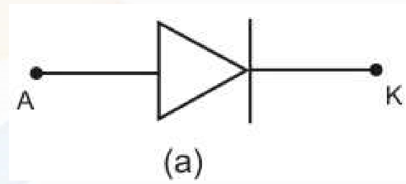
School of Electrical, Electronics and Communication Engineering

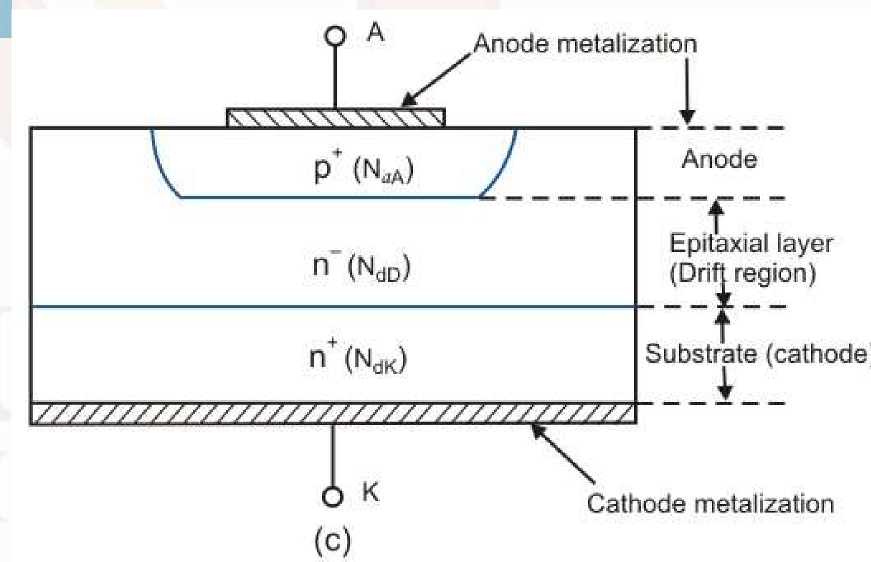
Course Code : BTEE3011 Course Name: Power Electronics

