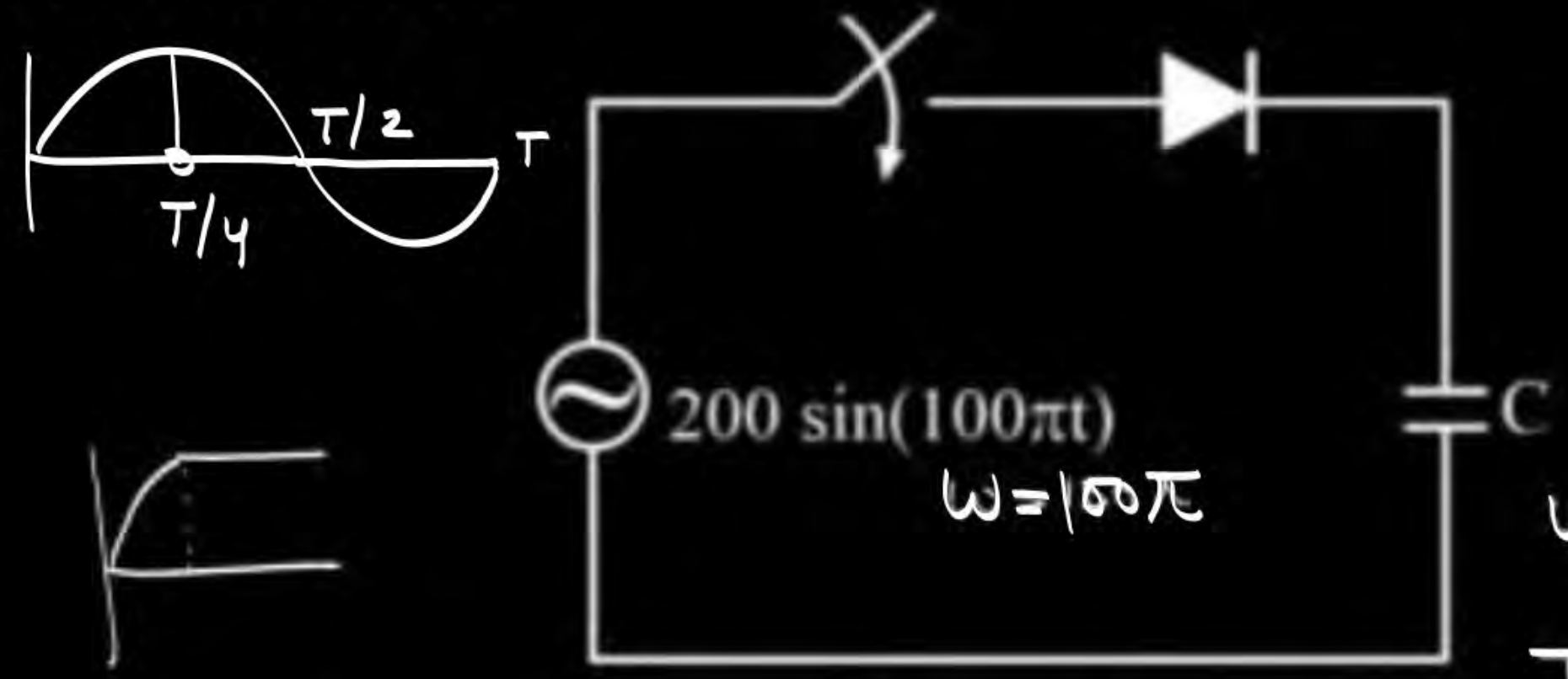
**Q.07** Which of the following type of diode is preferred for inverters and choppers? 

- A** General purpose diodes
- B** Fast recovery diodes ✓
- C** Schottky diodes
- D** Metal-semiconductor diodes

**Q.08** For the circuit shown in figure, if the switch S is closed at  $t = 0$  sec, the diode will conduct for



- A** 15 m sec
- B** 20 m sec
- C** 10 m sec
- D** 5 m sec ✓



diode conduct  $= \frac{T}{4} = \frac{1}{50 \times 4} = \frac{1}{200} = 5 \text{ m sec}$

$$\omega = \frac{2\pi}{T}$$

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{100\pi} = \frac{1}{50}$$

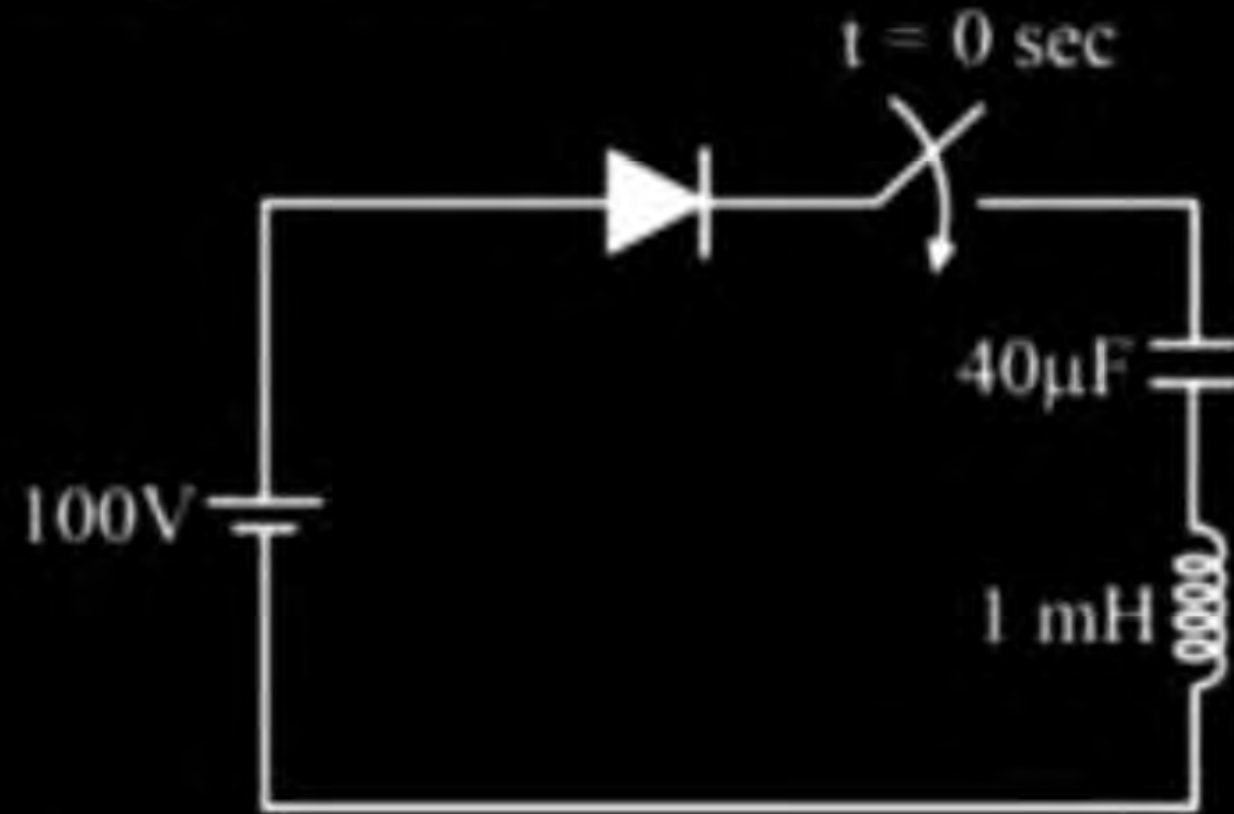
**Q.09** For the circuit shown below, the value of peak current is (Assume the circuit is initially relaxed) 

