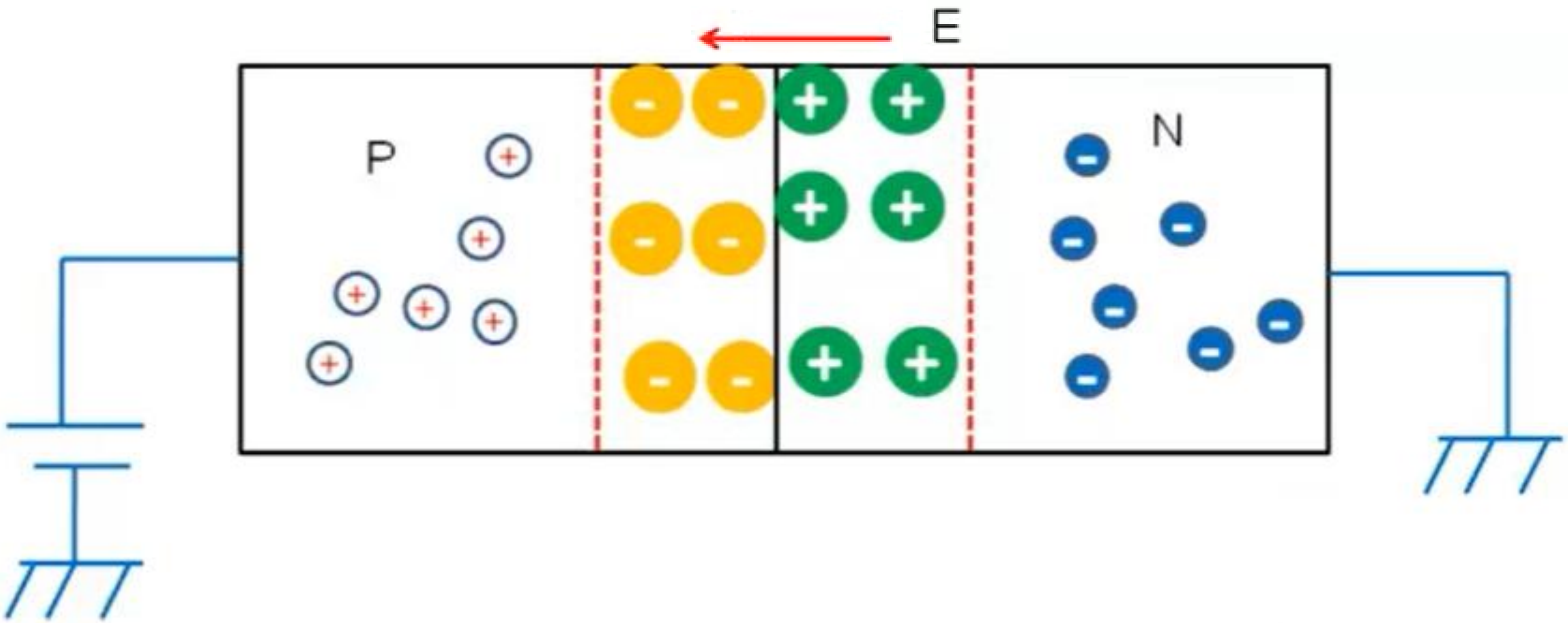
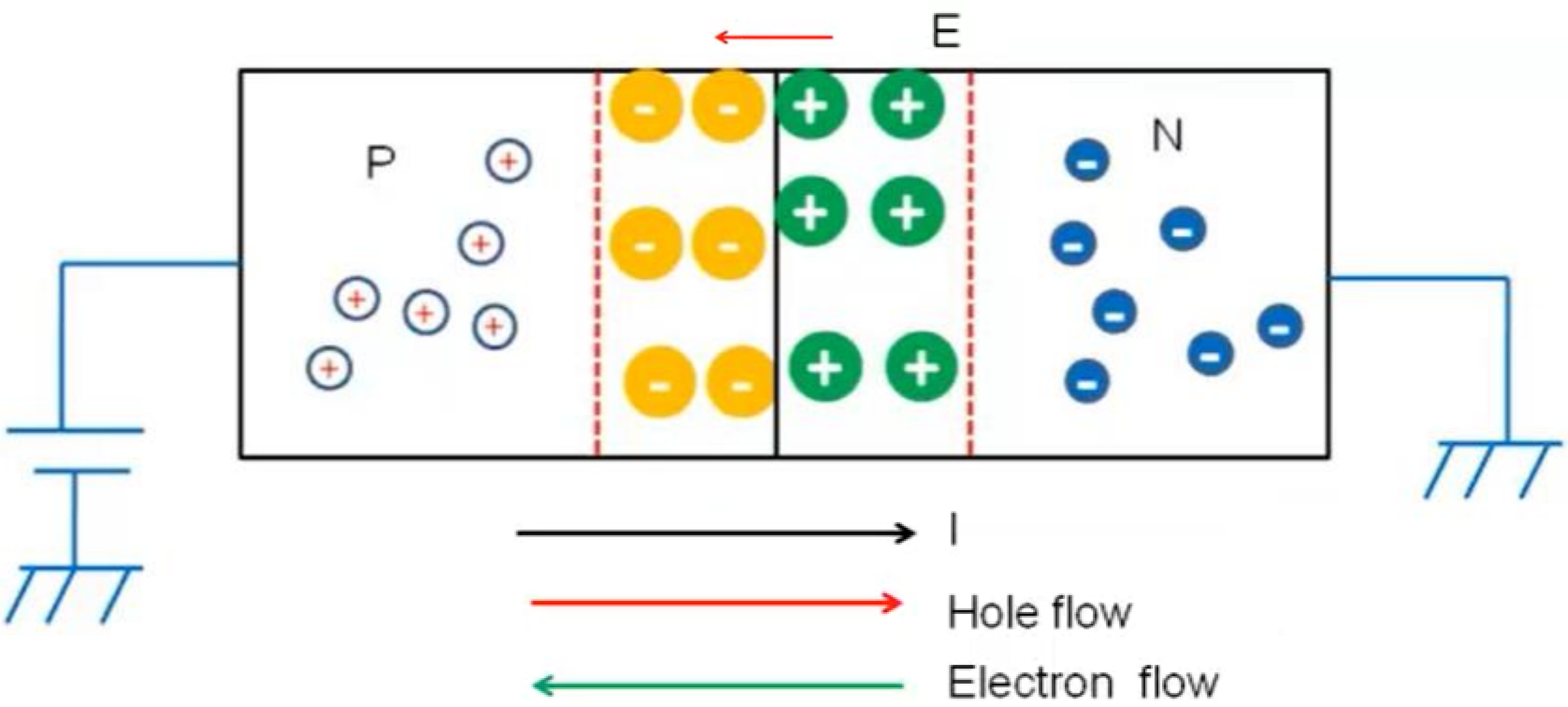
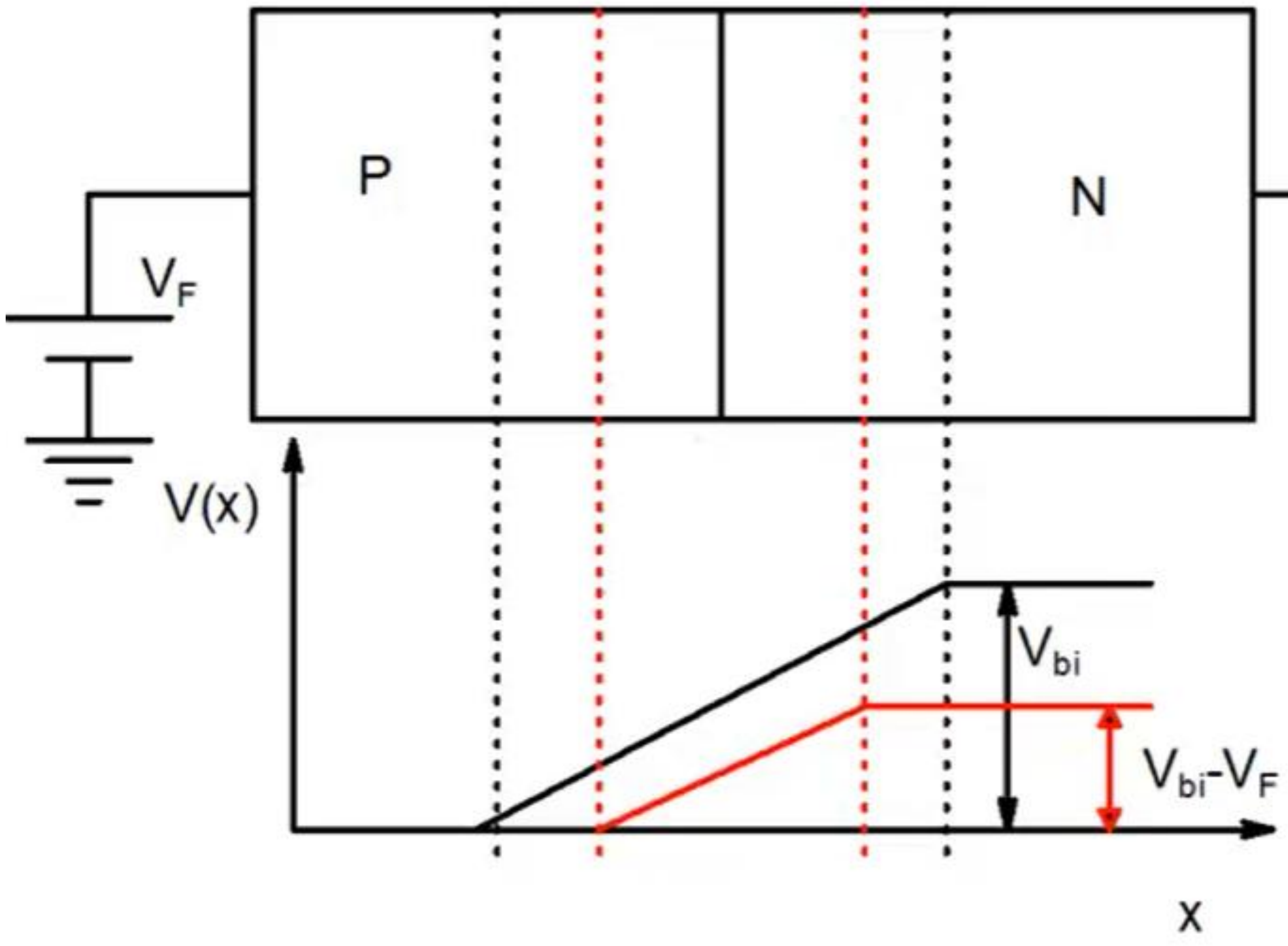
Forward Bias



Forward Bias

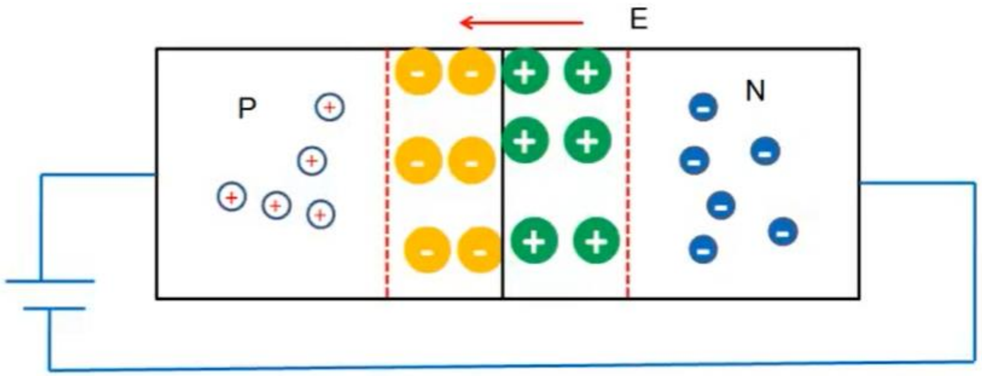


Application of forward bias lowers the built-in potential and allows holes and electrons to cross the junction and result in current flow