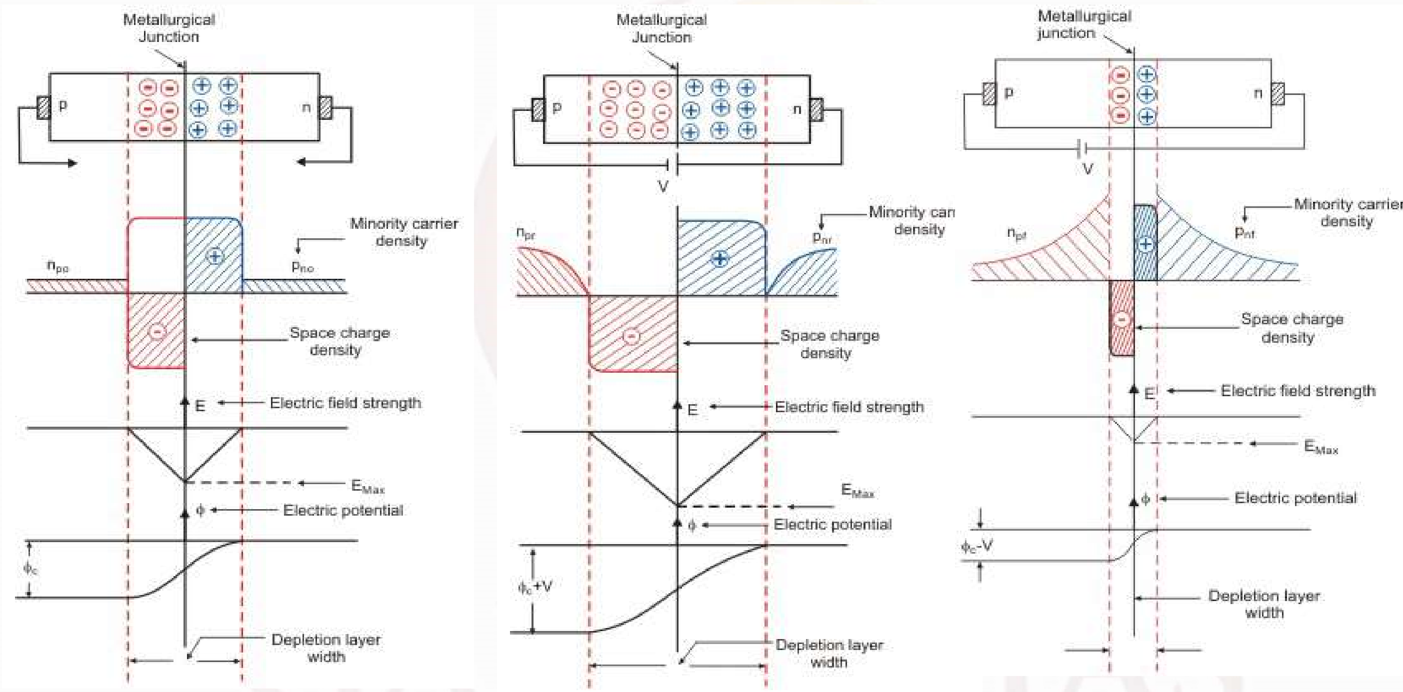
Power Diode

Name of the Faculty: Saravanan D Program Name: B.Tech-EE/EEE


DIODE


A
K
(a)


A
Anode metalization
p^+ (N_{aA})
Anode
n^- (N_{dD})
Epitaxial layer
(Drift region)
n^+ (N_{dK})
Substrate (cathode)
K
Cathode metalization
(c)



Space change density the electric field and the electric potential in side a p-n junction under (a) thermal equilibrium condition, (b) reverse biased condition, (c) forward biased condition.

Basic structure of Power Diode:

- Power diode consists of three layers. Top layer is a heavily doped P^+ layer. Middle layer is lightly doped n^- layer and the last layer is a heavily doped n^+ layer.

- The heavily doped p^+ layer act as an anode. The thickness of this layer is around 10 μm and doping level is 10^{19} cm^{-3}.

- Last layer of the heavily doped n^+ act as a cathode. The thickness of this layer is around 250 to 300 μm and doping level is 10^{19} cm^{-3}.

- Middle layer of lightly doped n^- is known as a drift layer. The thickness of the drift layer depends on the required breakdown voltage. The breakdown voltage increases with an increase in the width of the drift layer. Resistivity of this layer is high because of the low level of doping.

- The doping level of the drift layer is 10^{14} cm^{-3}. The junction is form between the anode layer (p^+) and drift layer (n^-).