**A** 80 A

**B** 50 A

**C** 0 A

**D** 20 A ✓



$$i = i_{cp} \sin \omega_0 t$$

$$i_{cp} = V_s \sqrt{\frac{C}{L}}$$

$$= 100 \times \sqrt{\frac{40 \times 10^{-6}}{1 \times 10^{-3}}}$$

$$= 100 \times 20 \times 10^{-2}$$

$$= 20$$

$$i = \frac{V_s}{\omega_0 L} \sin \omega_0 t$$

$$i = V_s \sqrt{\frac{C}{L}} \sin \omega_0 t$$

**Q.10** In the previous question, the frequency of current is



- A** 795.78 Hz ✓
- B** 0 Hz
- C** 5 kHz
- D** 10 kHz

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{1 \times 10^{-3} \times 40 \times 10^{-6}}} = \frac{1}{2\pi\sqrt{40 \times 10^{-9}}}$$

$$= \frac{1}{2\pi\sqrt{4 \times 10^{-8}}} = \frac{1}{2\pi \times 2 \times 10^{-4}}$$

$$= \frac{10^4}{4\pi} = 795.78 \text{ Hz}$$

**Q.11** The most suitable device for high frequency inversion in SMPS is

- A** BJT
- B** IGBT
- C** MOSFET ✓
- D** GTO

**Q.12** Turn-on and turn-off times of transistor depend on

- A** static characteristic
- B** junction capacitances ✓
- C** current gain
- D** None of the above

**Q.13** Consider the following statements about IGBT

1. It has high input impedance ✓ Due to  $\text{SiO}_2$
2. It has low ON state voltage drop. ✓ (conductivity modulation)
3. Its switching speed is higher than that of the MOSFET. ✗
4. It is a voltage-controlled device. ✓  $V_{ge}$

Which of the above statements are correct?

- A** 1, 2 and 3 only
- B** 2, 3 and 4 only
- C** 1, 2 and 4 only ✓
- D** 1, 2, 3 and 4

**Q.14** In a Bipolar Junction Transistor (BJT) due to current flow to small portion of the base, hot spots are produced causing localized excessive heating and damaging the transistor. This switching limit is called

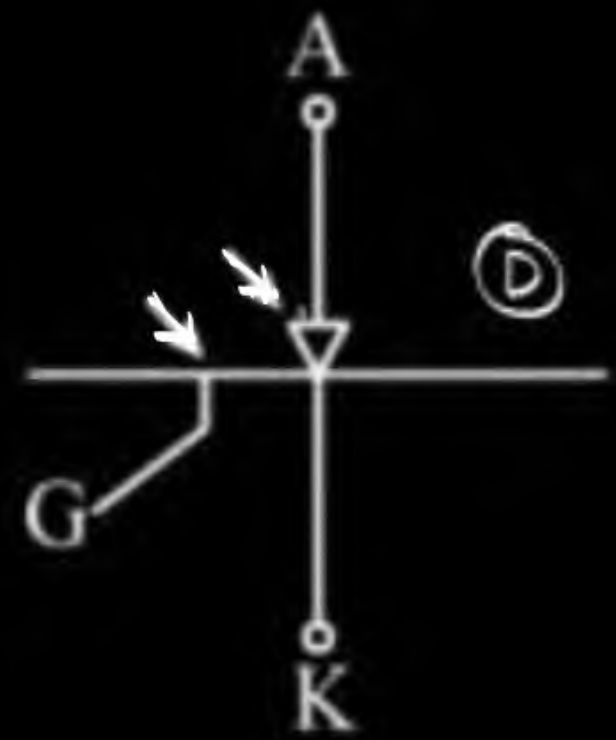
- A** Forward-Biased Safe Operating Area (FBSOA)
- B** Reverse-Biased Safe Operating Area (RBSOA)
- C** Power Derating
- D** Second Breakdown (SB) ✓

**Q.15** Match List-I (Thyristors) with List-II (Symbols) and select the correct answer: 

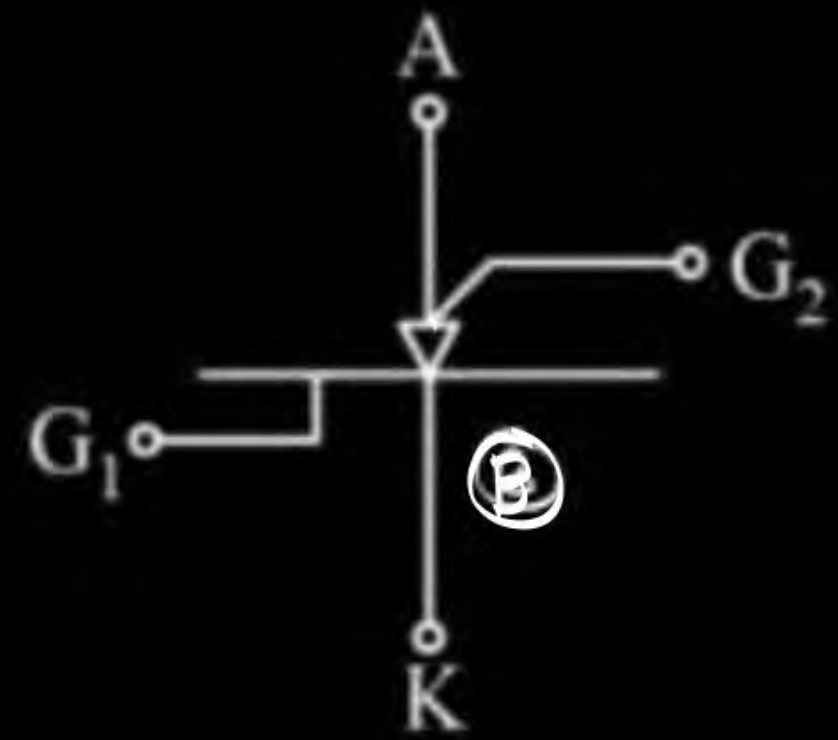
**List-I**

- A. Silicon-controlled rectifier (SCR)
- B. Silicon-controlled switch (SCS)
- C. Silicon-unilateral switch (SUS)
- D. Light-activated SCR (LASCR)

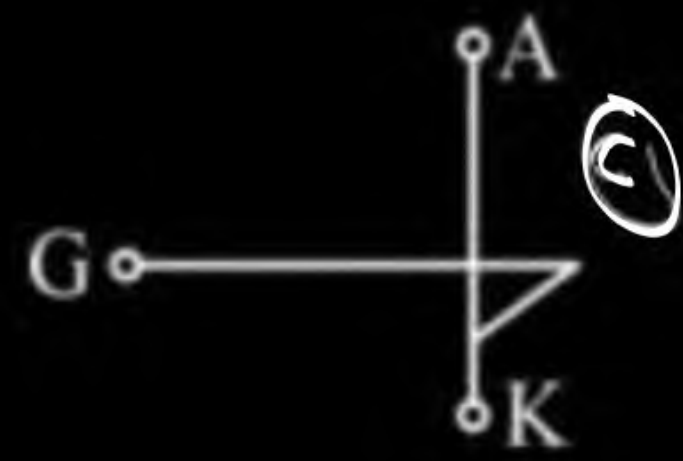
1.



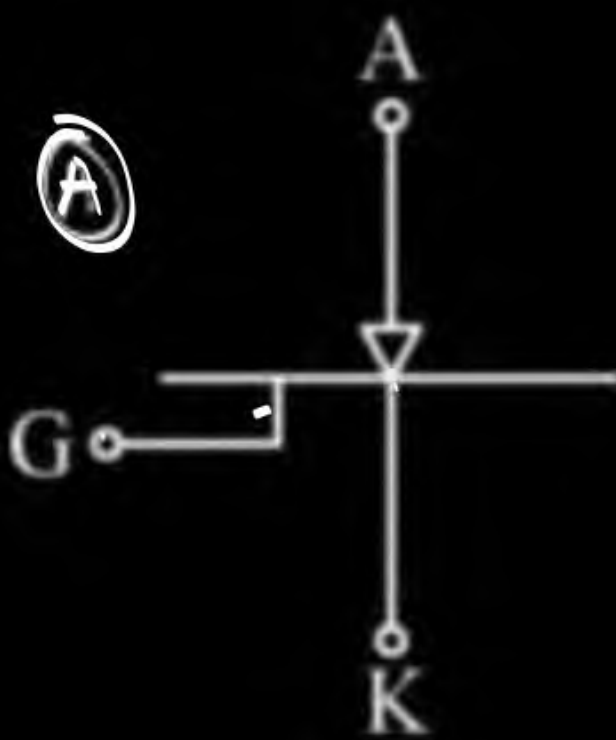
3.