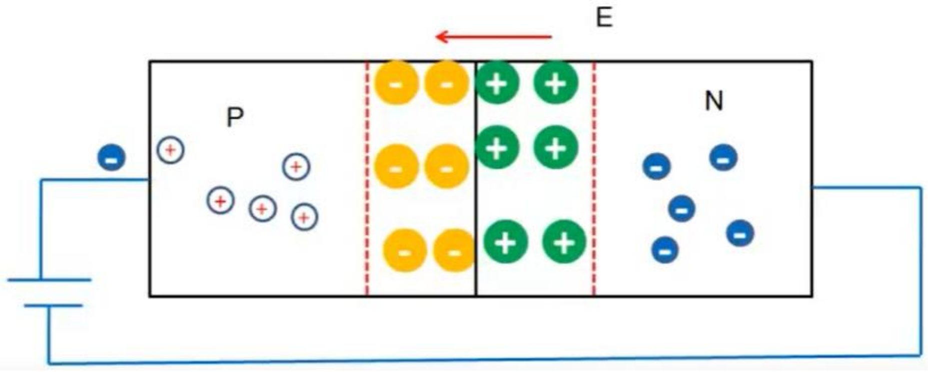


P
N
V_F
V(x)
V_{bi}
V_{bi}-V_F
x

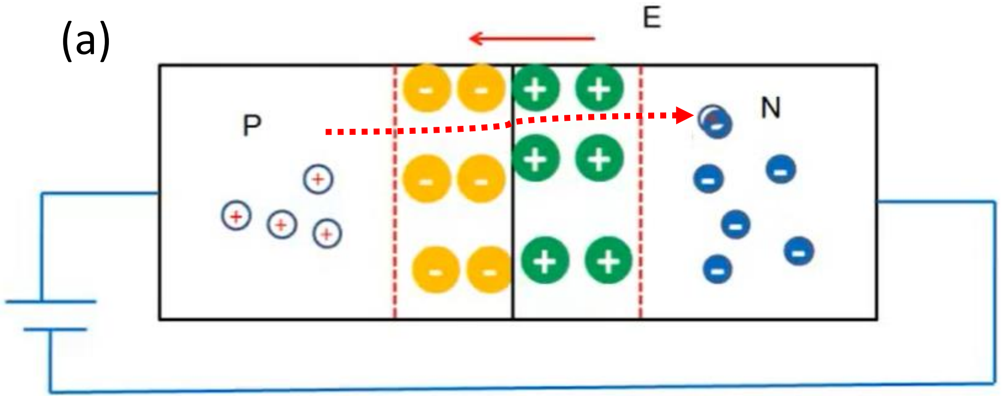
Mechanism of Current flow



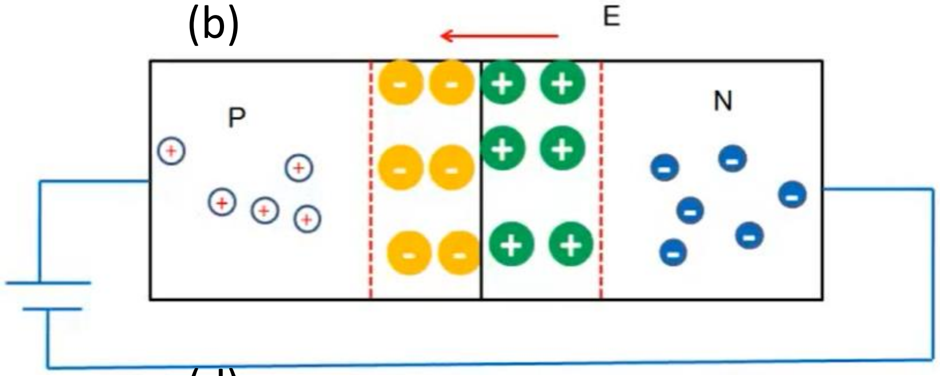
(a)



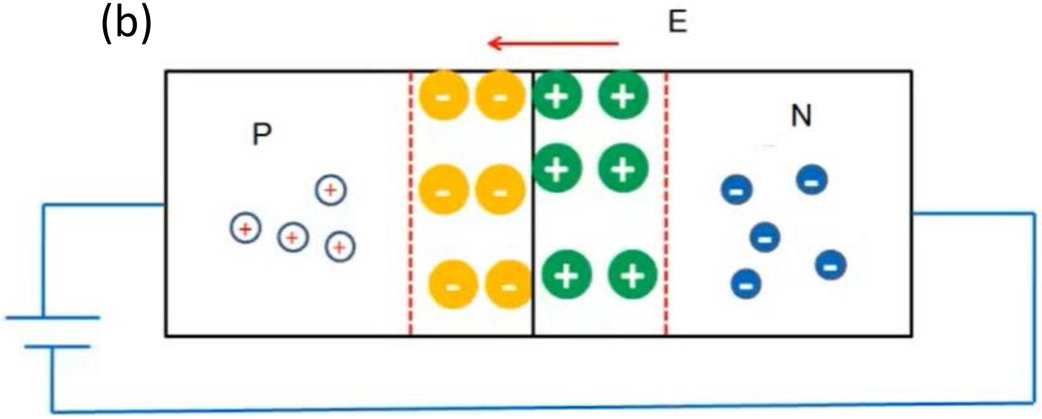
(b)



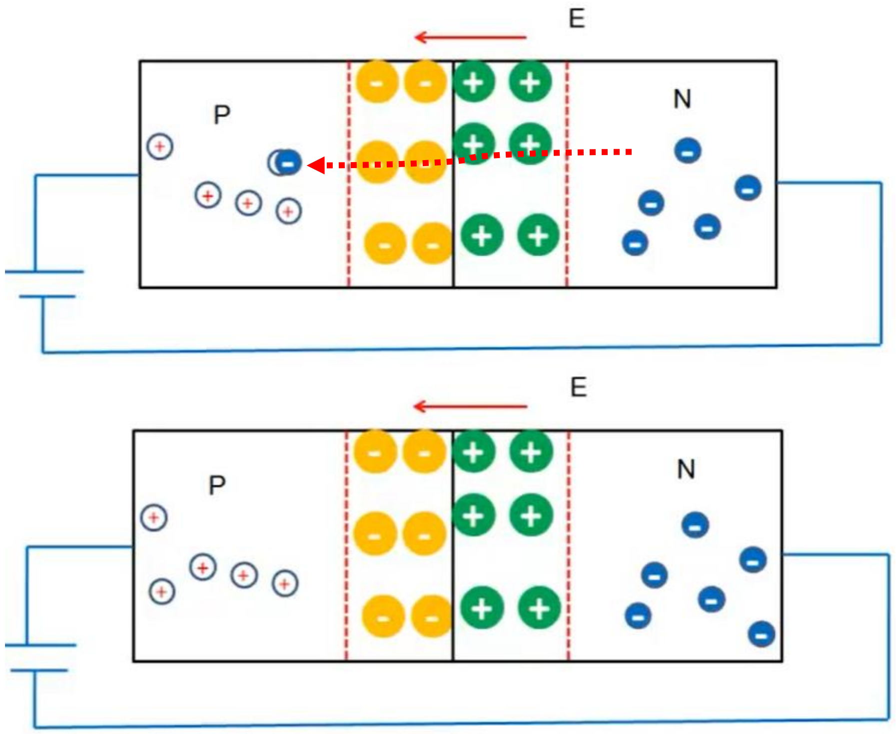
(b)



(d)

