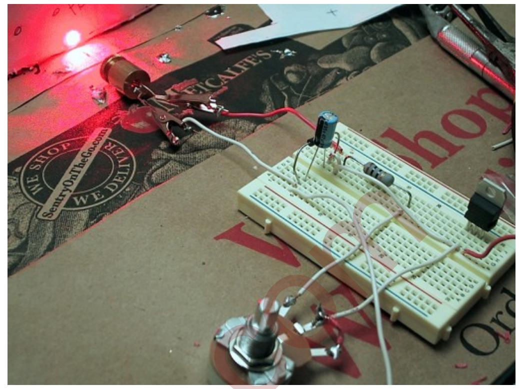
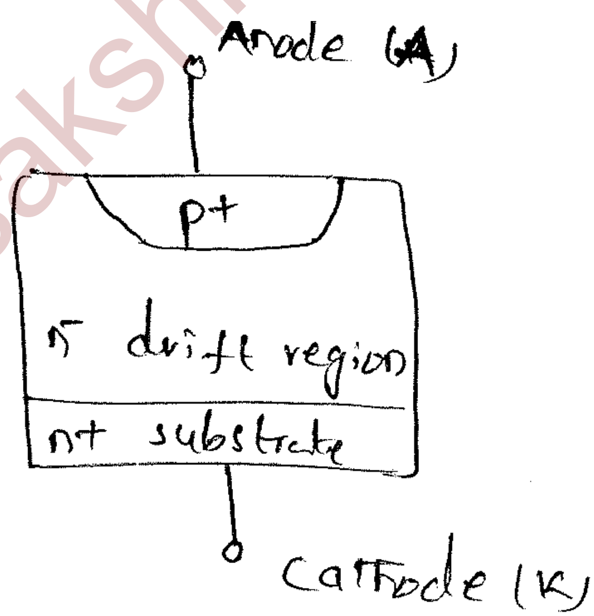
Power Diodes



- Power semiconductor diodes are similar to low power p-n junction diodes, called signal diodes similarly, power transistors are identical with npn or pnp signal transistors.
- Power diodes are uncontrolled devices because the ON and OFF states decided by nature of the supply.
- Anode and cathode are the main terminals to decide the ON and OFF states of the device. Hence it is uncontrolled device.
- Power semiconductor devices are more complex in structure and in operation than their low power counterparts. This complexity arises because low power devices must be modified in order to make them suitable for high-power applications.
- For example, power diodes are constructual with n^- layer, called drift region, between p^+ layer (anode) and n^+ layer or substrate (cathode). This is done to support large blocking voltages. This n^- layer, however not present in signal diode.

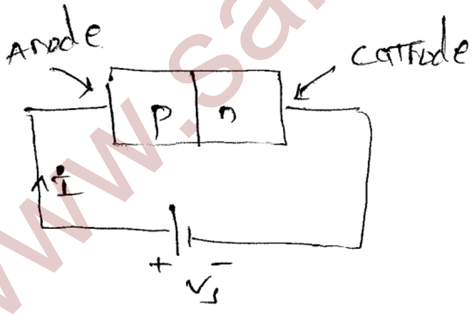
Structure of power diode:



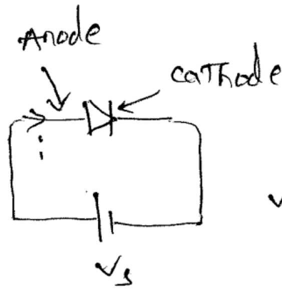
V-I characteristics:

Power diode is a two-layer, two terminal, p-n semiconductor device. It has one pn-junction formed by alloying, diffusing or epitarial growth. The two terminals of diode are called anode and cathode.