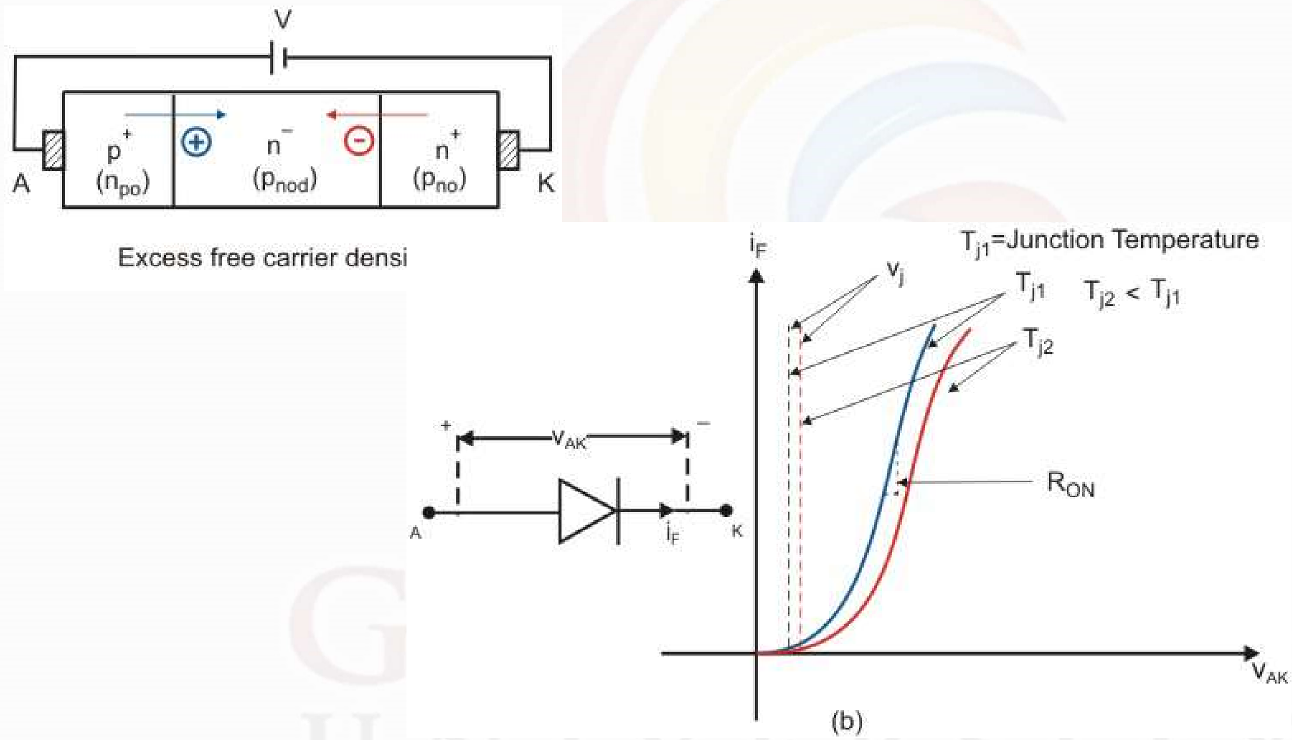
- The cross-section area of the diode depends on the magnitude of current to be handled. Higher the current to handle, more the area required.

Operating Principle of Power diode:

➢The operating principle of power diode is same as the conventional PN junction diode. A diode conducts when the anode voltage is higher than the cathode voltage.

➢The forward voltage drop across the diode is very low around 0.5V to 1.2V. In this region, the diode works as a forward characteristic.

➢If the cathode voltage is higher than the anode voltage, then the diode works as blocking mode. In this mode, diode works according to the reverse characteristic.



Characteristics of a forward biased power Diode; (a) Excess free carrier density distribution; (b) i-v characteristics.

I-V characteristic of Power Diode:

- The I-V characteristic of power diode is as shown in the figure. The forward current increase linearly with an increase in forward voltage.

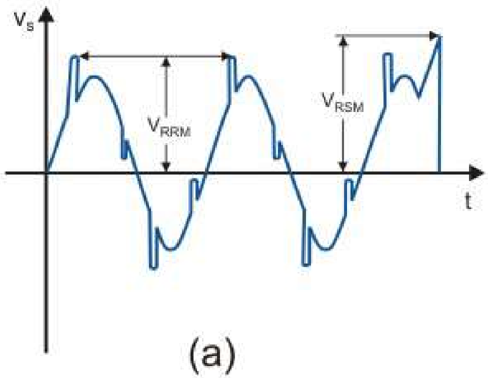
- A very small amount of leakage current flows in the reverse bias (blocking mode). The leakage current is independent of the applied reverse voltage. The leakage current flows due to the minority charge carriers.

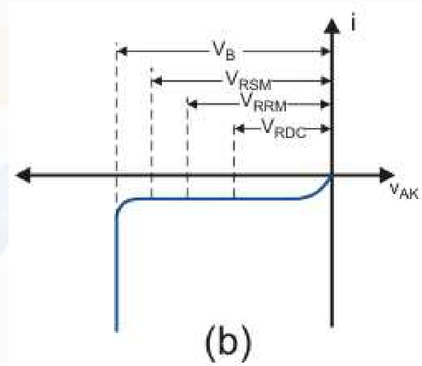
- When the reverse voltage reaches the reverse breakdown voltage, avalanche breakdown occurs. Once the reverse breakdown occurs, the reverse current increase drastically with small increase in reverse voltage. The reverse current can control by an external circuit.