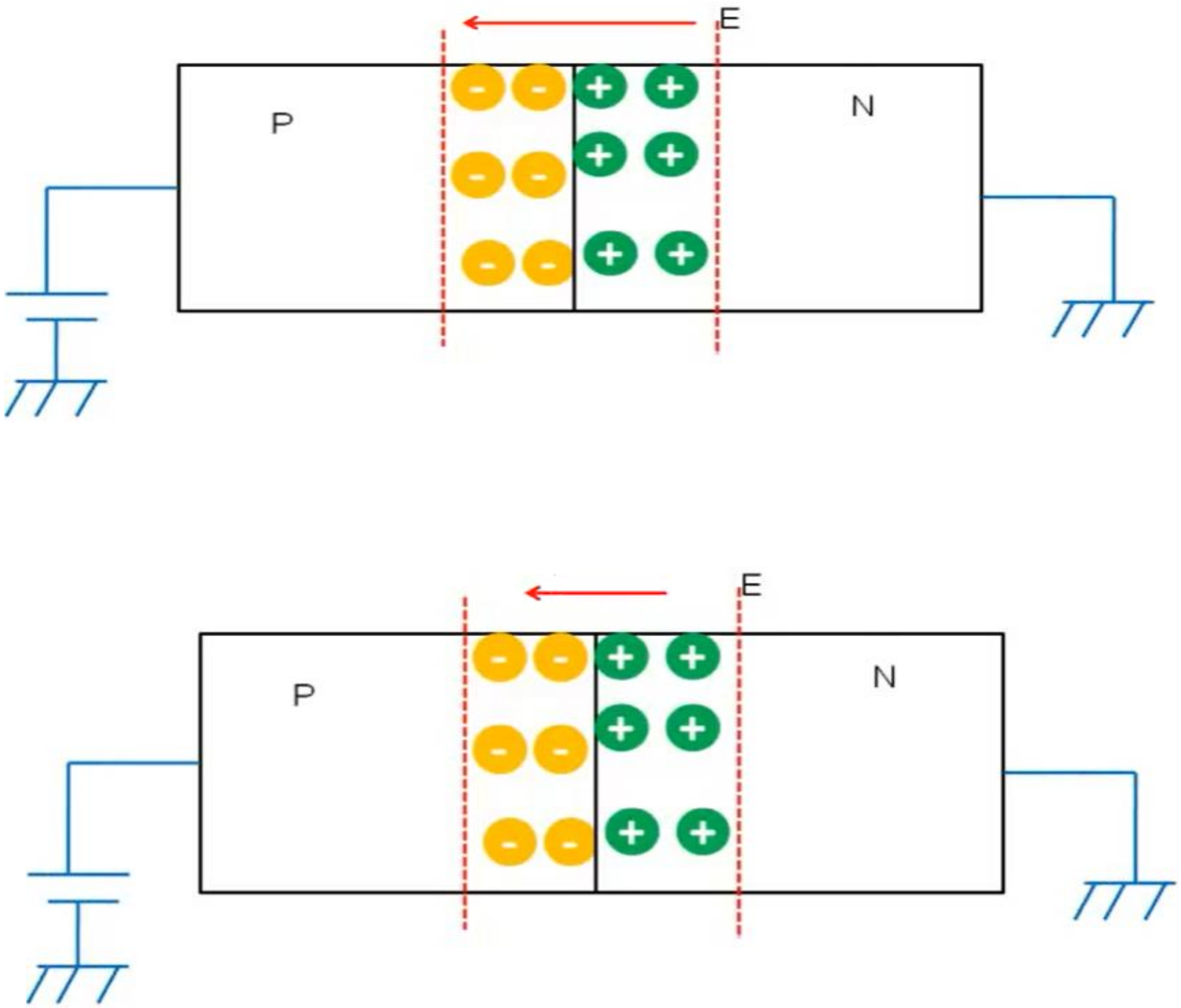


Mechanism of Current flow

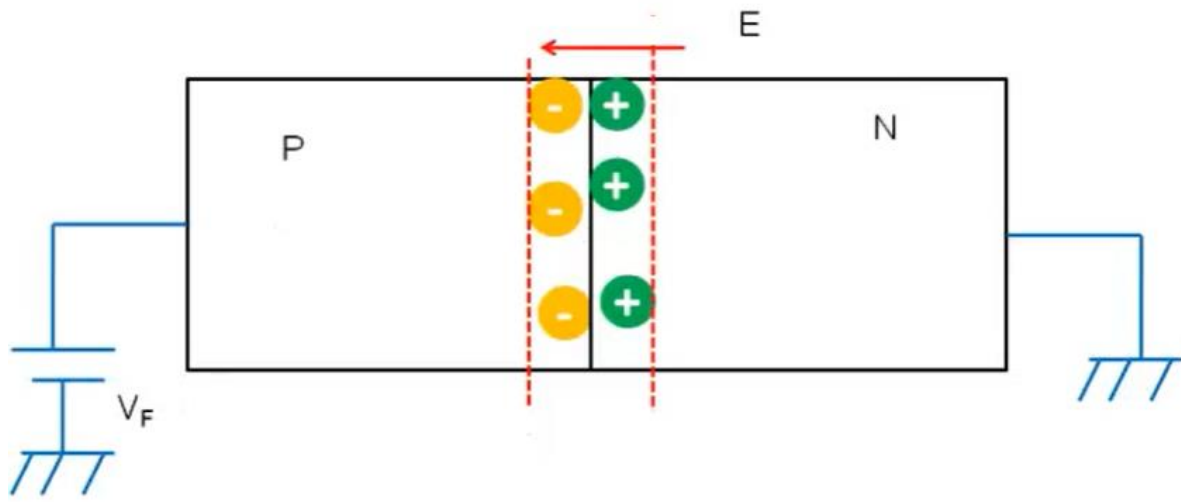


Current flows through carrier **injection** and **recombination**

Forward Bias



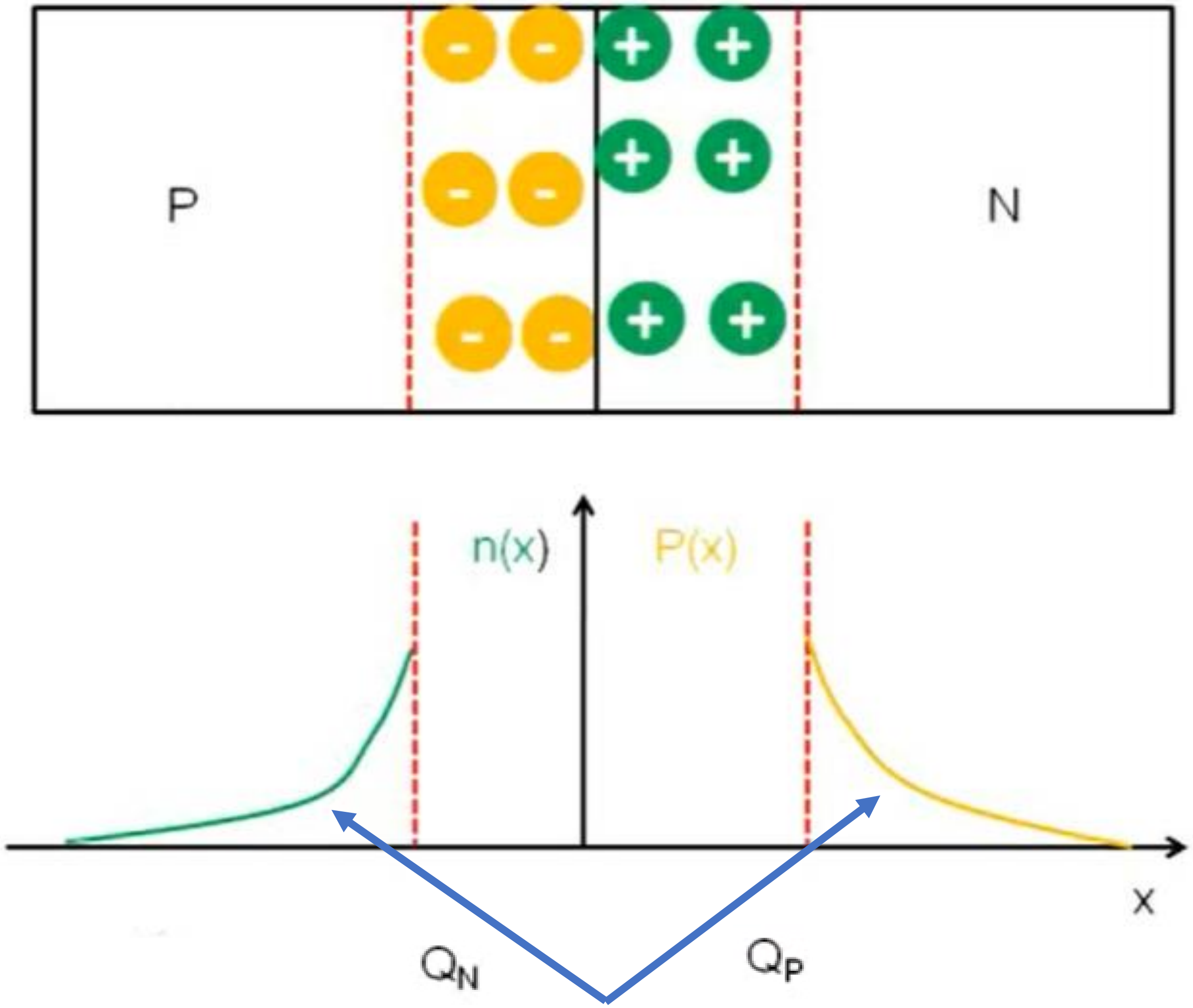
Forward Bias



Application of forward bias reduces depletion width.

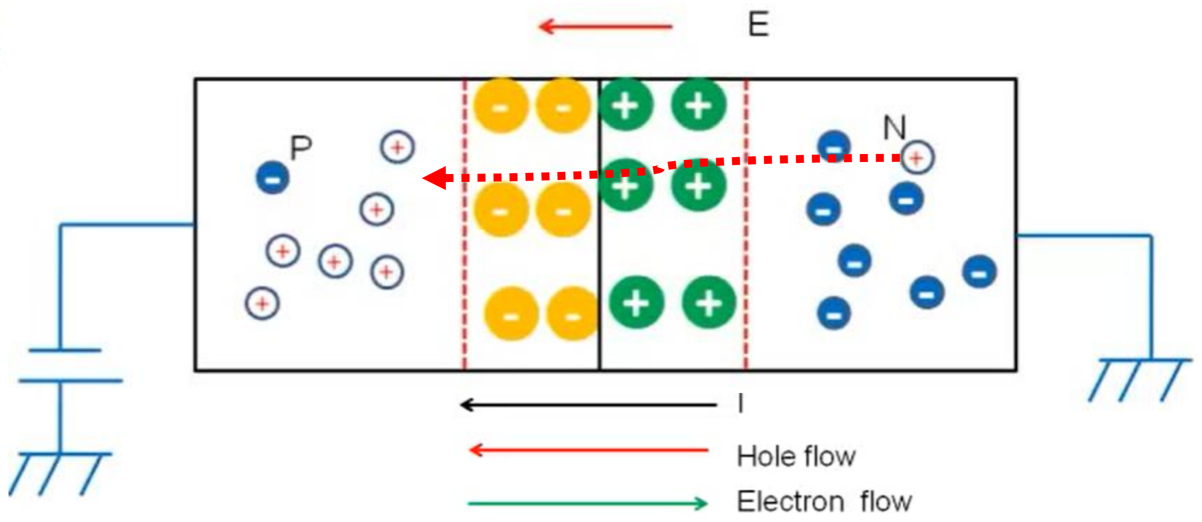
Change in depletion charge with voltage gives rise to junction capacitance (also called depletion capacitance) C_J

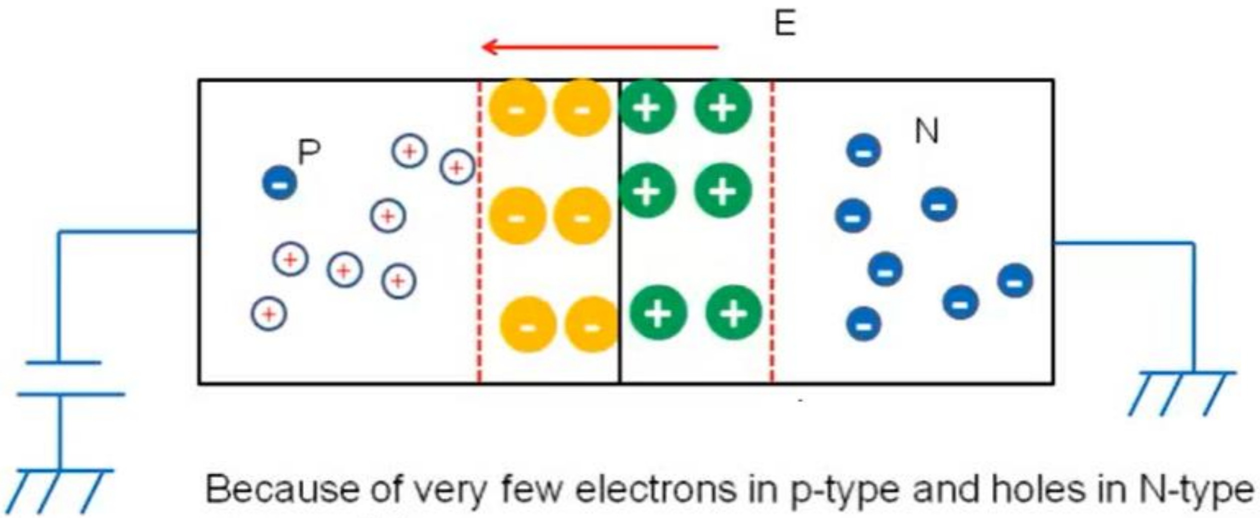
Excess carriers in P and N regions



Diffusion Capacitances

Reverse Bias

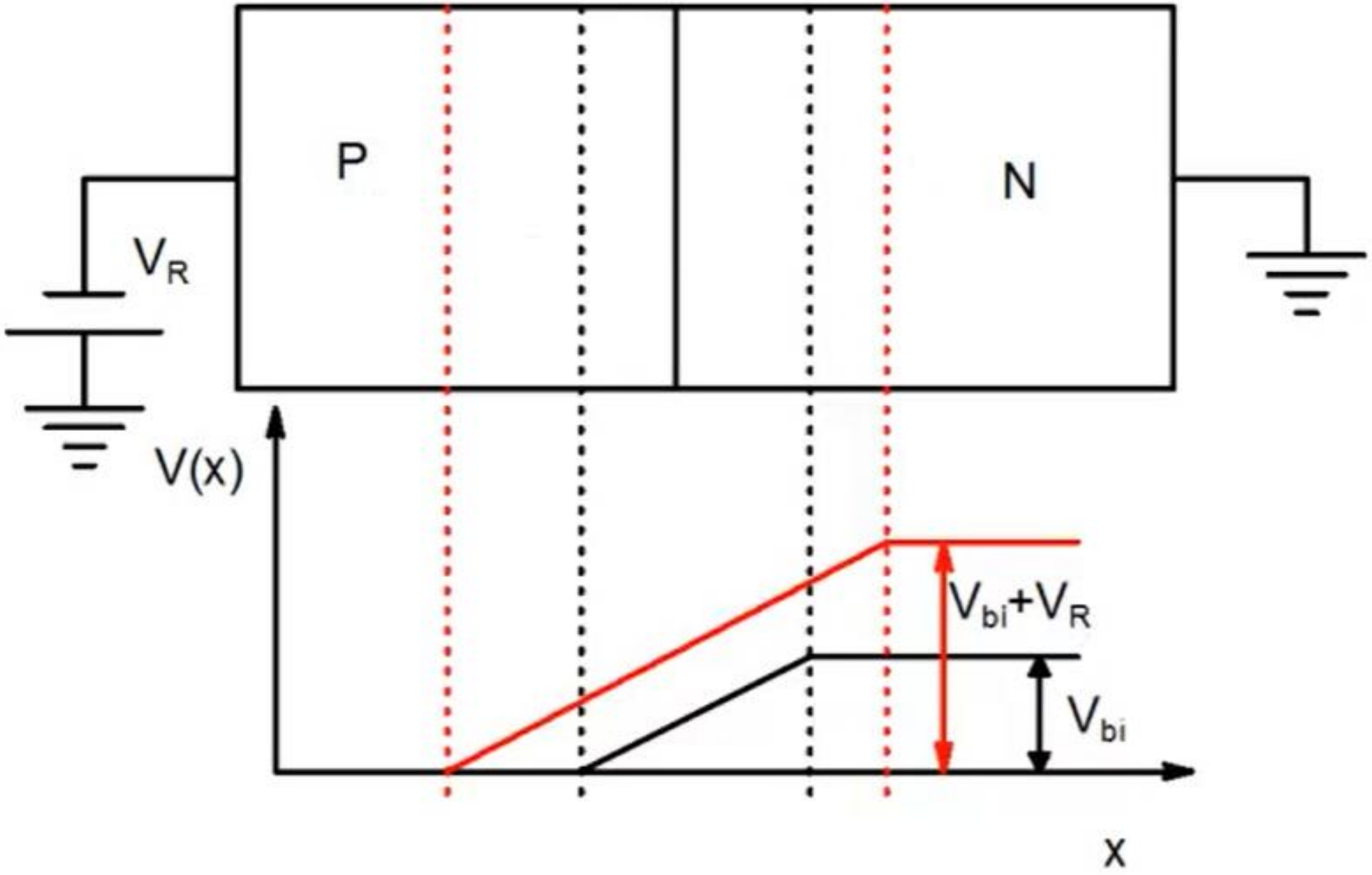




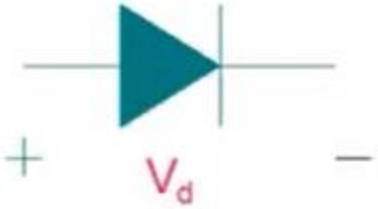
Because of very few electrons in p-type and holes in N-type current is very small !