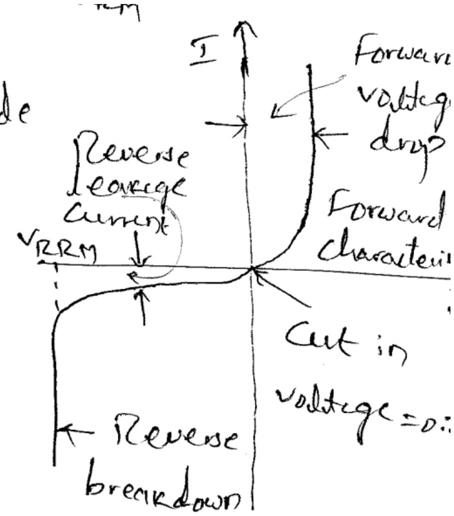
- When diode is positive with respect to cathode, diode is said to be forward biased with increase of source voltage vs from zero value, initially current value is zero. From Vs=0 to cut in voltage the forward diode current is very small. Cut in voltage is also known as threshold voltage or turn on voltage.
- Beyond cut in voltage, the diode current rises rapidly and the diode is said to be conduct. For silicon diode, the cut in voltage is around 0.7v, when diode conducts there is a forward voltage drop of the order of 0.8 to 1v.
- When cathode is positive with respect to anode, the diode is said to be reverse biased.
- In the reverse biased condition of the diode a small reverse current, called leakage current of the order of micoamperes or milliamperes (for large diodes) flows.
- The leakage current increases slowly with the reverse voltage until breakdown or avalanche voltage is reached. At this breakdown voltage, diode is turned on in the reverse direction. If the current in the reverse direction is not limited by a series resistance, the current becomes quite high to destroy the diode.
- The reverse avalanche breakdown of a diode is avoided by operating the diode below specified peak reverse voltage V_{RRM}



(a)



(b)



(c)

Fig: (a) p-n Junction (b) diode symbol (c) V-I ch. of di

- PIV: PIV is the largest reverse voltage to which a diode may be subjected during its working. PIV is the same as V_{RRM}.
- The power diodes are now available with forward current ratings of 1A to several thousands amperes and with reverse voltage ratings of 50V to 3000V or more.

Diode Reverse Recovery Characteristics:

- After the forward diode current decays to zero, the diode continues to conduct in the reverse direction because of the presence of stored charges in the two layers. The reverse current flows for a time called 'reverse recovery time t_{rr}'. The diode regain its blocking capability until reverse recovery current decays to zero.
- The reverse recovery time t_{rr} is defined as the time between the instant forward diode current becomes zero and the instant reverse recovery current decays to 25% of its reverse value I_{RR} as shown in figure.
- The reverse recovery time is composed of two segments of time t_a and t_b i.e, $t_{rr} = t_a + t_b$
- Time t_a is the time between zero crossing of forward current and peak reverse current $I_{RM.}$
- During the time t_a, charge stored in depletion region is removed.