A few other important specifications of a power Diode under reverse bias condition usually found in manufacturer's data sheet are explained below.

DC Blocking Voltage (V^{RDC}): Maximum direct voltage that can be applied in the reverse direction (i.e cathode positive with respect to anode) across the device for indefinite period of time. It is useful for selecting free-wheeling diodes in DC-DC Choppers and DC-AC voltage source inverter circuits.

RMS Reverse Voltage (V^{RMS}): It is the RMS value of the power frequency (50/60 HZ) since wave voltage that can be directly applied across the device. Useful for selecting diodes for controlled / uncontrolled power frequency line commutated AC to DC rectifiers. It is given by the manufacturer under the assumption that the supply voltage may rise by 10% at the most. This rating is different for resistive and capacitive loads.





Reverse Voltage ratings of a power diode; (a) Supply voltage wave form; (b) Reverse i-v characteristics

Peak Repetitive Reverse Voltage (V^{RRM}): This is the maximum permissible value of the instantiations reverse voltage appearing periodically across the device. The time period between two consecutive appearances is assumed to be equal to half the power cycle (i.e 10ms for 50 HZ supply). This type of period reverse voltage may appear due to "commutation" in a converter.

Peak Non-Repetitive Reverse Voltage (V^{RSM}): It is the maximum allowable value of the instantaneous reverse voltage across the device that must not recur. Such transient reverse voltage can be generated by power line switching (i.e circuit Breaker opening / closing) or lightning surges.

- The lightly doped drift region will offer high resistance during forward conduction.
- However, the effective resistance of this region in the ON state is much less than the apparent ohmic resistance calculated on the basis of the geometric size and the thermal equilibrium carrier densities.
- As the metallurgical p+ n- junction becomes forward biased there will be injection of excess p type carrier into the n- side.
- At low level of injections all excess p type carriers recombine with n type carriers in the n- drift region.
- However at high level of injection (i.e large forward current density) the excess p type carrier density distribution reaches the n- n+ junction and attracts electron from the n+ cathode.
- This leads to electron injection into the drift region across the n- n+ junction with carrier densities $\delta n = \delta p$. This mechanism is called "double injection"

The voltage dropt across a forward conducting power diode has two components i.e

$$V_{ak} = V_j + V_{RD}$$

Where V_j is the drop across the p^+n^- junction and can be calculated from the above equation for a given forward current j_F. The component V_{RD} is due to ohmic drop mostly in the drift region. Detailed calculation shows

$$V_{RD} \infty J_F W_D$$

Where J_F is the forword current density in the diode and W_D is the width of the drift region. Therefore

$$V_{ak} = V_j + R_{on} I_F$$

The ohmic drop makes the forward i-v characteristic of a power diode more linear.

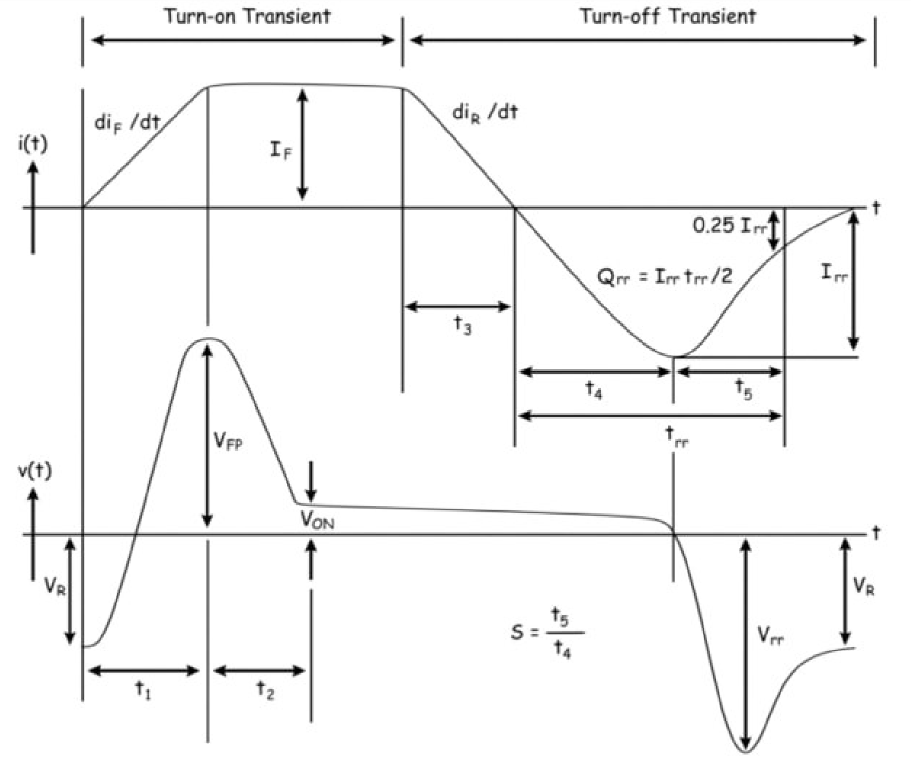
Few other important specifications related to forward bias operation of power diode as found in manufacturer's data sheet.