Application of reverse bias increases the built-in potential

Reverse Bias



Diode : I-V Characteristics



$$I = I_S \times \{\exp(\frac{V_D}{nV_T}) - 1\}$$

I_S : Reverse Saturation Current

$V_T = kT/q \cong 26mV$ at T = 300K

n is called ideality factor and is equal to 1 for ideal diodes

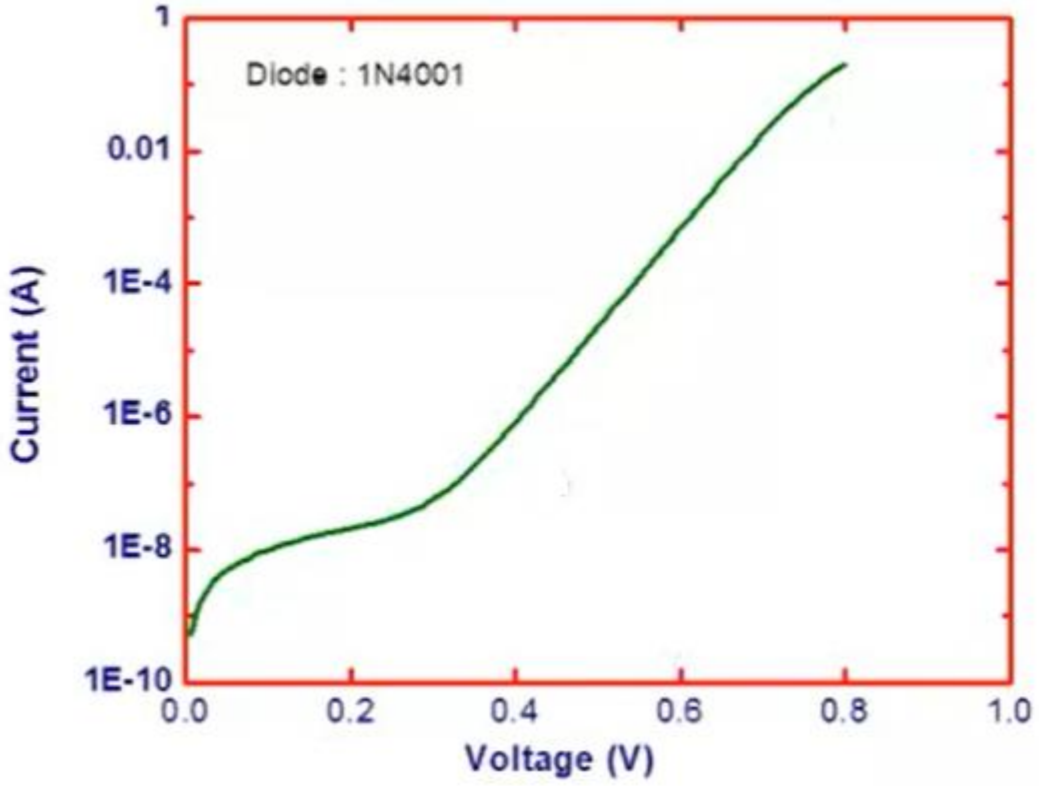
Forward Bias

$$I = I_S \times \{\exp(\frac{v_d}{V_T}) - 1\}$$

$$v_d >> V_T = 26mV$$

$$I \cong I_S \times \exp(\frac{v_d}{V_T})$$

$$\ln(I) = \ln(I_S) + \frac{v_d}{V_T}$$

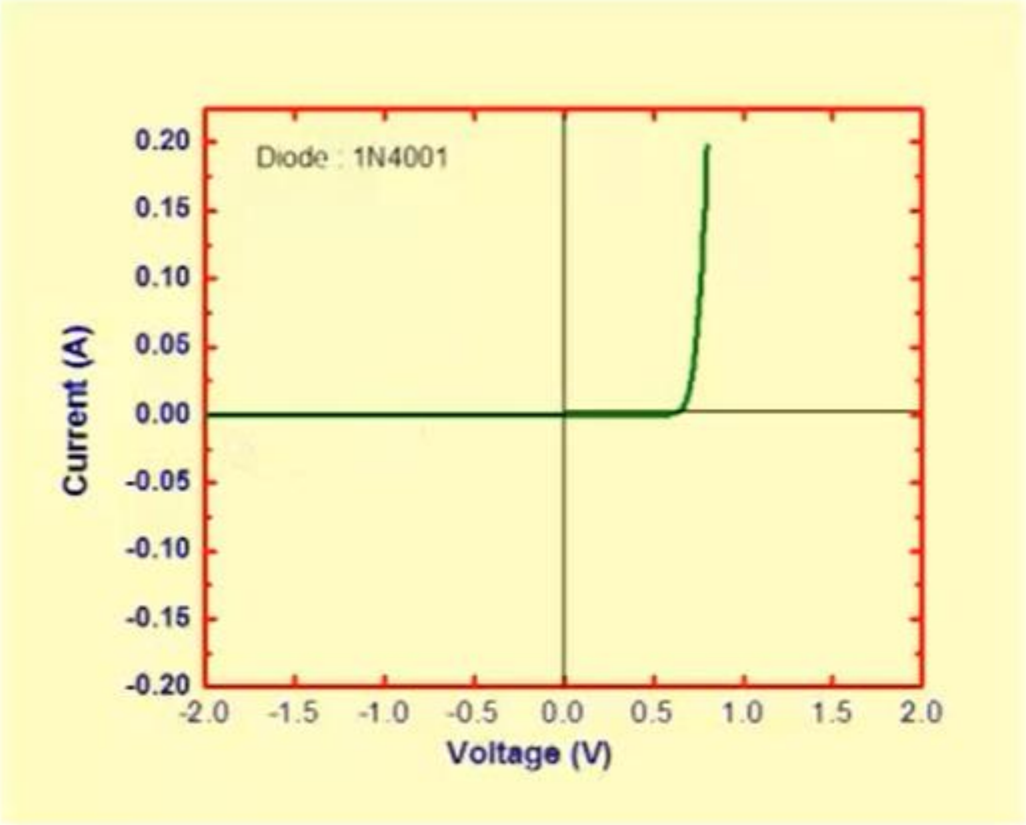


Reverse Bias

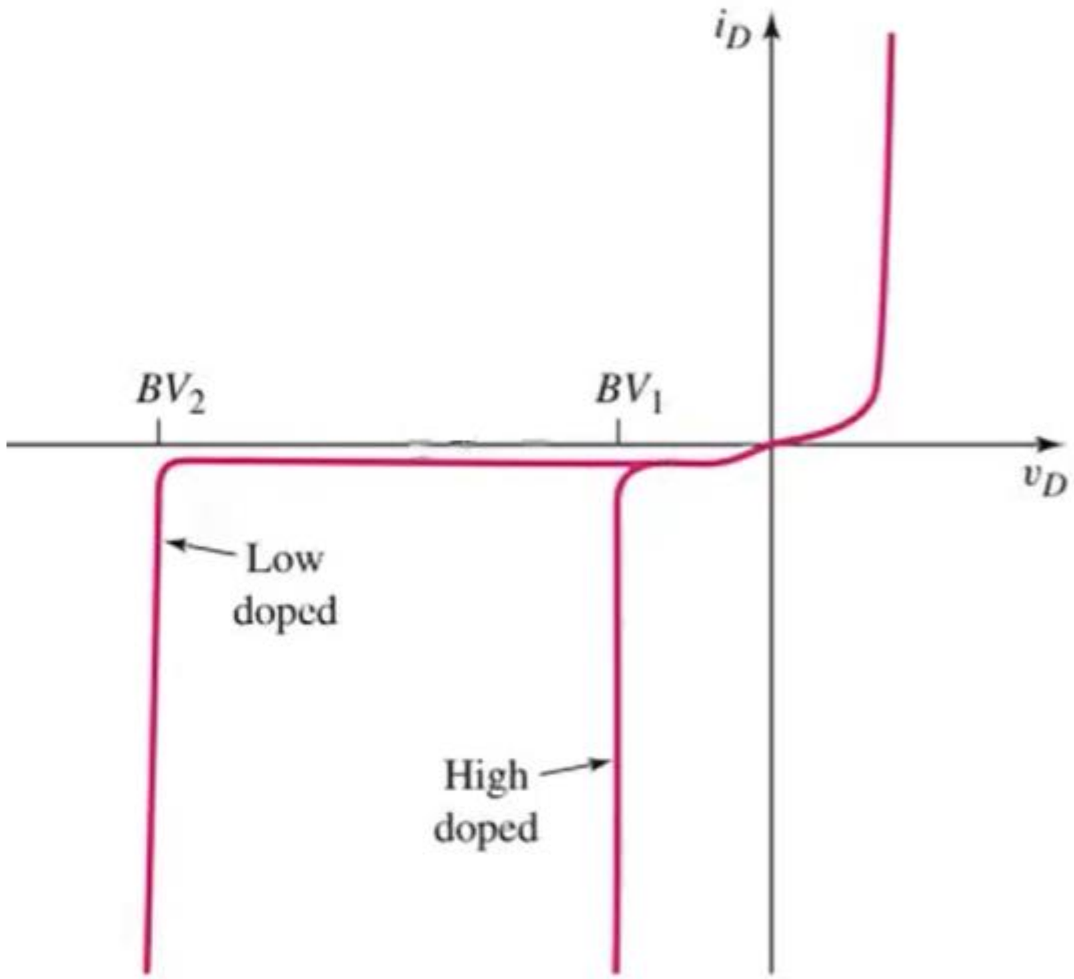
$$I = I_S \times \{\exp(\frac{v_d}{V_T}) - 1\}$$

$$v_d = -v_R$$

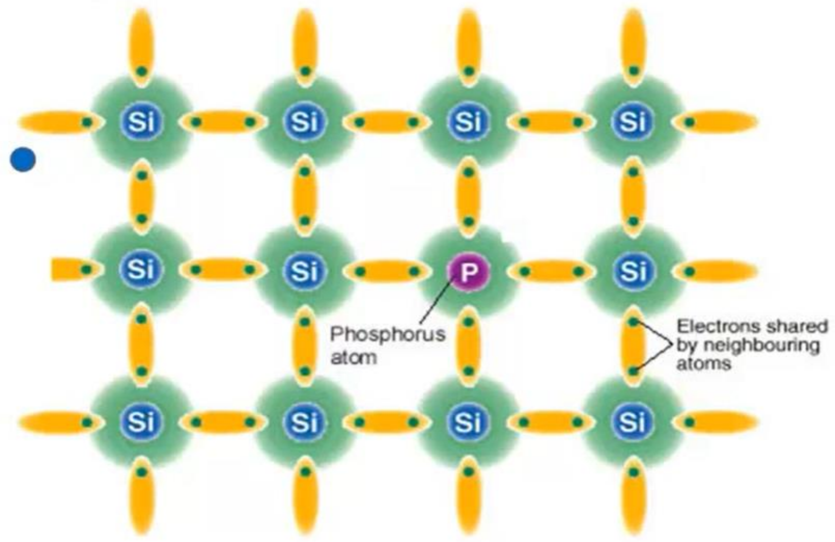
$$I = I_S \times \{\exp(-\frac{v_R}{V_T}) - 1\} \cong -I_S$$