2.



4.



### Codes

|            | A   | B | C | D |
|------------|-----|---|---|---|
| <b>A</b>   | 3   | 4 | 1 | 2 |
| <b>B</b>   | 4   | 3 | 1 | 2 |
| <b>C</b>   | 3   | 4 | 2 | 1 |
| ✓ <b>D</b> | ✓ 4 | 3 | 2 | 1 |

**Q.16**

The IGBT (Insulated GATE Bipolar Transistor) used in the circuit has the following data:  $t_{ON} = 3 \mu s$ ,  $t_{OFF} = 1.2 \mu s$ , Duty cycle (D) = 0.7,  $V_{CE(sat)} = 2V$  and  $f_s = 1 \text{ kHz}$ . What are the switching Power losses during turn-on and turn-off, respectively?



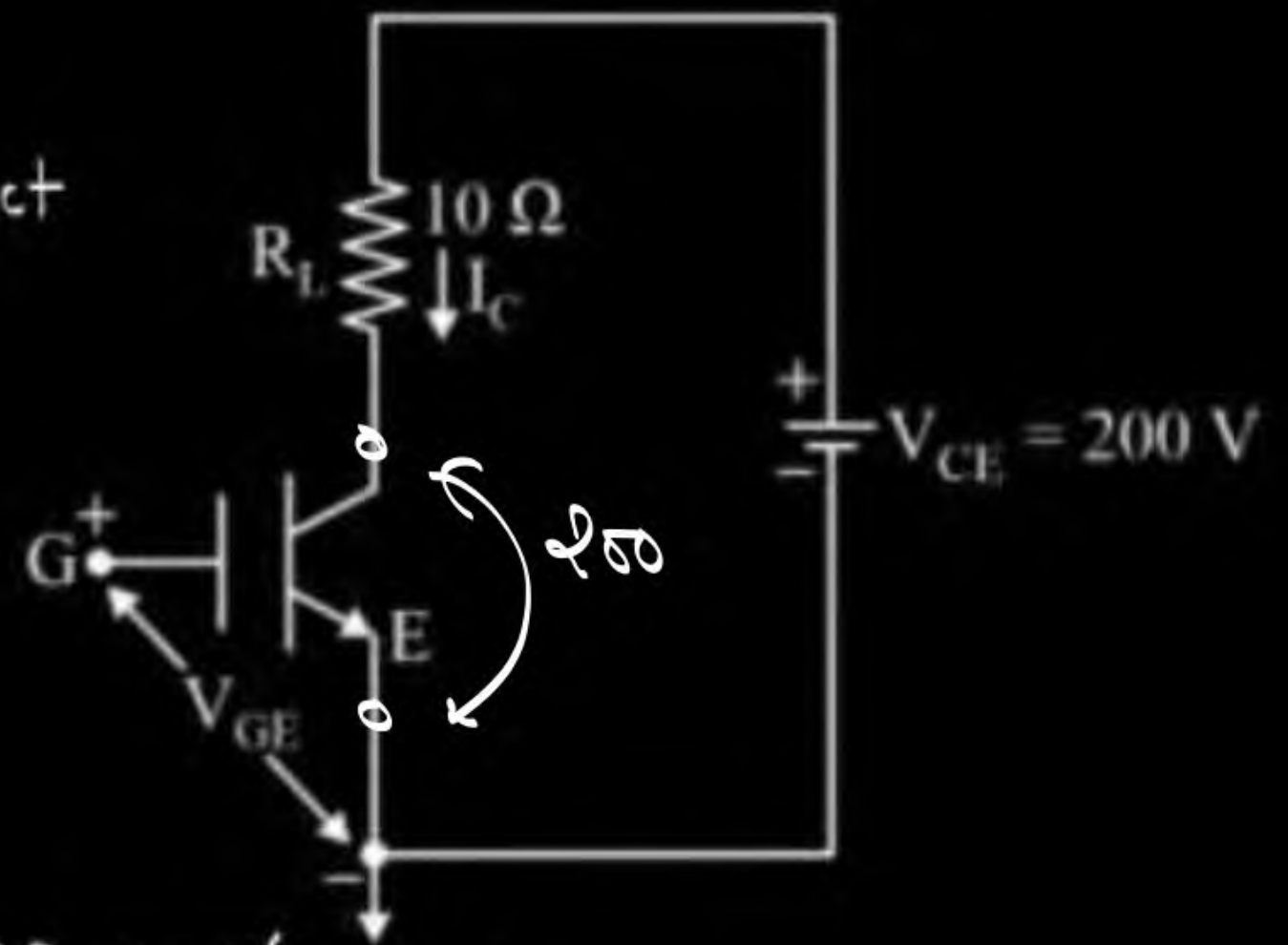
- A** 1.98 W and 1.7 W
- B** 2.2 W and 1.7 W
- C** ✓ 1.98 W and 0.792 W
- D** 2.2 W and 0.792 W

When switch conduct

$$= \frac{250 - 2}{10}$$
$$= 19.8 \text{ A}$$

Switching loss during turn on

$$= \frac{VI}{6} t_{on} f = \frac{250 \times 19.8}{6} \times 3 \times 10^{-6} \times 1 \times 10^3 = 1.98 \text{ W}$$



$$\text{Switching loss during turn off} = \frac{V I_x}{6} \times t_{off} \times f$$

$$= \frac{200 \times 19.8}{6} \times 1.2 \times 10^{-6} \times 1000$$

$$= 0.792 \text{ W}$$

**Q.17**

When cathode of a thyristor is made more positive than its anode



- A** all the junctions are reverse biased
- B** ✓ outer junctions are reverse biased and central one is forward biased
- C** outer junctions are forward biased and central one is reverse biased
- D** all the junctions are forward biased



**Q.18** The sharing of the voltages between thyristors operating in series is influenced by the 

- A**  $di/dt$  capabilities
- B**  $dv/dt$  capabilities
- C** junction temperatures
- D** ✓ static v-i characteristics and leakage currents