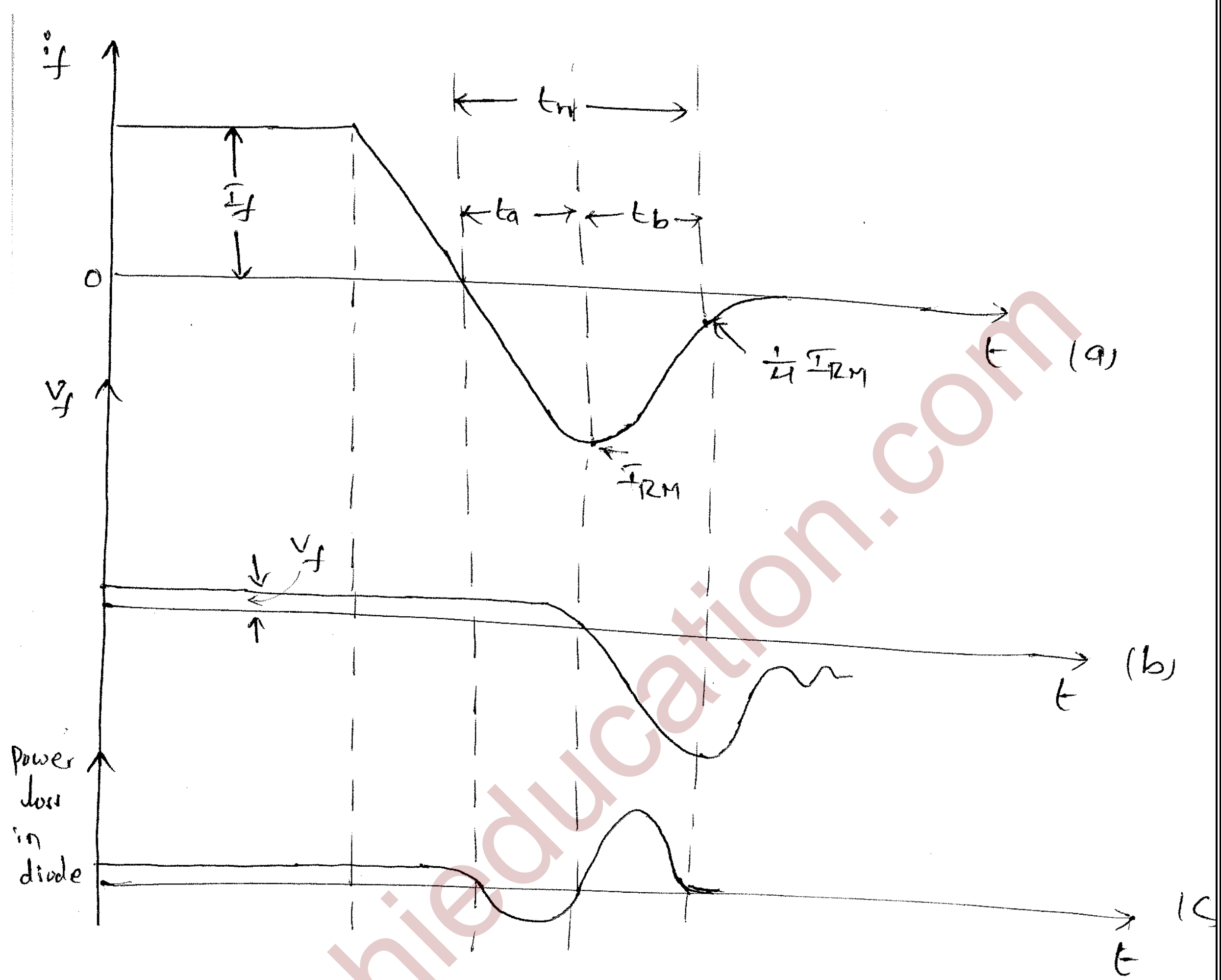


Fig: Reverse recovery characteristics a) variation of forward current if b) forward drop v_f and c) power loss in a diode

- The time t_b is measured from the instant of I_{RM} to the instant where 0.25 I_{RM} is reached. During the change from the two semiconductor layers is removed.
- The shaded area in big represents the stored charge or reverse recovery charge Q_R which must be removed during the reverse recovery time t_{rr}.
- The ratio t_b/ t_a is called the 'softness factor' or s-factor. This is a measure of the voltage transients that occur during the time diode recovers.
- Its used value is unity and this indicates low oscillatory over voltages.
- A diode with s-factor eqaul to one is called soft recovery diode and a diode with a s-factor less than one is called snappy recovery diode or fast recovery diode.
- Peak inverse current I_{RM} can be expressed as

  $I_{RM} = t_a \, di/dt$ ------1

- di/dt is the rate of change of reverse current.

  storage charge Q_R, is given by

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

  $$I_{RM} = \frac{2Q_R}{t_{rr}} \text{ --------2}$$

  If $t_a \approx t_b$, then from eqn 1

  $$I_{RM} = t_{rr}\frac{di}{dt} \text{ --------3}$$

  From eqns 2 and 3, we get

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

  $$t_{rr} = \left[\frac{2Q_R}{(\frac{di}{dt})}\right]^{\frac{1}{2}} \text{ ----------4}$$

  From 1, with $t_a \approx t_{rr}$, we get

  $$I_{RM} = t_{rr}.\ di/dt = \left[\frac{2Q_R}{(\frac{di}{dt})}\right]^{\frac{1}{2}}.\ di/dt$$

- Switching frequency of the diode depends on the reverse recovery time of the diode (t_{rr}).
- Lesser the 't_{rr}' higher switching frequency of the diode.

General Purpose Diode:

- Reverse recovery time t_{rr} is about 25µsec.
- 1A to several thousands of Amperes, 50V to 5KV.
- Bipolar device.
- Applications: Charging batteries, low frequency appliances.