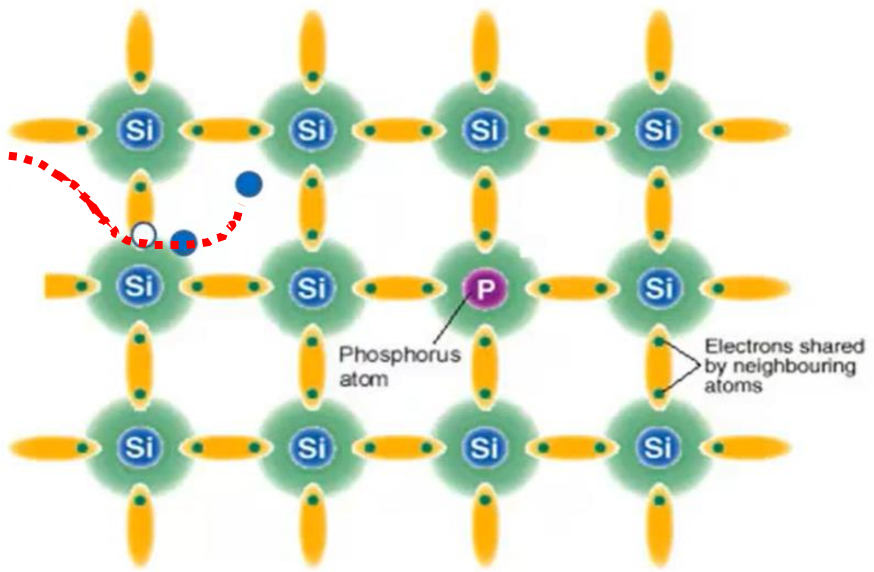


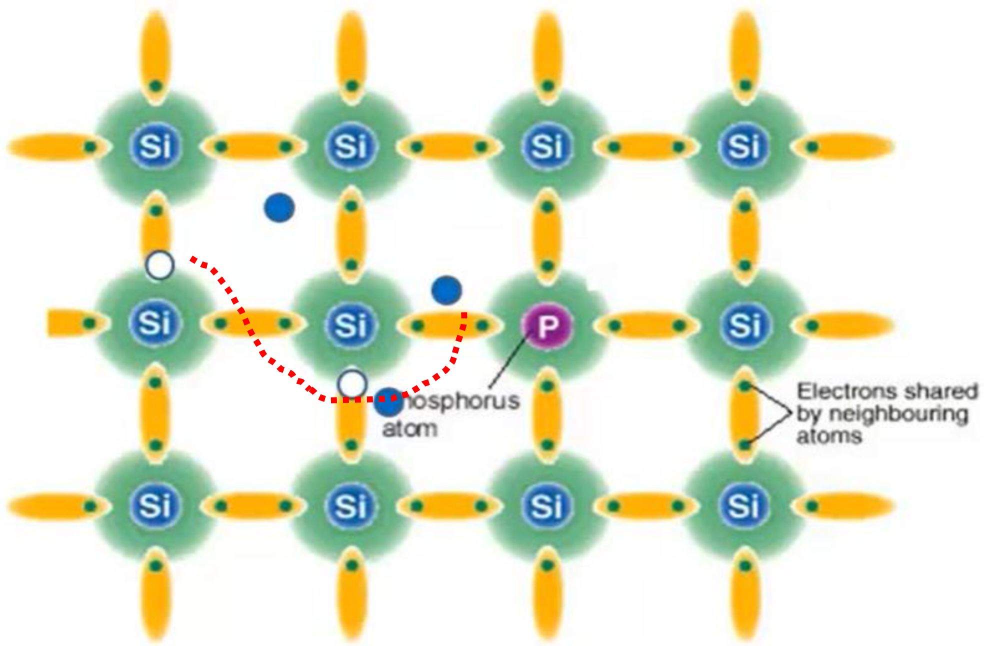
Breakdown



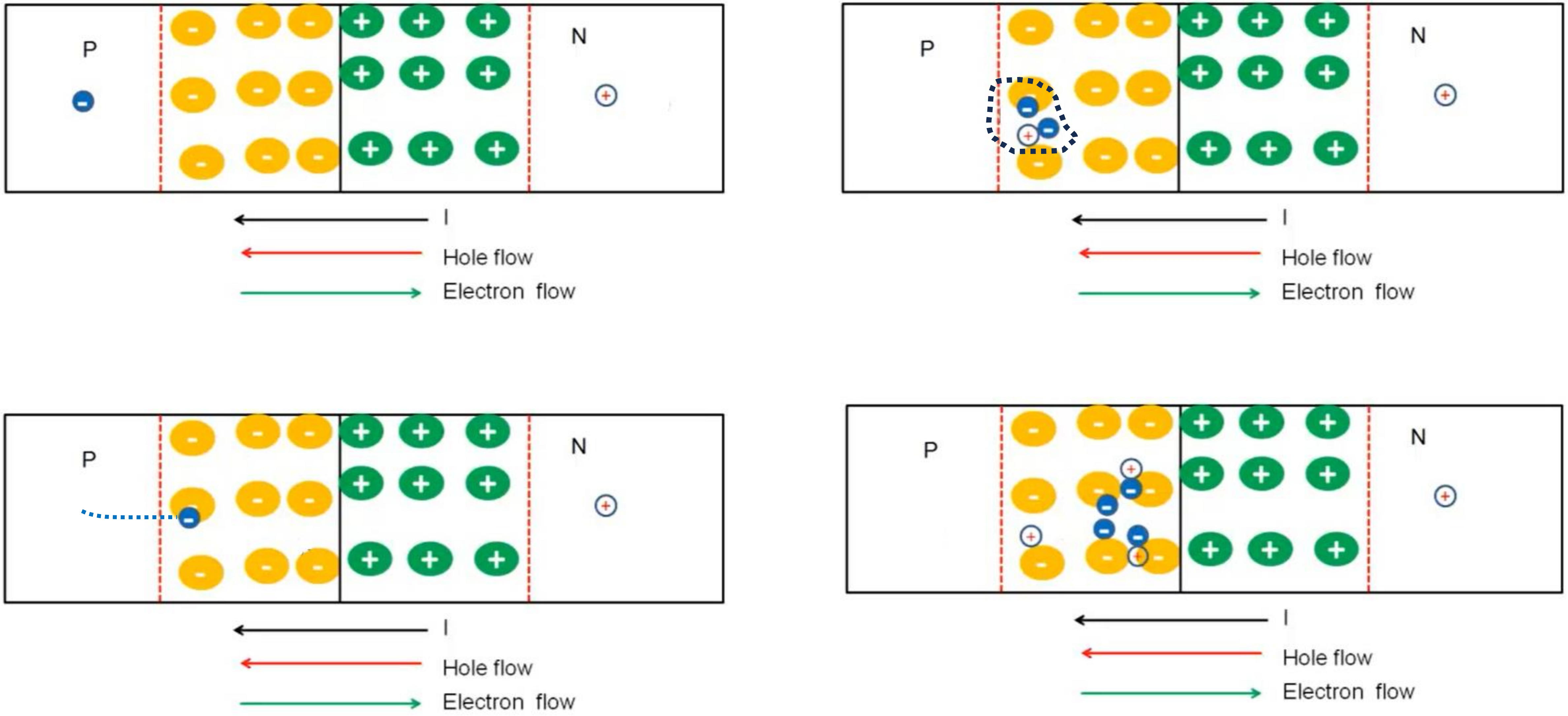
Impact Ionization



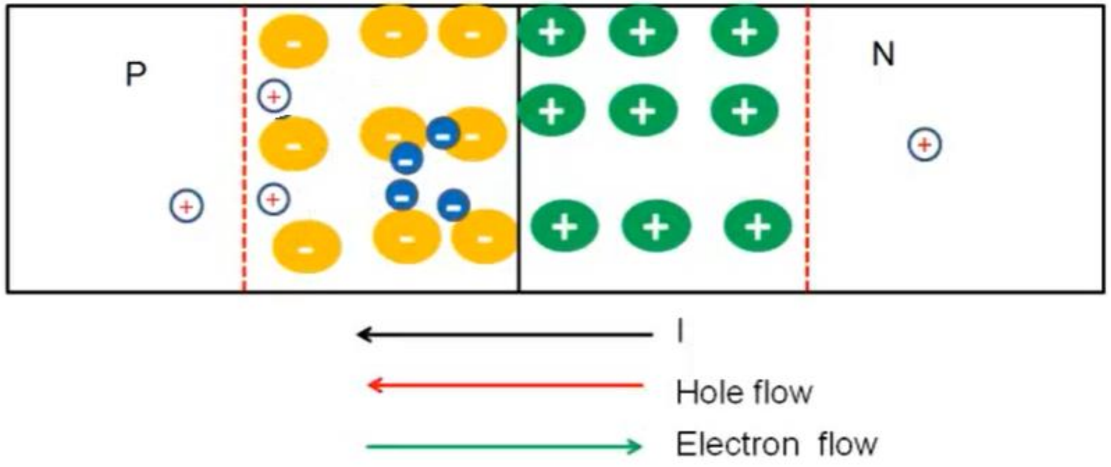


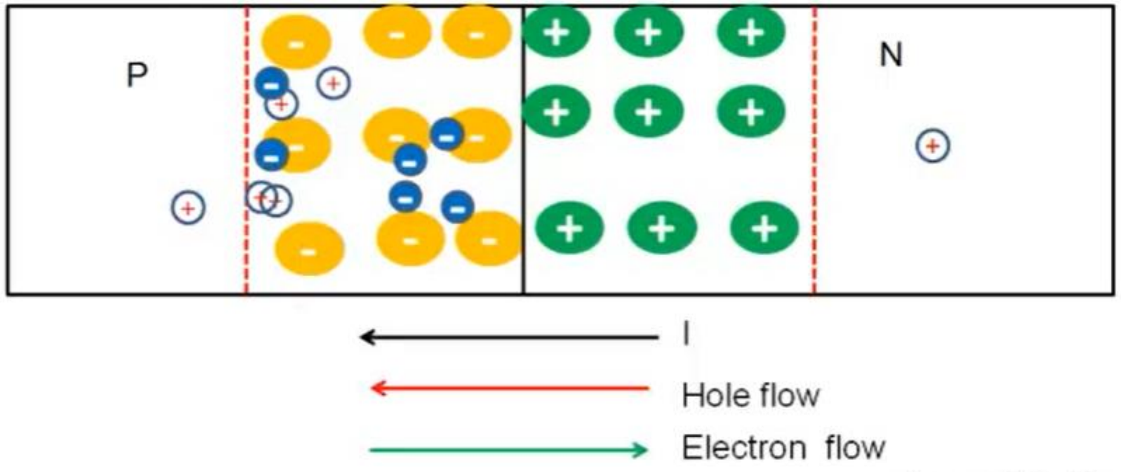


Breakdown Mechanism: Avalanche



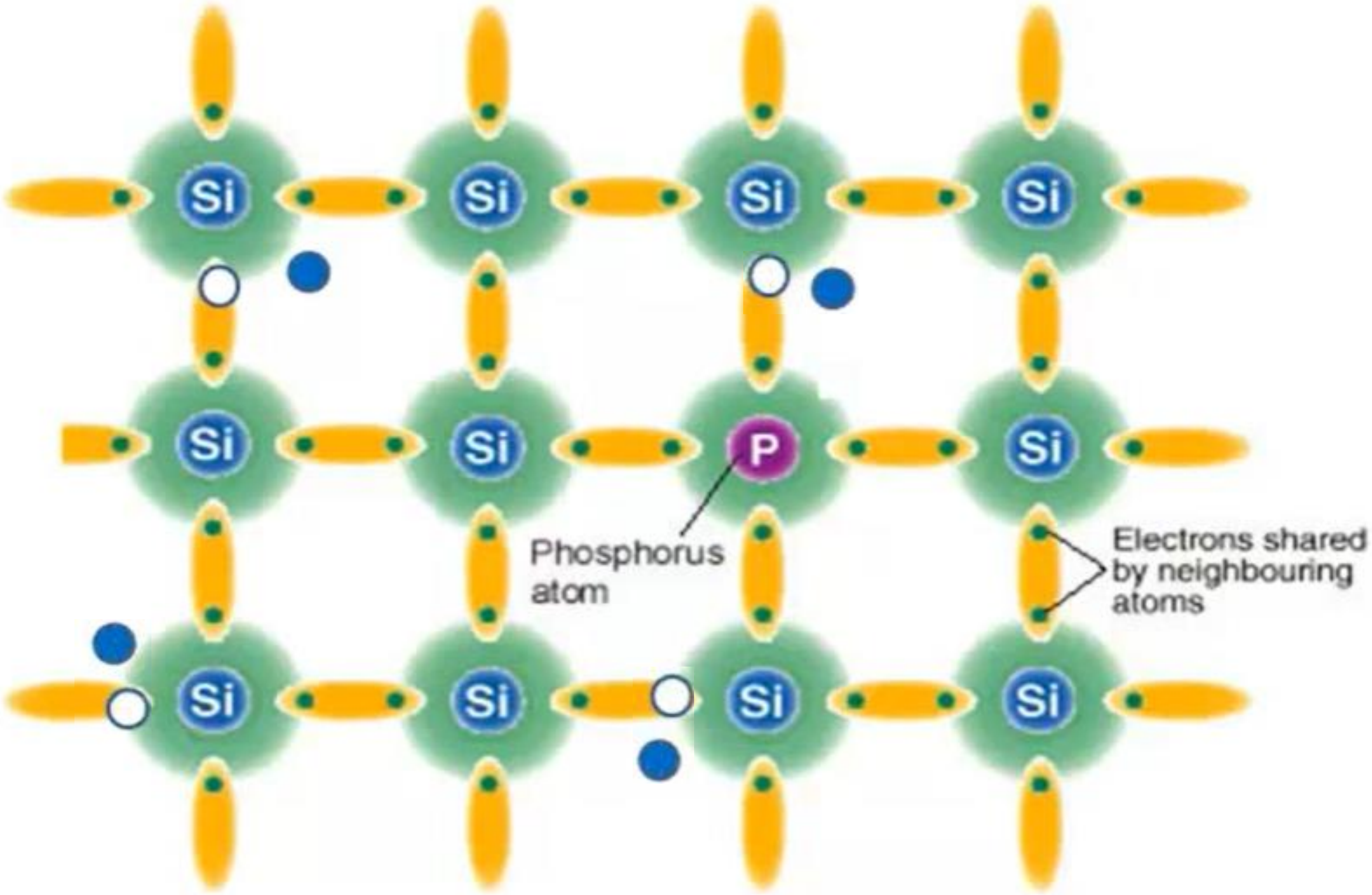
Breakdown Mechanism: Avalanche





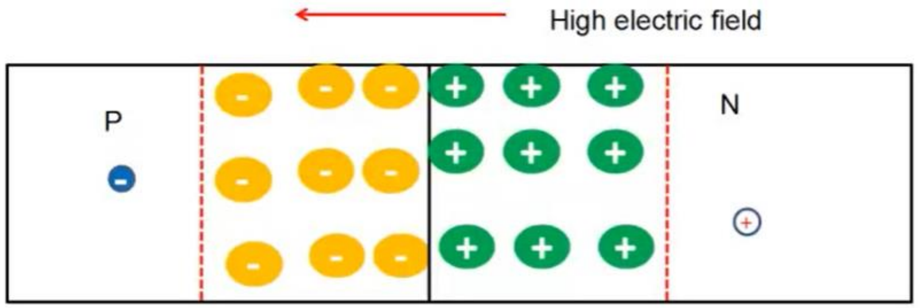
A multiplication of carriers takes place due to impact ionization in the depletion region, as a result of which large current begins to flow.