**Q.19** R-C snubber is used in parallel with the thyristor to

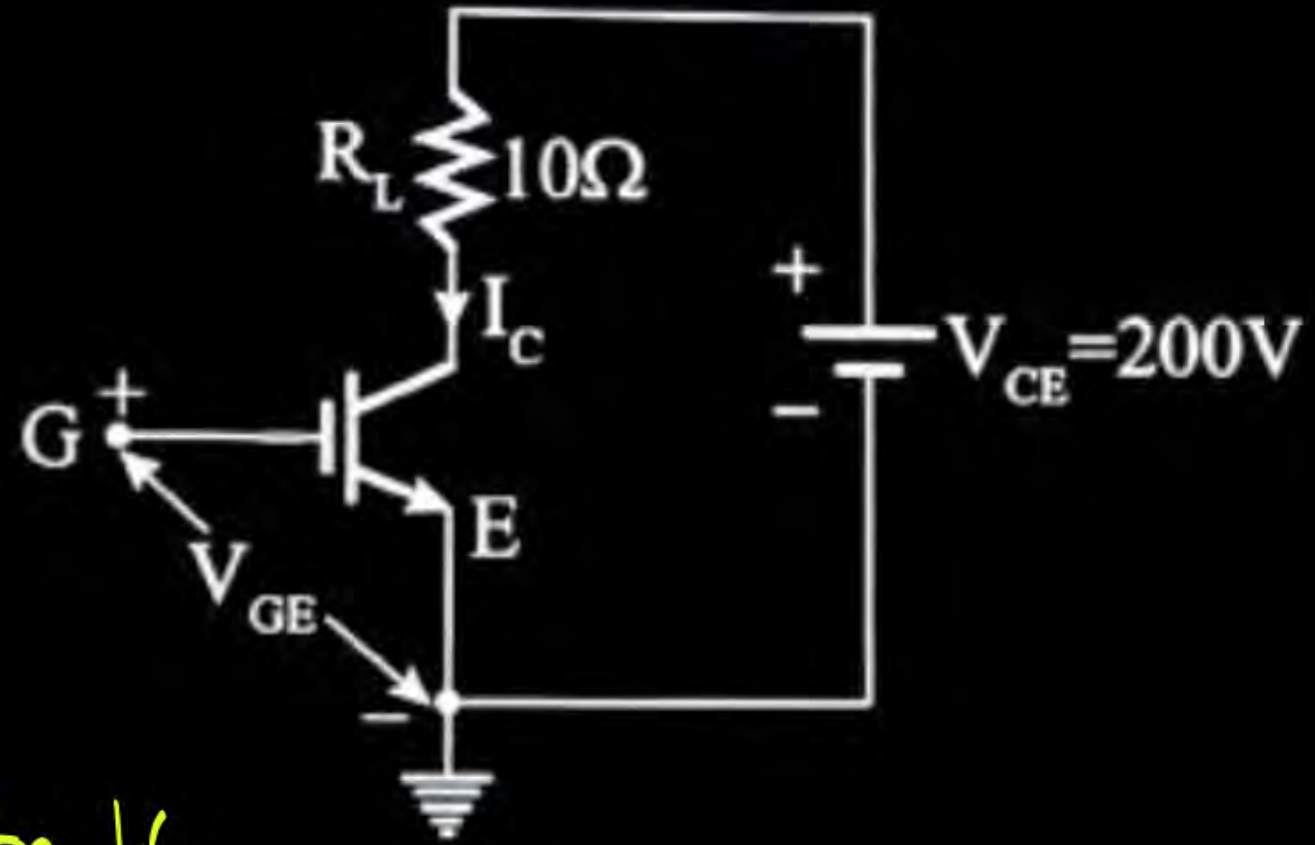
- A** reduce  $dv/dt$  across it ✓
- B** reduce  $di/dt$  through it
- C** limit current through the thyristor
- D** ensure its conduction after gate signal is removed

**Q.20** A Gate Turn Off (GTO) thyristor has capacity to

- A** Amplify the gate-current
- B** Turn-off when positive current pulse is given at the gate
- C** Turn-off when a gate-pulse is given at the gate even though it is reverse biased
- D** Turn-off  when a negative current pulse is given at the gate

**Q.21** The IGBT (Insulated Gate Bipolar Transistor) used in the circuit has the following data:  $t_{ON} = 3 \mu s$ ,  $t_{OFF} = 1.2 \mu s$ , Duty cycle (D) = 0.7,  $V_{CE(sat)} = 2 V$  and  $f_s = 1 kHz$ . What are the switching power losses during turn-on and turn-off, respectively?

- A** 1.98 W and 1.7 W
- B** 2.2 W and 1.7 W
- C** ✓ 1.98 W and 0.792 W
- D** 2.2 W and 0.792 W



∴ Same as Question 16

**Q.22** The  $i_g$ - $v_g$  characteristics of a thyristor is a straight line passing through origin with a gradient of  $2.5 \times 10^3$ . If  $P_g = 0.015$  watt, the value of gate voltage will be nearly

- A** 5.0 V
- B** ✓ 6.1 V
- C** 7.5 V
- D** 8.5 V

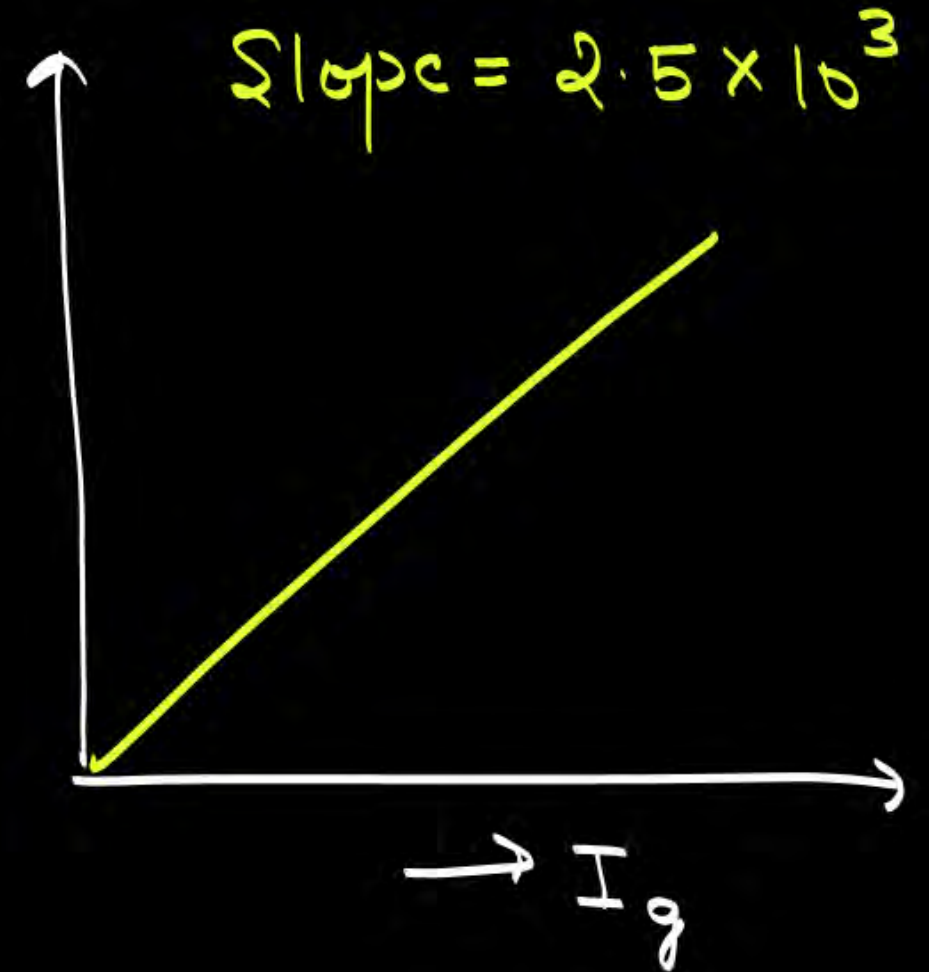
$$\frac{V_g}{I_g} = 2.5 \times 10^3 \Rightarrow I_g = \frac{V_g}{2.5 \times 10^3}$$

$$P_g = V_g I_g = 0.015$$

$$V_g \cdot \frac{V_g}{2.5 \times 10^3} = 0.015$$

$$V_g^2 = 37.5$$

$$V_g = 6.1$$



**Q.23** For an SCR, the gate cathode characteristic has a straight line slope of 140. For trigger source voltage of 20 V and allowable gate power dissipation of 0.5 watts, what is the gate source resistance?