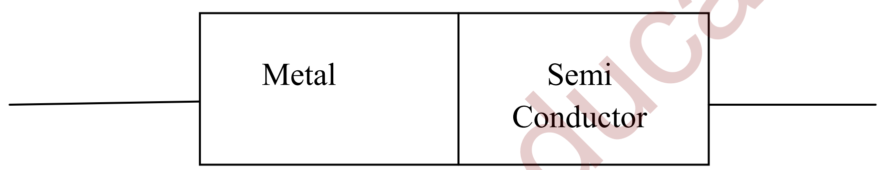
Fast Recovery Diode:

- Reverse recovery time t_{rr} is about 5µsec.
- 1A to several thousands of Amperes, 50V to 3KV.
- The inner layers are doped with gold/ platinum.
- By adding gold/ platinum it reduces the life time of the charge carriers then t_{rr} decreases and f_s increases. (Minority carriers are responsible for high t_{rr}).
- It is a bipolar device.

- If voltage rating < 400V epitaxial process for fabrication of the diode.
- If V> 400V diffusion process is used for fabrication of the diode.
- Fast rectifier diodes are found in strobe applications that require high surge resistance as well as in the industrial, commercial and automotive sectors. High voltage resistance fast rectifier diodes, which are ideal for use in switching power supplies of all types, feature fast switching speeds along with improved efficiency and reduced loss. Fast rectifiers are also used in PDPs (sustain circuits) and PFC circuits. Also, detectors of radio signals serve as rectifiers.

Schottky Diode:

- t_{rr} is in Nanoseconds.
- 1A to 300A and limited to 100V.
- It is metal to semiconductor junction diodes.

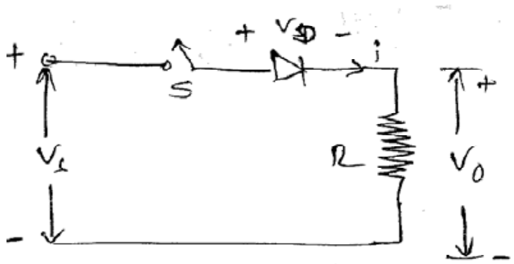


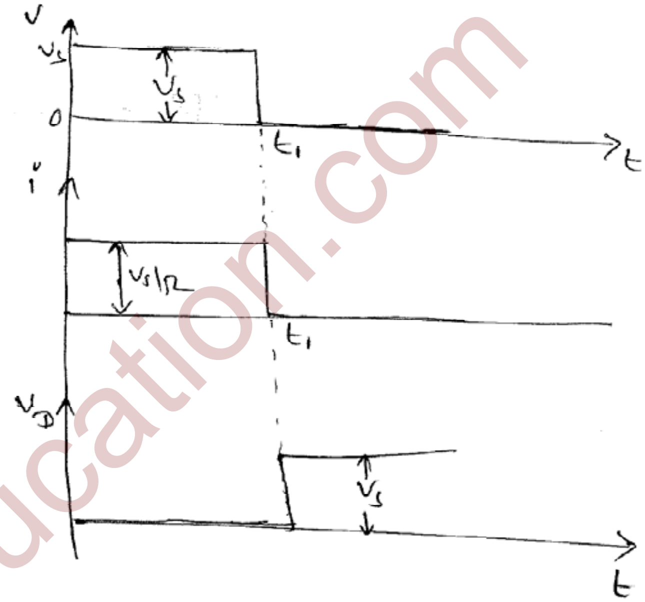
- Conduction is due to only majority carriers (due to absence of minority carriers which are responsible for increase of t_{rr}). The t_{rr} is almost reduced in this case.
- It is a unipolar device.
- Applications: SMPS, high frequency instrumentation.
- Disadvantages: Power rating is less.

Diode circuits:

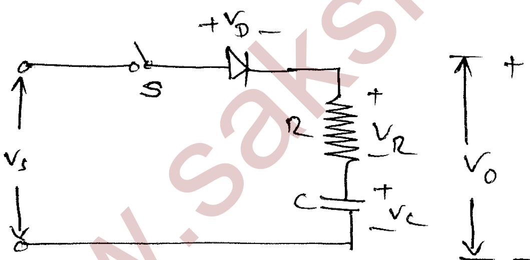
Diode circuits with DC source:

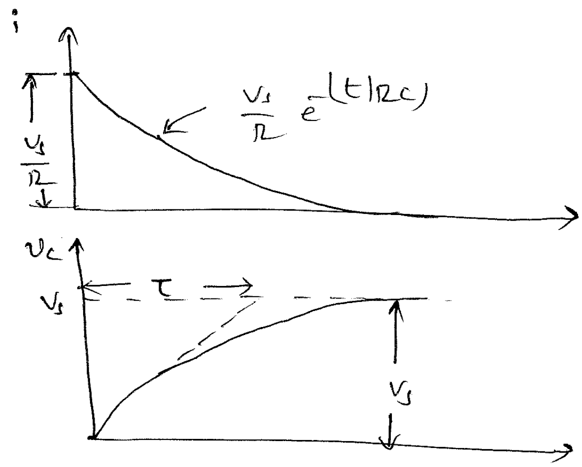
(i) Resistive Load:





(ii) RC Load:





When switch s is closed at t=0 KVL gives

$$Ri + \frac{1}{C}\int i\,dt = V_s$$

Its Laplace transform is

$$RI(s) + \frac{1}{C}\left[\frac{I(s)}{s} + \frac{q(0)}{s}\right] = \frac{V_s}{s}$$

As the initial volatge across C is zero, q(0)=0

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

$$I(s) = \left[\frac{CV_s}{RC\left(s + \frac{1}{RC}\right)}\right] = \frac{V_s}{R} \times \frac{1}{s + \frac{1}{RC}}$$

Its Laplace inverse is

$$i(t) = \frac{V_s}{R}\, e^{-\frac{t}{RC}}$$

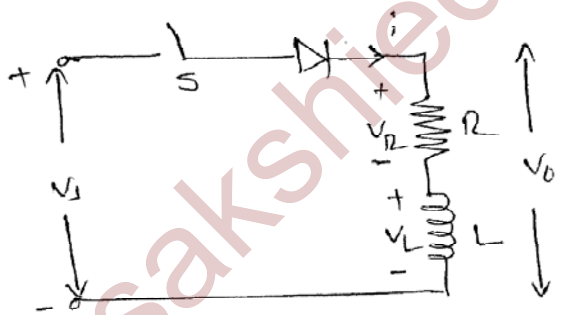
The voltage across capacitor is

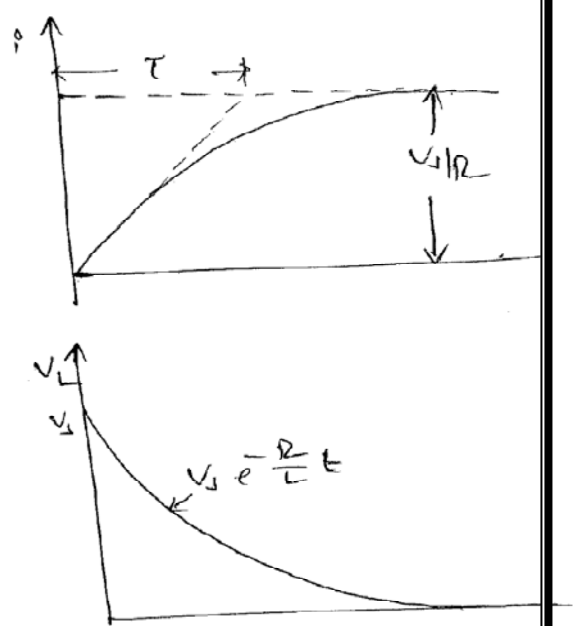
$$v_c(t) = \frac{1}{C}\int_0^t i(t)\, dt = \frac{V_s}{RC}\int_0^t e^{-\frac{t}{RC}}$$

$$= V_s\left(1 - e^{-\frac{t}{RC}}\right)$$

$$v_c(t) = V_s\left(1 - e^{-\frac{t}{\tau}}\right)$$

(iii) RL Load:





when switch s is closed at t=0 in the RL load, KVL gives

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

with initial current in the inductor as zero

$$i(t) = \frac{V_s}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

initial rate of rise of current is

$$\frac{di}{dt}\Big|_{t=0} = \left[\frac{V_s}{L}.e^{-\frac{R}{L}t}\right]_{t=0} = \frac{V_s}{L}$$