Ionization can also occur due to electric field

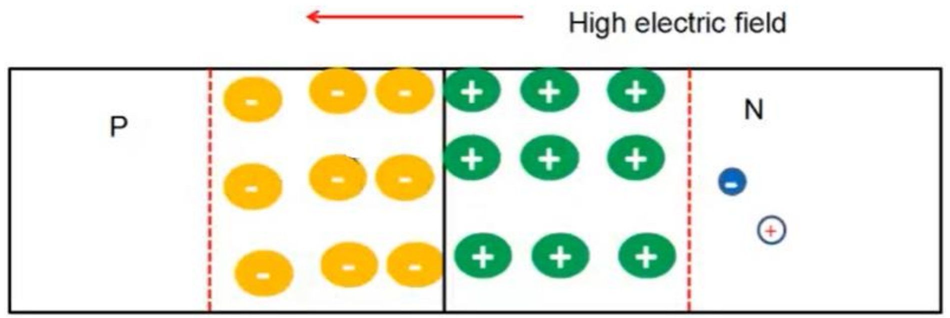


Breakdown: Zener

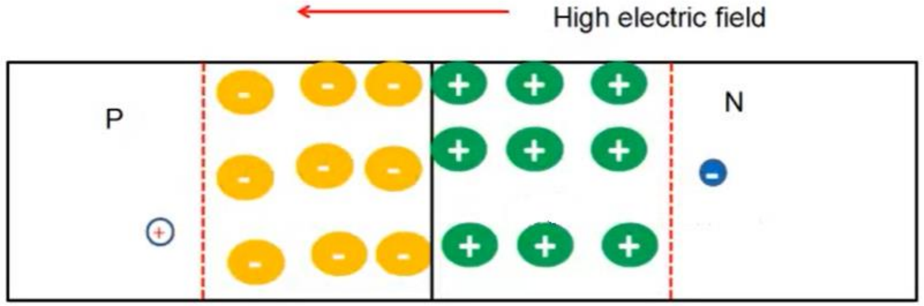
Heavily doped junctions



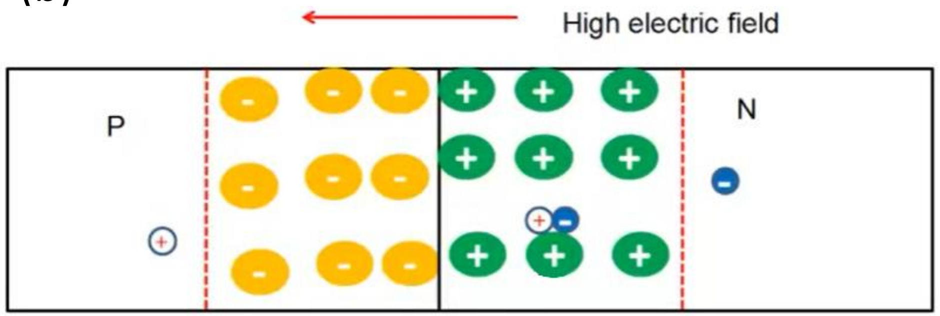
(a)



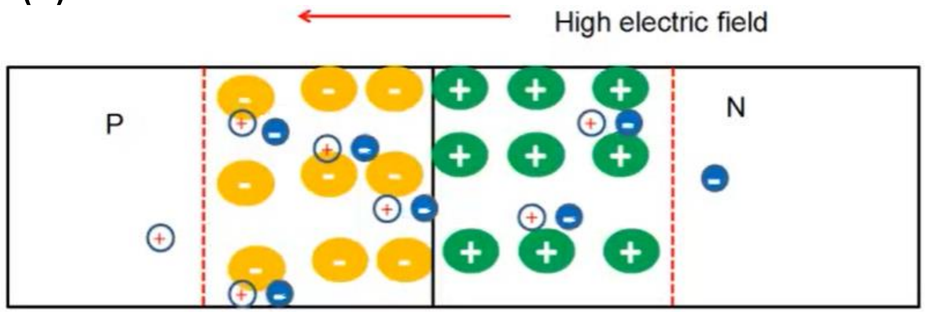
(b)



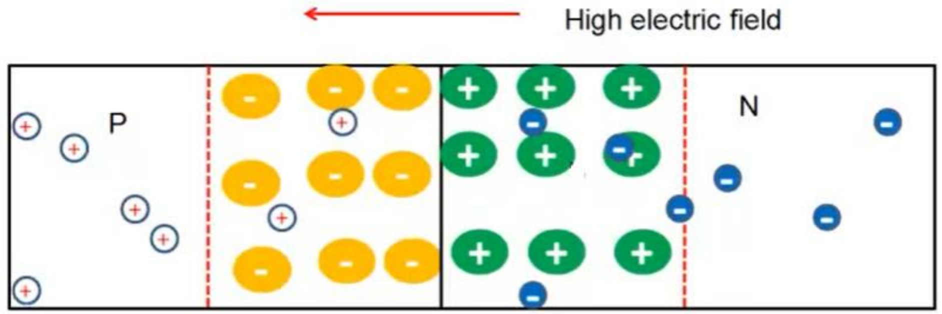
(c)



(d)



(e)

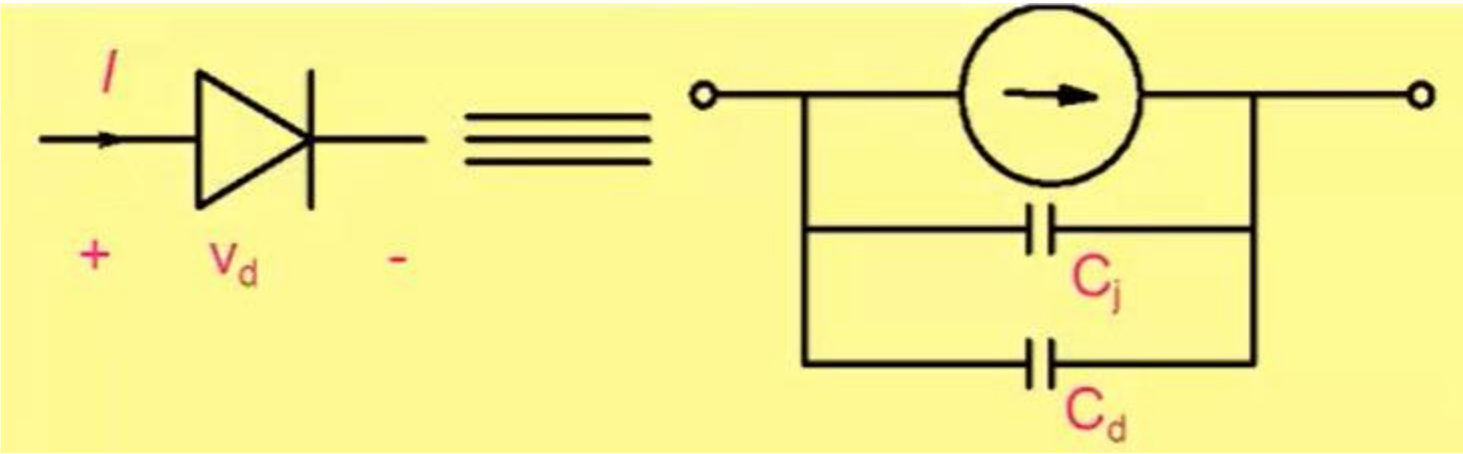


(f)

Electric field "**breaks the bond"** creating electron and hole pairs. These carriers move to give rise to large current.

Most of the common pn junction diodes breakdown due to avalanche mechanism. Even diodes which are called zener diodes have avalanche breakdown

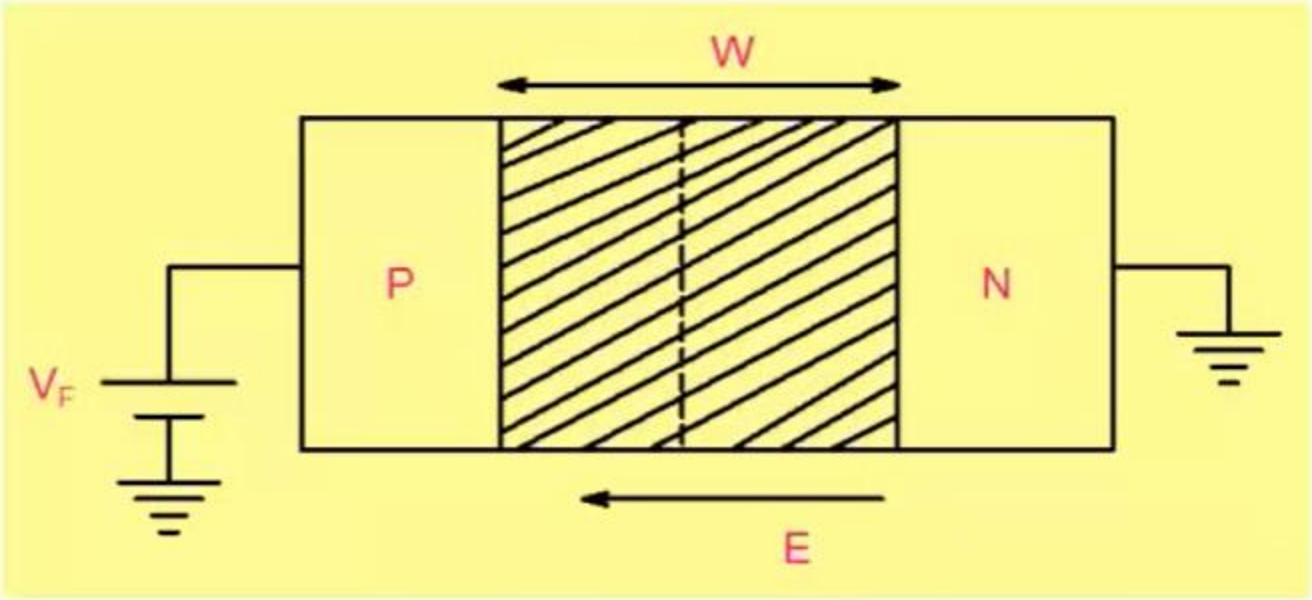
Diode Model: Forward Bias



$$I = I_S \times \{\exp(\frac{V_d}{nV_T}) - 1\}$$

For dc and low frequency ac circuits, the effect of diode capacitance can be neglected