➢Maximum RMS Forward current (IFRMS): Due to predominantly resistive nature of the forward voltage drop across a forward biased power diode, RMS value of the forward current determines the conduction power loss.

➢Maximum Average Forward Current (IFAVM): Diodes are often used in rectifier circuits supplying a DC (average) current to be load.

➢Average Forward Power loss (PAVF): Almost all power loss in a diode occurs during forward conduction state.

Switching characteristic is the dynamic characteristic which shows the variation of the diode current or voltage with respect to the time. A power diode takes finite time to change its state from **ON (conduction-state)** to **OFF (blocking-state)** and vice-versa.



Switching Characteristics is divided into two regions

- Turn-on Transient
- Turn-off Transient (i.e. the Reverse Recovery Characteristics)

Turn-on transient spans over time periods t_1 and t_2 and two processes occur during these periods

During t_1: space-charge stored in the depletion region due to the reverse biasing is removed because the diode is now forward biased.

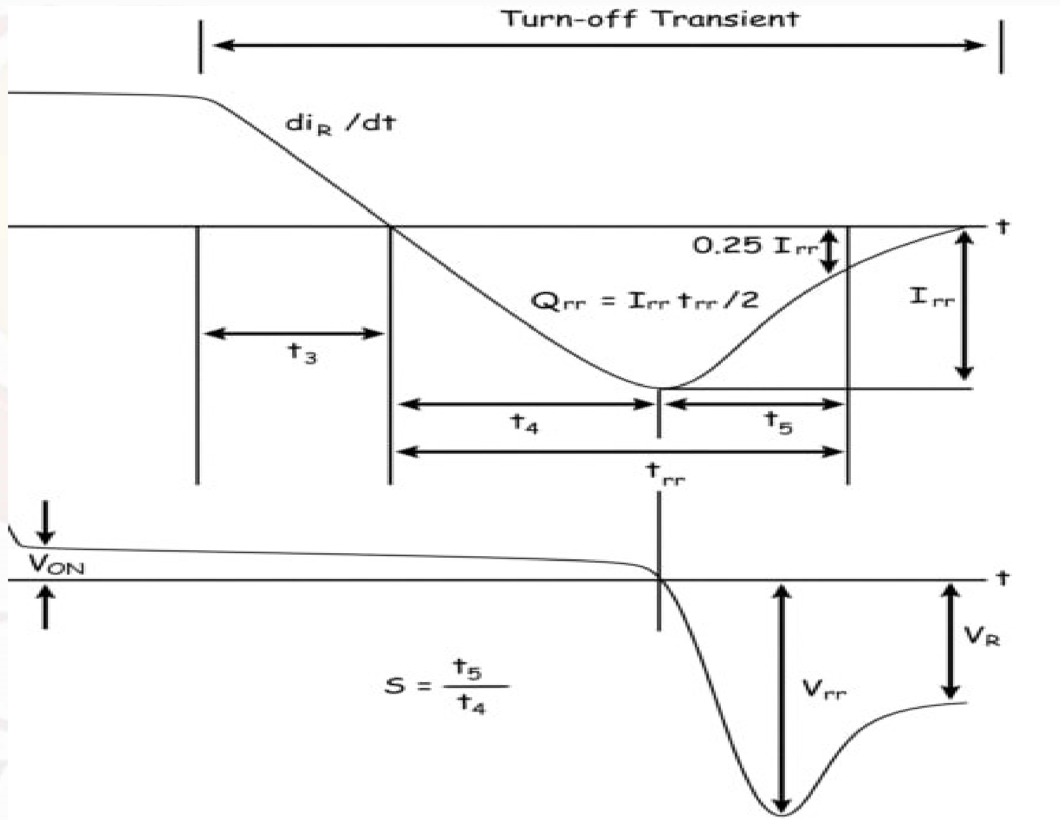
During t_2: the forward biased diode causes the injection of the excess carriers into the drift region actually *double injection* takes place.