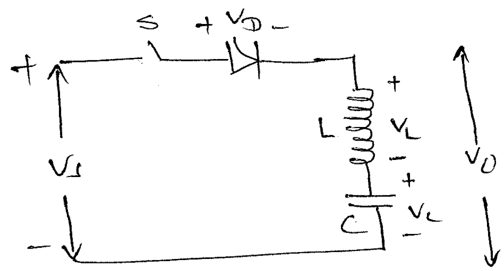
the voltage across L is

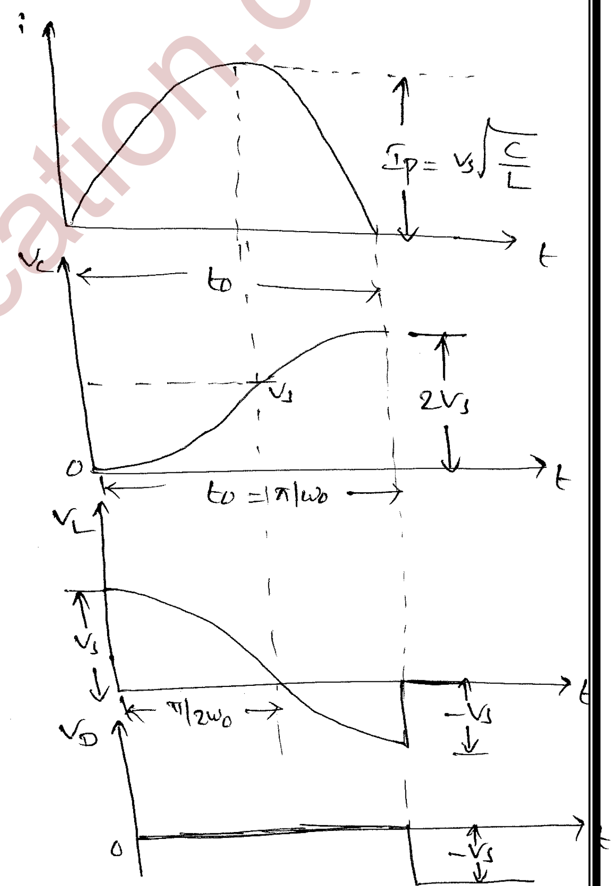
$$v_L(t) = L\frac{di}{dt} = V_s.e^{-\frac{R}{L}t}$$

$$v_L(t) = V_s.e^{-\frac{R}{L}t}$$

As AS

(iv) LC Load:-





when switch S is closed at t=0,

$$L\frac{di}{dt} + \frac{1}{C}\int i\,dt = V_s \quad \text{---(1)}$$

Its Laplace transform is

$$L\left[sI(s) - i(0)\right] + \frac{1}{C}\left[\frac{I(s)}{s} + \frac{q(0)}{s}\right] = \frac{V_s}{s} \quad \text{---(2)}$$

As the circuit is initially relaxed i(0)=0 and $V_c(0)$=0 (or) q(0)=c, $V_c(0)$=0

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

$$I(s) = \frac{V_s}{L}.\frac{1}{s^2 + \frac{1}{LC}} ------(3)$$

Let $w_o = \frac{1}{\sqrt{LC}}$, this gives, $I(s) = \frac{V_s}{Lw_o} \cdot \frac{w_o}{s^2+w_o}$

$$= V_s . \sqrt{\frac{C}{L}} . \frac{w_o}{s^2 + w_0^2}$$

Its Laplace transform is $i(t) = V_s . \sqrt{\frac{C}{L}} sinw_o t - - - - - - (4)$

Here $w_o = \sqrt{\frac{1}{LC}}$ is called resonant frequency of the circuit. Capacotor voltage is given by

$$v_c(t) = \frac{1}{C}\int_0^t i(t)\, dt = \frac{1}{C}\int_0^t V_s . \sqrt{\frac{C}{L}} sinw_o t$$

$$= V_s(1 - cosw_o t) - - - - - (5)$$

voltage across inductor is given by

$$v_L(t) = L\frac{di(t)}{dt} = V\ cosw_o t - - - - (6)$$

when $w_0 t_0 = \pi$ or when $t_0 = \pi / w_0$

from eqn. (4) $i(t_0) = 0$ and from eqn. (5) $v_c(t) = 2V_s$ and $v_L(t_0) = -V_s$

Here $t_0 = \frac{\pi}{w_o} = conduction\ time\ of\ diode = \pi\sqrt{LC}$

from eqn. (4) circuit or diode current at $\frac{t_0}{2} = \frac{\pi}{2w_o}$ attains a peak value of $I_p = V_s . \sqrt{\frac{C}{L}}$ as shown in fig (b). Voltage across diode, soon after diode stops conduction at t_0 is given by

$V_D = -V_L - V_C + V_s = 0 - 2V_s + V_s = - V_s$