Junction Capacitance



$(\uparrow)\ V_F \longrightarrow E(\downarrow) \longrightarrow Q_j(\downarrow)$

$$C_j = -\frac{\partial Q_j}{\partial V_F}$$

$$C_j = \frac{\varepsilon_s}{W} \times Area$$

$$C_j = \frac{C_{j0}}{\left(1 - \frac{V_d}{V_{bi}}\right)^m}$$

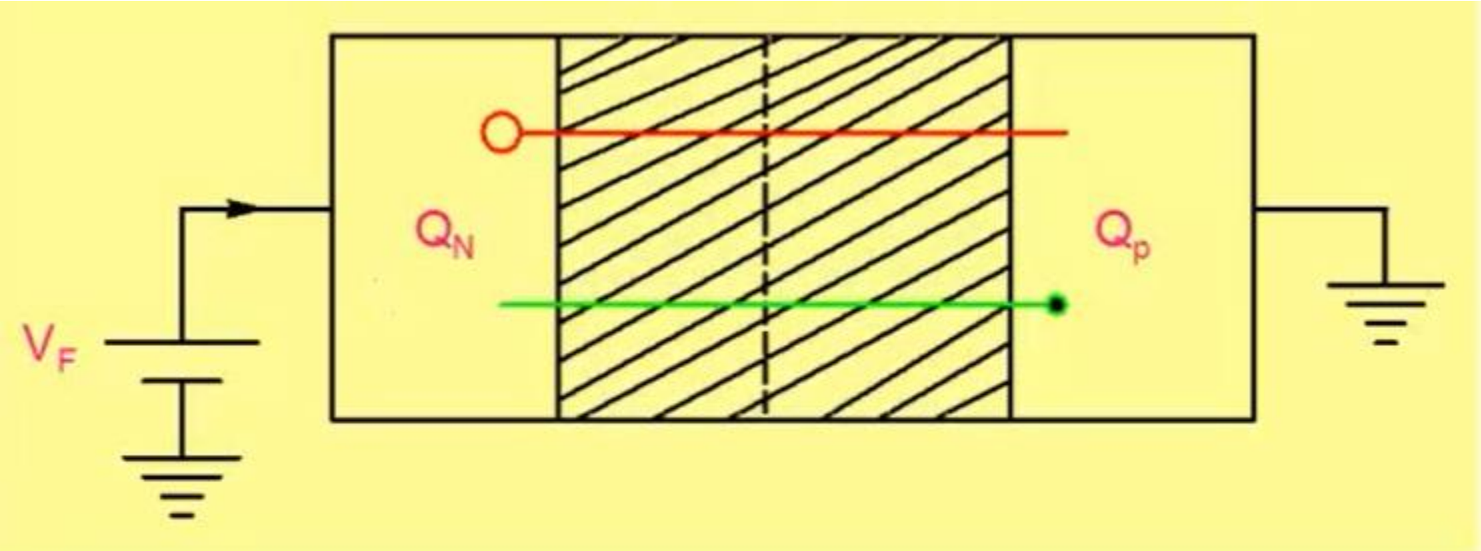
C_{jo} : Zero bias junction Capacitance

V_{bi} : built-in potential

m : grading coefficient (~ 0.5, 0.33)

- Junction capacitance increases with forward bias
- Junction capacitance increases with doping
- Junction capacitance increases with Area

Diffusion Capacitance

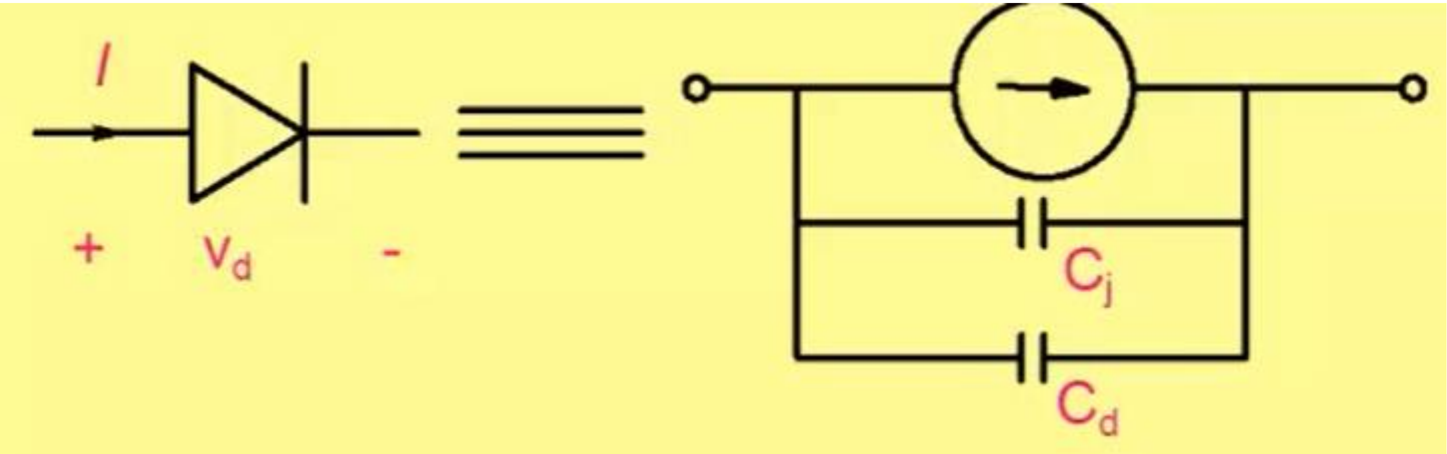


$$C_d = \frac{\partial\left(Q_P + |Q_N|\right)}{\partial V_F}$$

$$C_d = \frac{I_F}{V_T} \cdot \tau$$

τ : *transit time*

Diode Model: Forward Bias



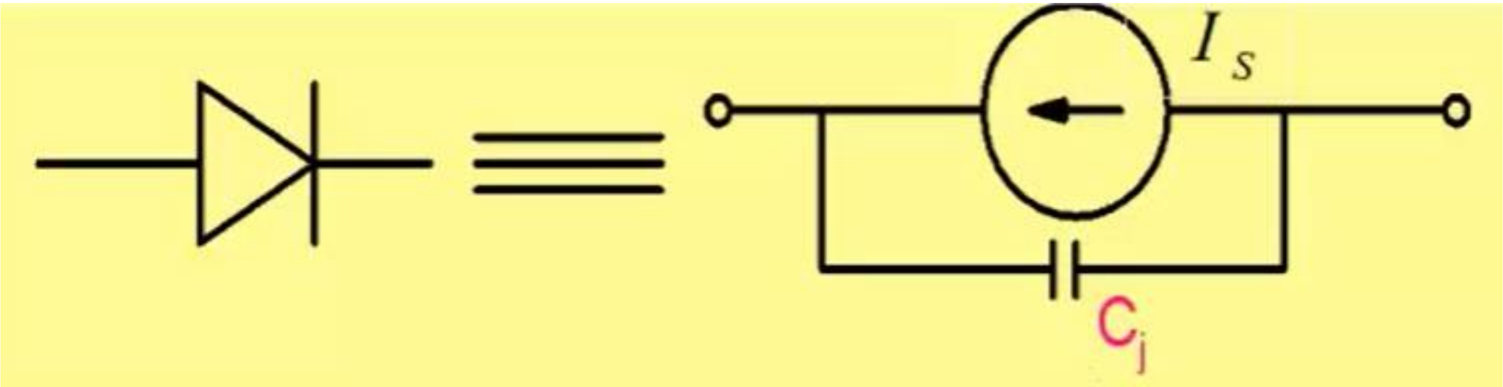
$$I = I_S \times \{\exp(\frac{V_d}{nV_T}) - 1\}$$