During the Reversed Biased condition, the stored charge exists in the depletion region hence the region acts like a capacitor. Hence, even if the Diode is abruptly forward biased, the **voltage** across the diode increases smoothly because of the capacitance of the Space-charge region and current starts to increase **see the waveform during t_1.**

Forward turn ON time i.e. $t_{on} = t_1 + t_2$.

Turn OFF Transient / Reverse Recovery Characteristics

It is the transient condition obtained when the Diode enters the Reverse biased state (i.e. the Off-state) from the Forward Biased state (i.e. the On-state). It is exactly the reverse process of Turn ON transient. Turn-off characteristic is also known as Reverse Recovery Characteristics.



1. After the time period t_3, the reverse current begins to flow.
2. As the stored excess carriers from the Drift Region decreases, ohmic resistance 'R' of Drift Region increases which causes V_{ON} to decrease quickly after t_3.
3. Reverse current increases to its maximum when all charges in the depletion region flow out represented by I_{rr} as shown in the figure. After maximum reverse current at the end of t_4, when very few excess charge carriers are left then reverse current decreases and the depletion region increases, Voltage across the diode attains negative value when depletion region expands further (flow of Reverse current in the negative direction causes the negative voltage drop).

The Terminology used in Reverse Recovery Characteristics

1.t_4 : Time is taken by the reverse recovery current to become maximum I_{rr}.
2.t_5 : Time is taken by the reverse recovery current to decreases to 25% of I_{rr} from the maximum value I_{rr}.
3.$S = t_5 / t_4$, where S = snappiness or softness factor
4.Reverse Recovery Time t_{rr} : Total time taken by the reverse recovery current to reach 25% of the maximum value i.e. I_{rr}. It is denoted by t_{rr}. From the above figure,
5.Reverse Recovery Charge Q_{RR} : Amount of charge carriers that flow across the diode during the flow of reverse current. The area enclosed by Reverse Recovery current (from thefigure)

$$Q_{rr} = \frac{1}{2} I_{rr} t_4 + \frac{1}{2} I_{rr} t_5 \Rightarrow Q_{rr} = \frac{1}{2} I_{rr} t_{rr} \quad \cdots (i)$$

Derivation for the reverse recovery time (t_{rr}) and reverse recovery current (I_{rr})

From the above waveform;

$$t_{rr} = \sqrt{\frac{2Q_{rr}}{\frac{di}{dt}}} \cdots (iv)$$

From equation (i) we get,

$$I_{rr} = \sqrt{2Q_{rr} \cdot \frac{di}{dt}} \cdots (v)$$

Hence,

If snappiness 'S' is neglected i.e. S = 0

Which implies $t_5 << t_4$ (from $S = t_5 / t_4$) which then leads to $t_{rr} = t_4$.

Substituting the value of $t_4 = t_{rr}$ in equation (iii) gives

From equation (ii) and (iv), we get

Conclusion

- T_{rr} and I_{rr} both depend on Q_{rr}.
- And Q_{rr} is dependent on I_F therefore everything depends on max forward current.