- A** 200  $\Omega$
- B** 255  $\Omega$
- C** 195  $\Omega$
- D** 185  $\Omega$

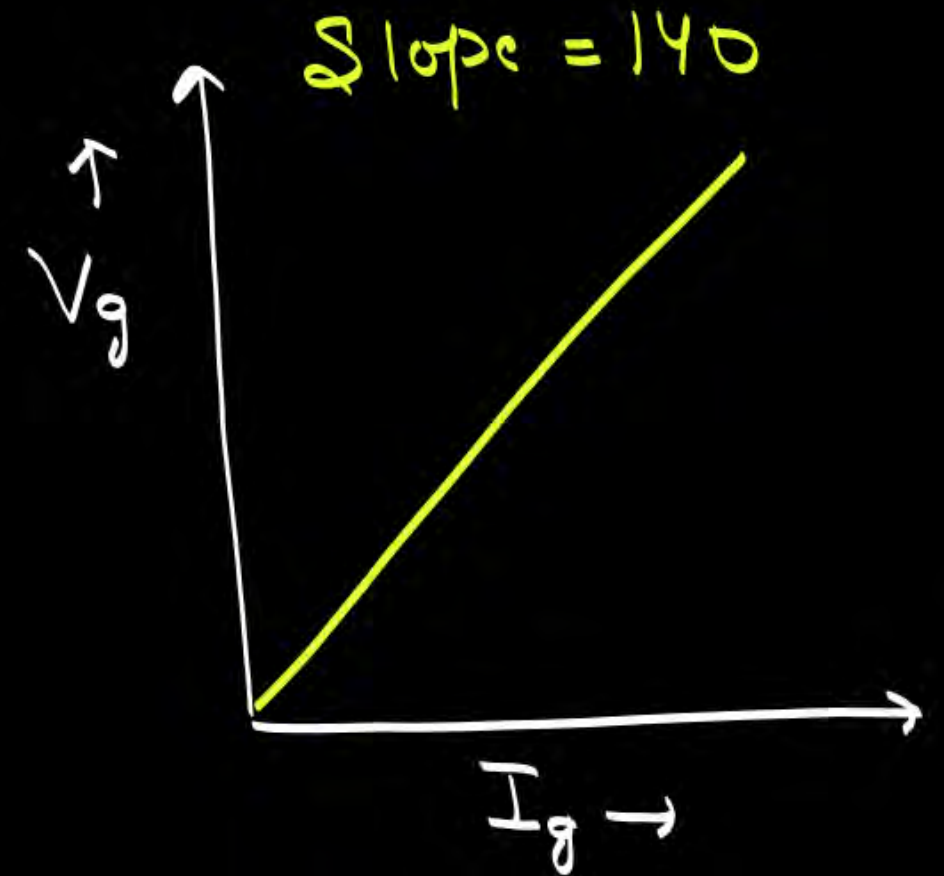
$$\frac{V_g}{I_g} = 140 \Rightarrow V_g = 140 I_g$$

$$P_g = V_g I_g = 0.5$$

$$140 I_g^2 = 0.5$$

$$I_g = 0.0597 \quad - \textcircled{1}$$

$$V_g = 140 I_g = 140 \times 0.0597 = 8.367 \quad - \textcircled{2}$$



$$E_s = V_g + I_g R_s$$

$$20 = 8.367 + (0.0597) R_s$$

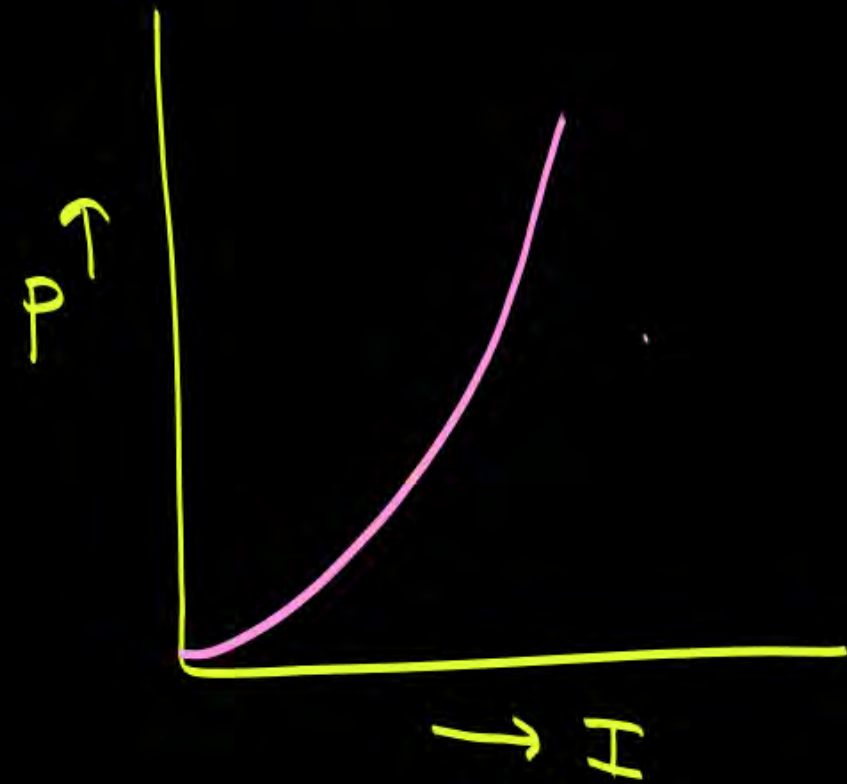
$$R_s = 194.8 \Omega$$

**Q.24** The conduction loss versus device current characteristic of a power MOSFET is best approximated by

- A** a parabola ✓
- B** a straight line
- C** a rectangular hyperbola
- D** an exponentially decaying function

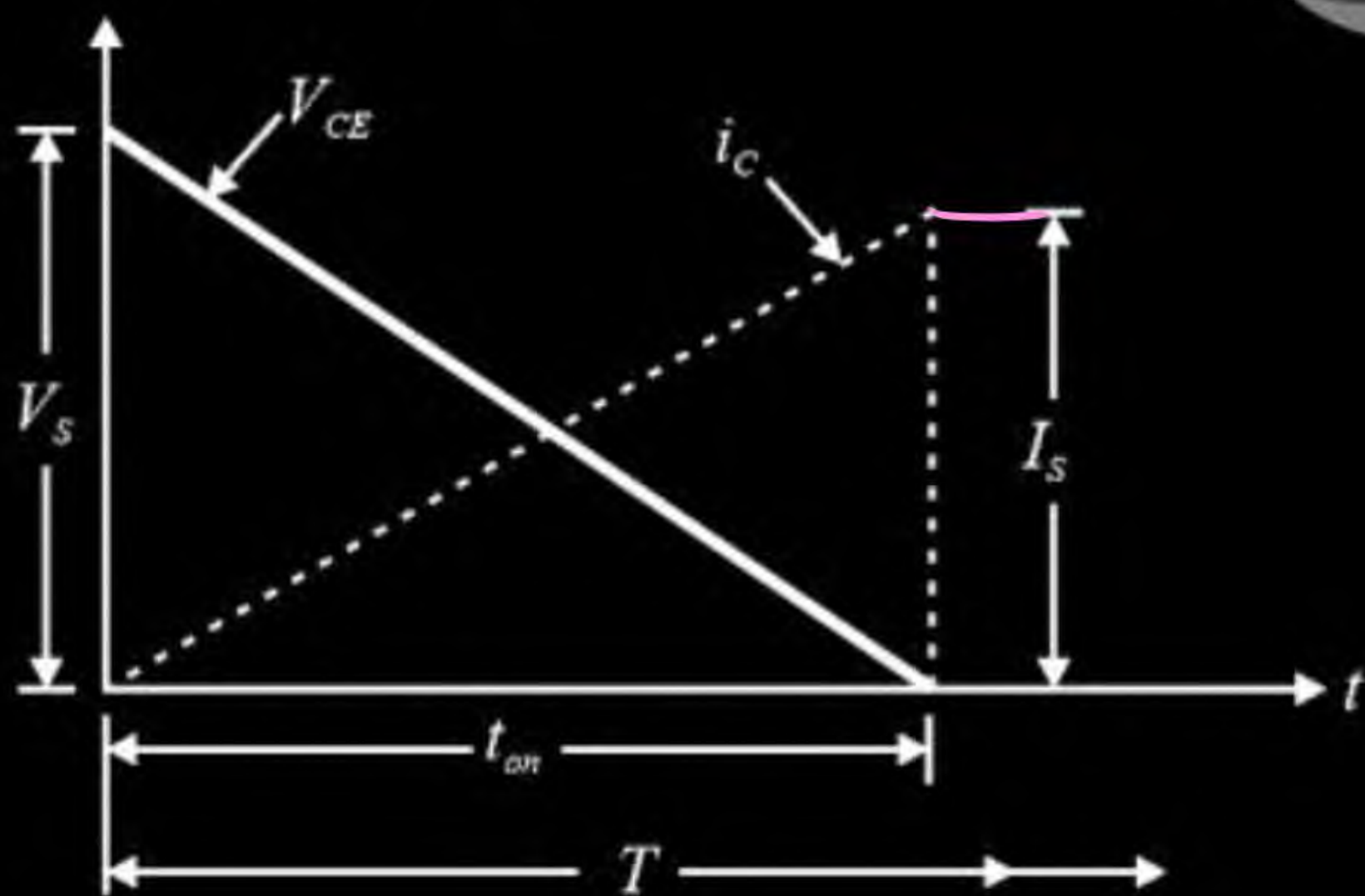
$$P = I^2 R_d$$

$R_d$  (lightly Doped)



**Q.25** For the switching waveform shown in the figure for a power transistor, the peak instantaneous power loss is

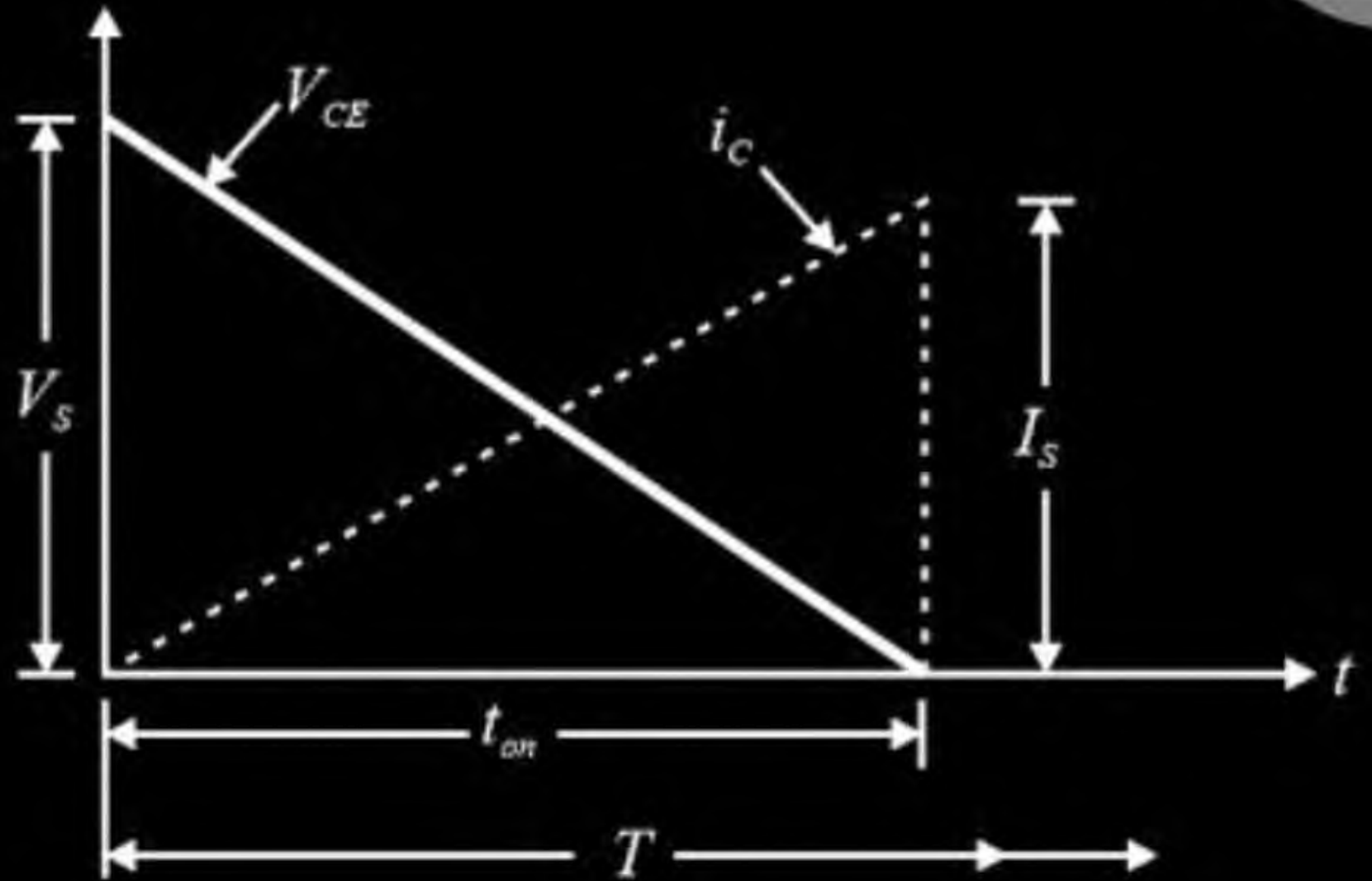
- A**  $\frac{V_s I_s}{4}$  ✓
- B**  $\frac{V_s I_s}{6}$
- C**  $\frac{V_s I_s}{3}$
- D**  $\frac{V_s I_s}{8}$



**Q.26** In the previous question, if  $V_s = 100$  V,  $I_s = 10$  A, then peak instantaneous power loss in watts is

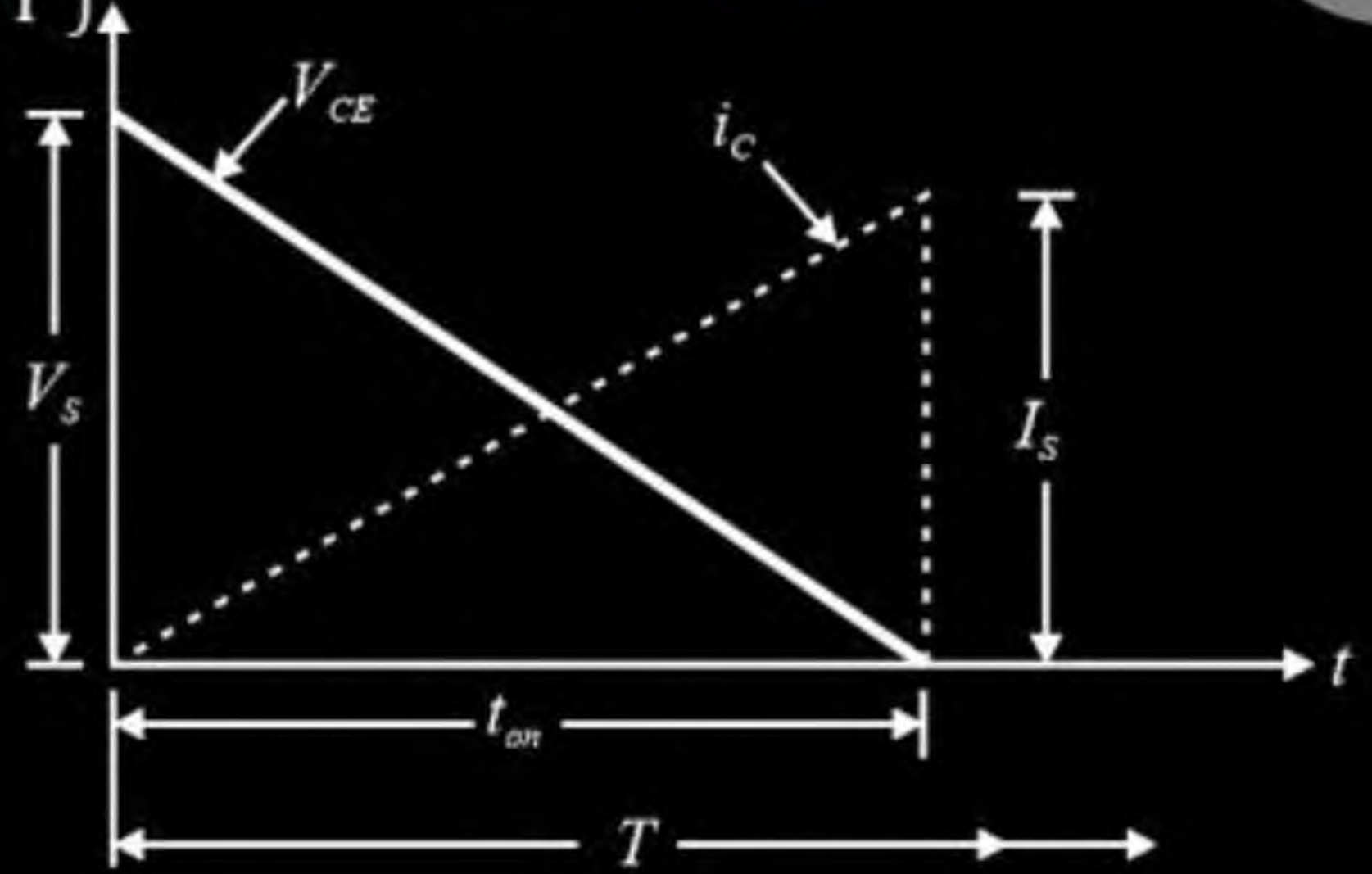
- A** 500
- B** 166.67
- C** 333.33
- D** 250 ✓

$$\begin{aligned}
 P &= \frac{V_s I_s}{4} \\
 &= \frac{100 \times 10}{4} \\
 &= 250 \text{ W}
 \end{aligned}$$



**Q.27** For the switching waveform shown in question 25 for a power transistor, the average value of switch-on power loss at a switching frequency  $f$  is ( $f = 1/T$ )

- A**  $\frac{V_s I_s}{4} \cdot t_{on} \cdot f$
- B** ✓  $\frac{V_s I_s}{6} \cdot t_{on} \cdot f$
- C**  $\frac{V_s I_s}{3} \cdot t_{on} \cdot f$
- D**  $\frac{V_s I_s}{8} \cdot t_{on} \cdot f$



Energy loss during turn on time  $E_{on} = \frac{VI}{6} t_{on}$

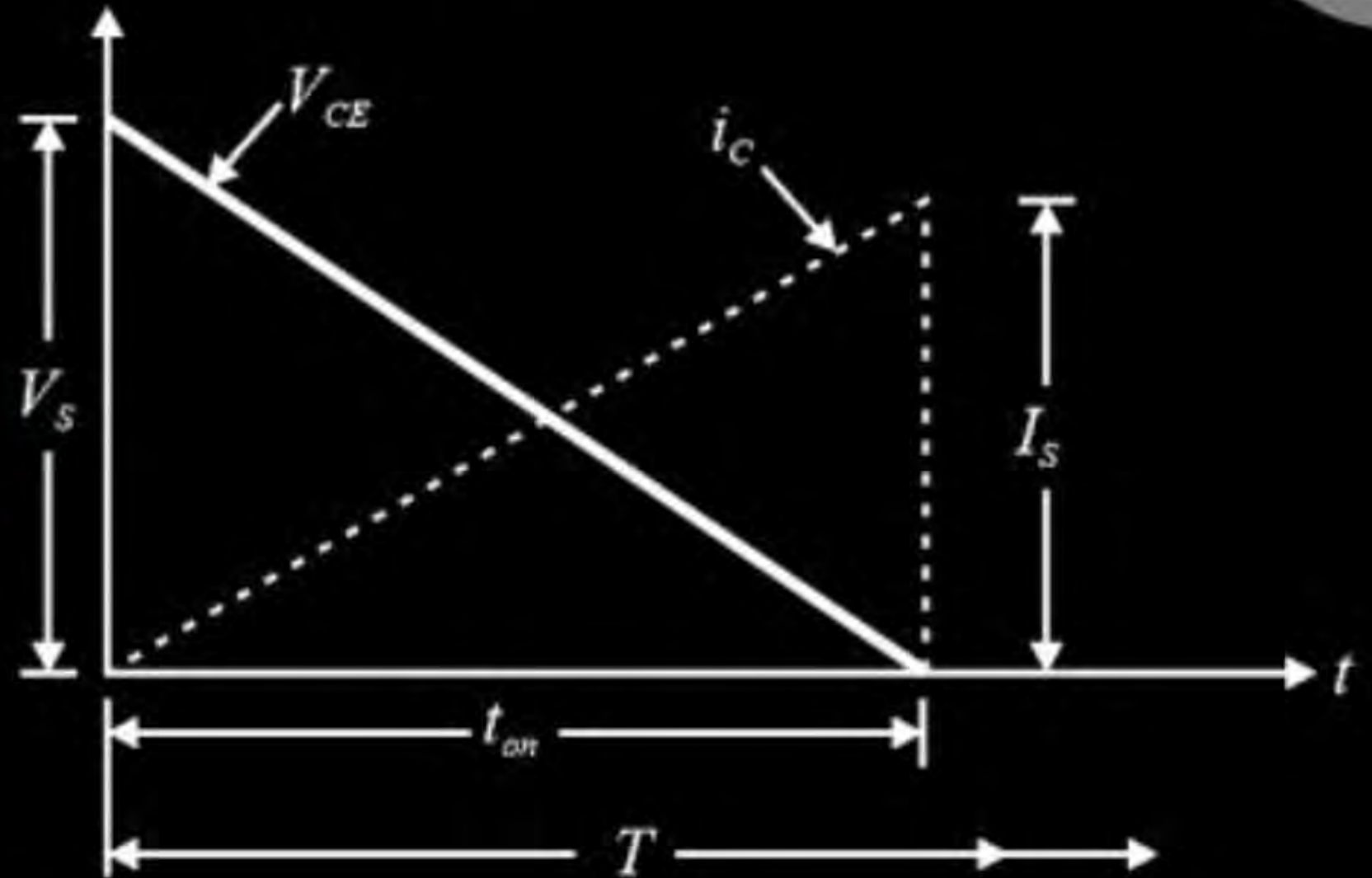
Average power turn on loss  $P = \frac{E_{on}}{T} = E_{on}f$

$$P = \frac{VI}{6} t_{on} f.$$

**Q.28** In question 25, if  $V_s = 100$  V,  $I_s = 10$  A,  $t_{on} = 1.2$   $\mu$ s and  $f = 10$  kHz, then average value of switch-on power loss is

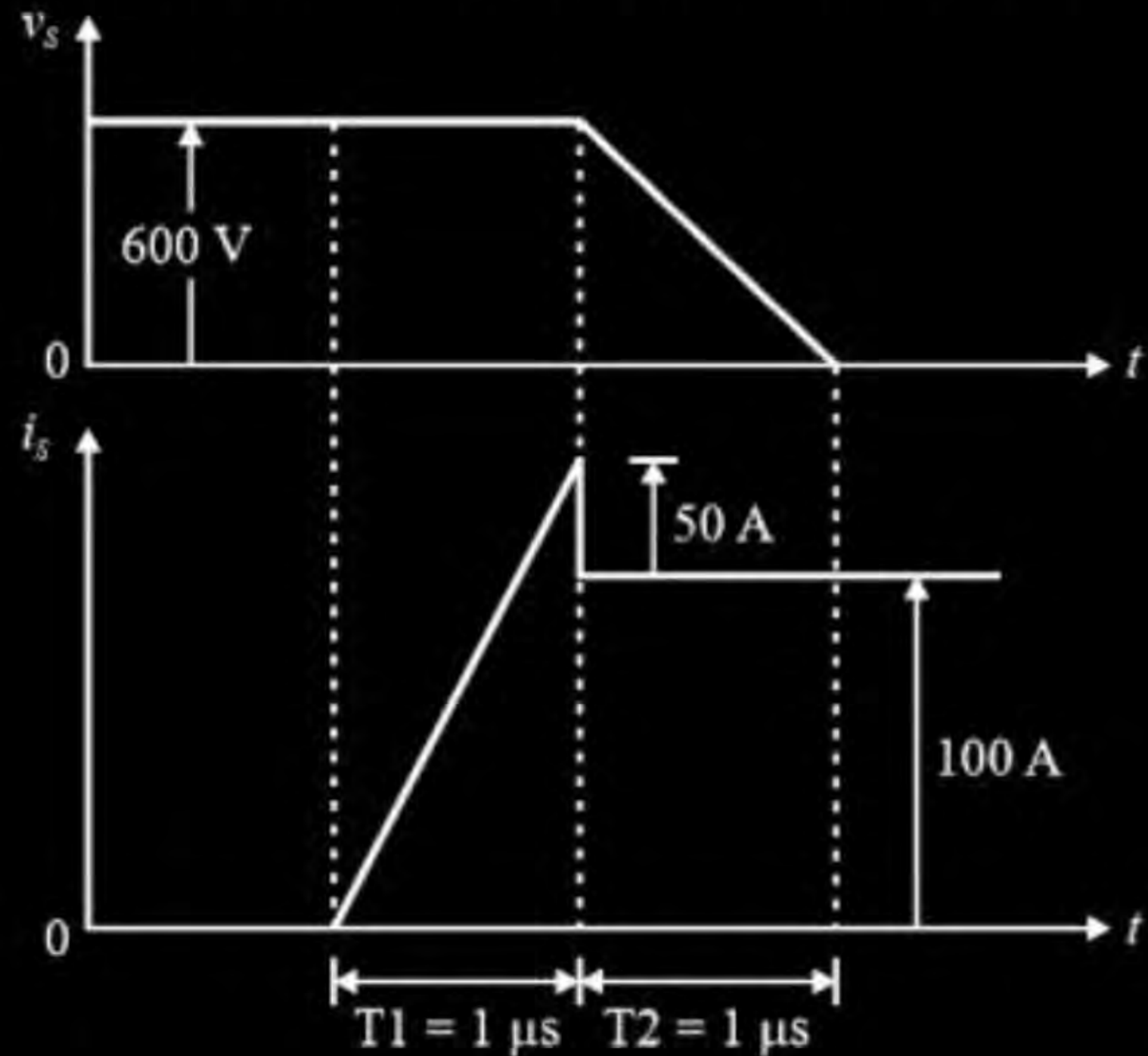
- A** 1 W
- B** 4 W
- C** ✓ 2 W
- D** 3 W

$$\begin{aligned}
 P &= \frac{V_s I_s t_{on}}{6} \\
 &= \frac{100 \times 10 \times 1.2 \times 10^{-6} \times 10 \times 10^3}{6} \\
 &= 2 \text{ W}
 \end{aligned}$$



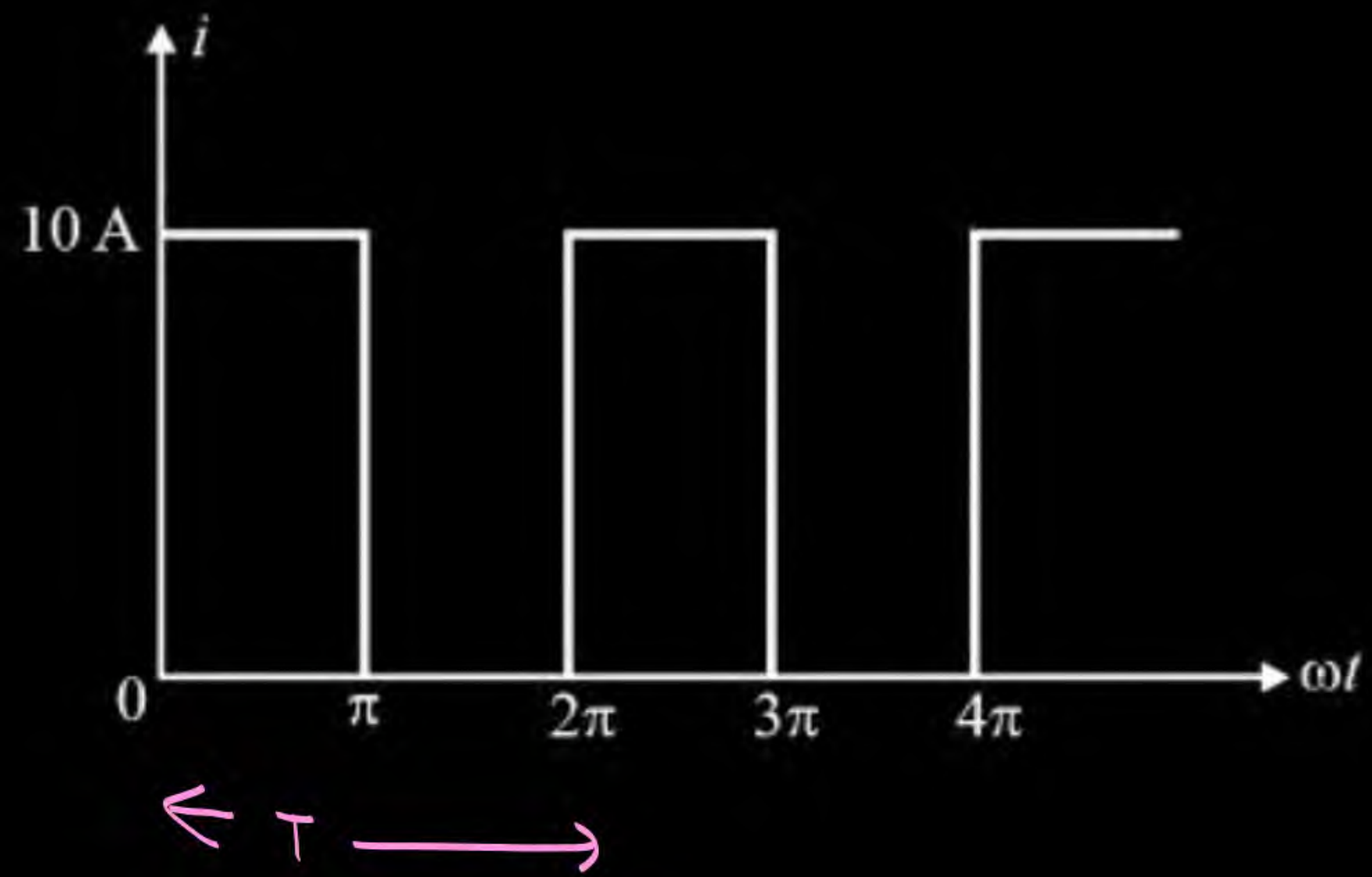
**Q.29** The voltage ( $v_s$ ) across and the current ( $i_s$ ) through a semiconductor switch during a turn-ON transition are shown in the figure given below. The energy dissipated during the turn-ON transition, in mJ, is..7.5

Question solve in class.



**Q.30** A MOSFET rated for 15 A, carries a periodic current as shown in the figure given below. The on-state resistance of the MOSFET is 0.15 ohm. What is the average on-state loss in the MOSFET ?

- A** 3.75 W
- B** 7.5 W ✓
- C** 15.0 W
- D** 30 W



$$P_{av} = I_{rms}^2 R$$

$$= \left( \frac{10}{\sqrt{2}} \right)^2 \times 0.15$$

$$P_{av} = 7.5 \text{ W}$$

$$I_{rms} = 10 \times \sqrt{\frac{\pi}{2\pi}} = \frac{10}{\sqrt{2}}$$