$$C_j = \frac{C_{j0}}{\left(1 - \frac{V_d}{V_{bi}}\right)^m}$$

$$C_d = \frac{I_F}{V_T} \cdot \tau$$

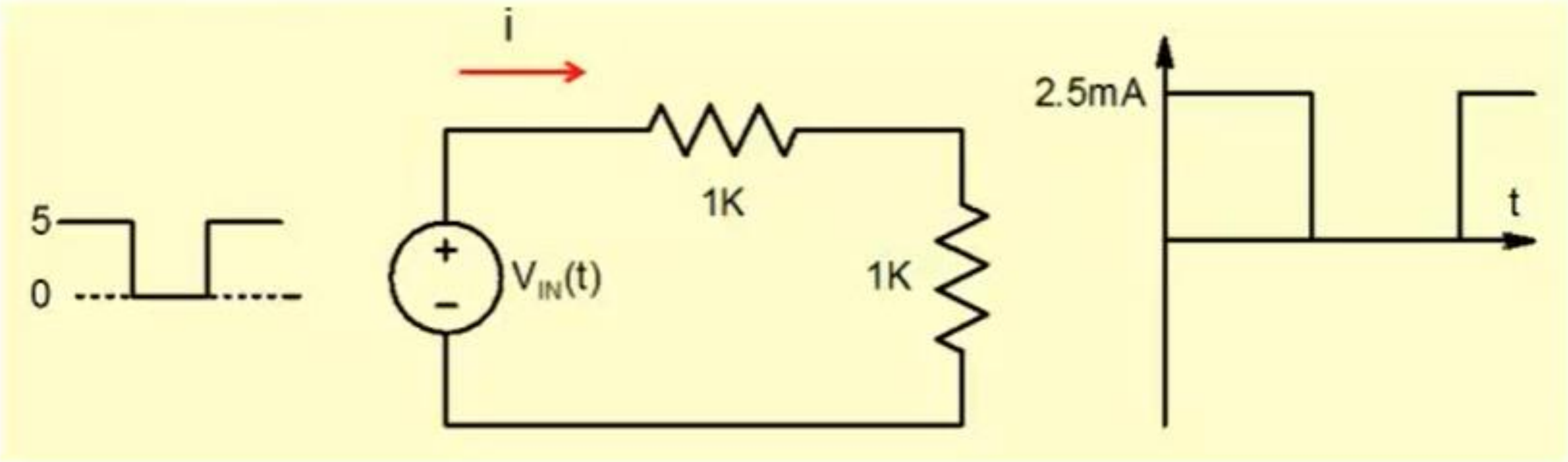
No. of parameters: 3+3+1

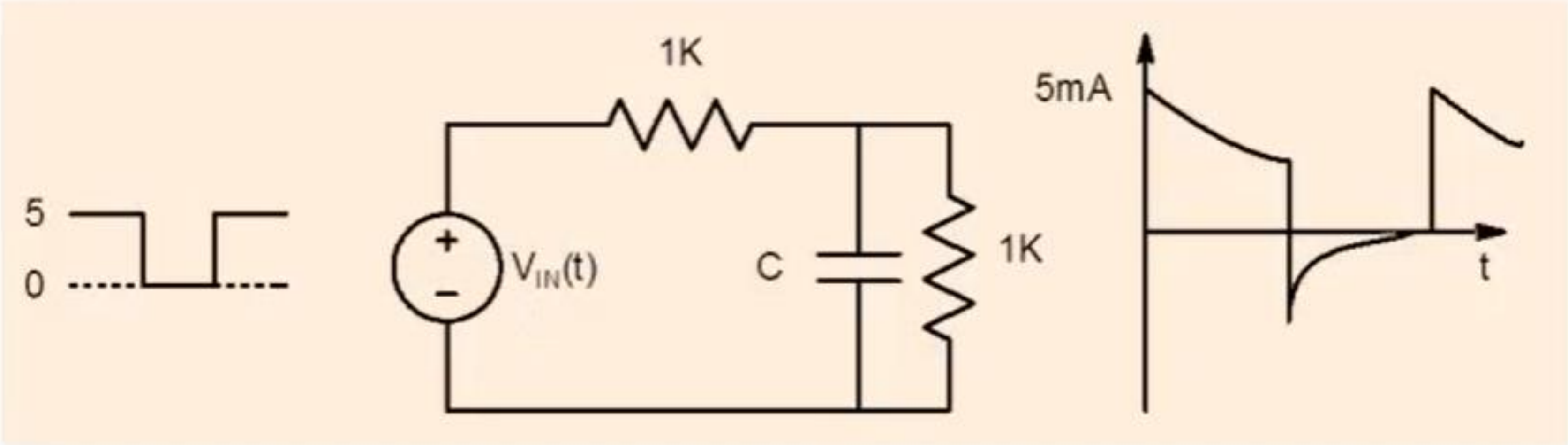
Diode Model: Reverse Bias

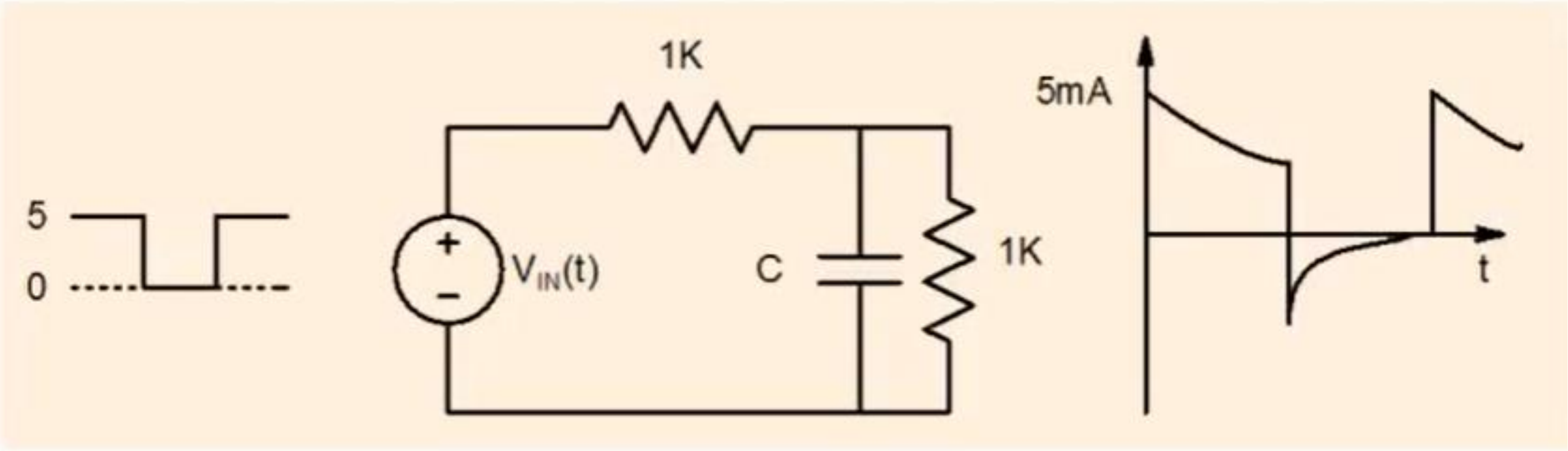


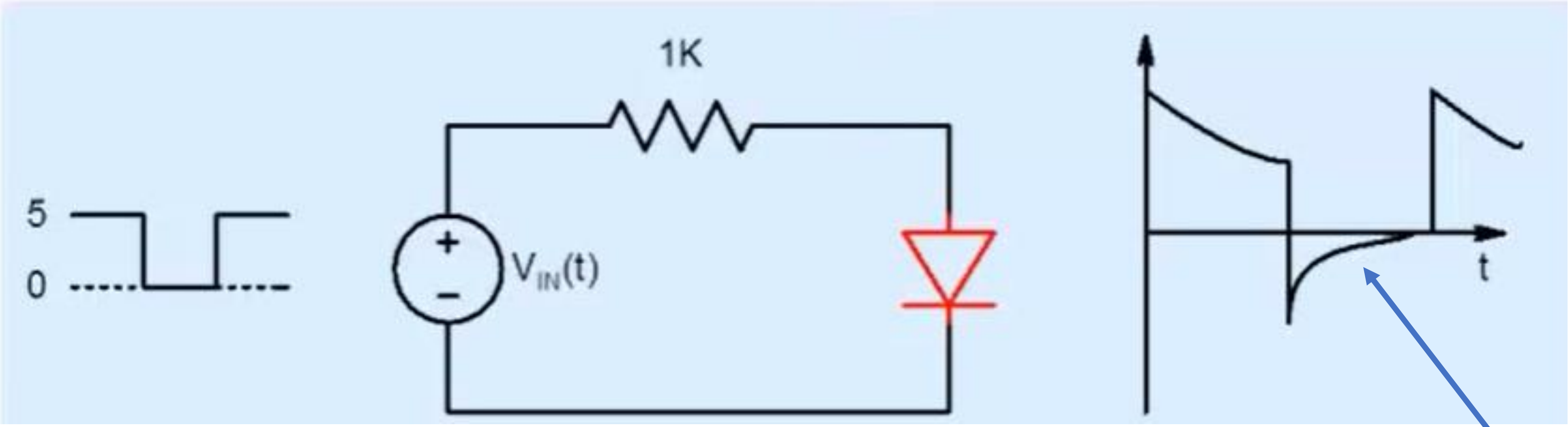
Because of capacitance, a diode even though reverse biased, can carry significant current momentarily

Example



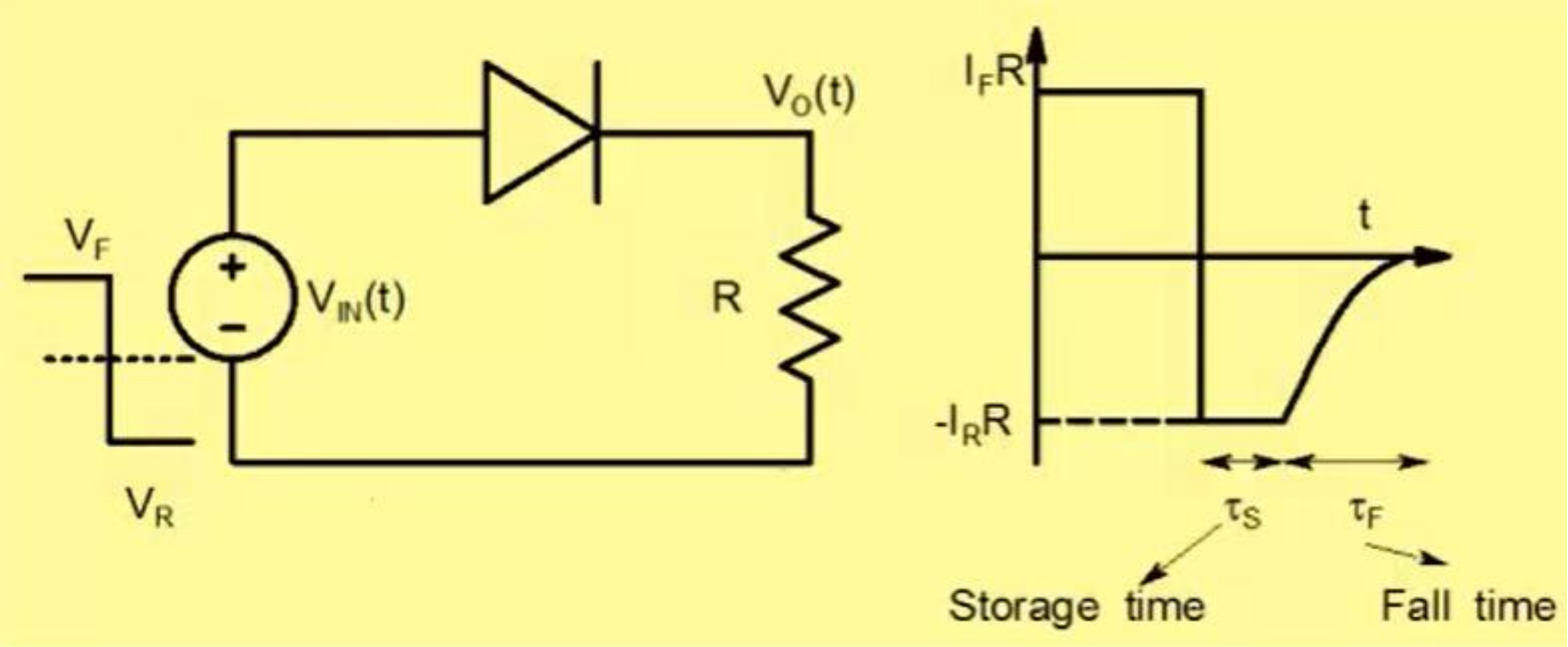






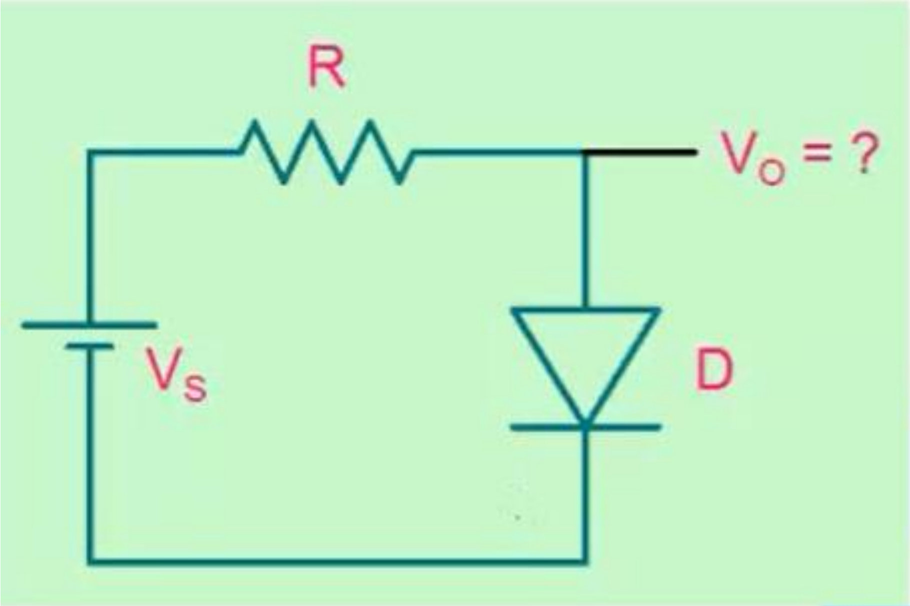
Current in reverse direction

Transient Response



Diode does not switch off instantly but remains conducting for a period called reverse recovery time which is sum of storage and fall delay times..

Analysis using non-linear diode model is not easy



$$V_S = IR + V_O \quad (1)$$

$$I = I_S \times \{\exp(\frac{V_O}{nV_T}) - 1\} \; (2)$$

$$\Rightarrow \quad V_O = nV_T \times \ln(\frac{\mathrm{I}}{\mathrm{I_S}} + 1) \quad (3)$$

$$\Rightarrow \quad V_S = IR + nV_T \times \ln(\frac{\mathrm{I}}{\mathrm{I_S}} + 1) \quad (4)$$

Iterative Method:

$$V_S = IR + V_O \quad (1)$$

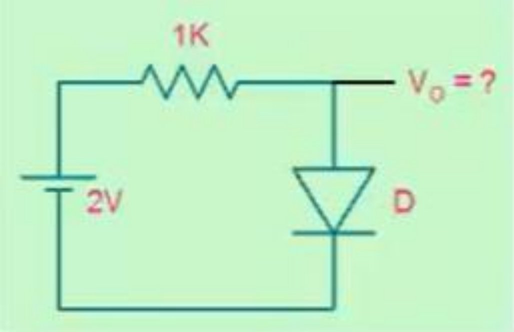
$$I = I_S \times \left\{\exp\left(\frac{V_O}{nV_T}\right) - 1\right\} \quad (2)$$

Assume $V_O = 0.6\mathrm{V}$

Calculate $I = \dfrac{V_S - V_O}{R}$

Re-calculate $V_O = nV_T \times \ln(\mathrm{I}/\mathrm{I_S} + 1)$

Convergence: $\dfrac{\Delta I}{I} \leq \varepsilon$



$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15}\ A$$

$$V_T = kT / q \cong 26\ mV \text{ at } T = 300K$$

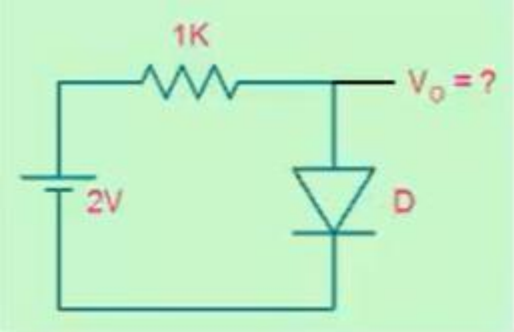
Assume V_o

$$I = \frac{V_s - V_o}{R}$$

$$V_o = nV_T \times \ln(I/I_s + 1)$$

$V_o = 0.5$	$V_o = 0.711$	$V_o = 0.707$
$I = 1.5 \times 10^{-3}$	$I = 1.289 \times 10^{-3}$	$I = 1.293 \times 10^{-3}$
$V_o = 0.711$	$V_o = 0.707$	$V_o = 0.707$

CONVERGENCE



$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15}\ A$$

$$V_T = kT / q \cong 26\ mV \text{ at T = 300K}$$

Assume V_O

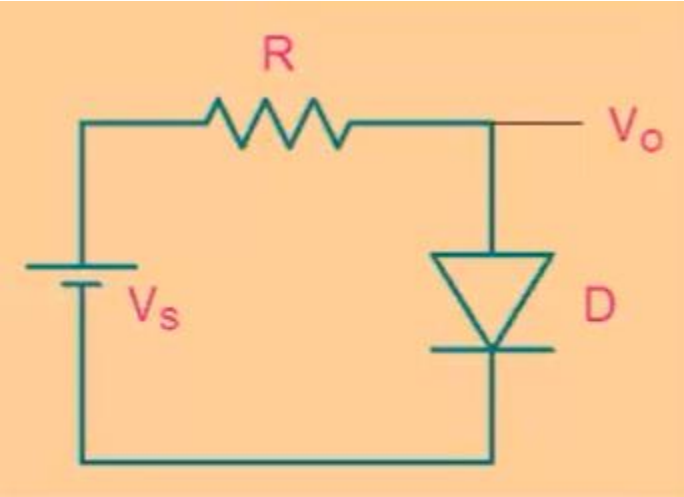
$$I = \frac{V_S - V_O}{R}$$

$$V_O = nV_T \times \ln(I/I_s + 1)$$

$V_O = 1.0$	$V_O = 0.7$	$V_O = 0.707$
$I = 1.0 \times 10^{-3}$	$I = 1.3 \times 10^{-3}$	$I = 1.293 \times 10^{-3}$
$V_O = 0.7$	$V_O = 0.707$	$V_O = 0.707$

CONVERGENCE to the same Result

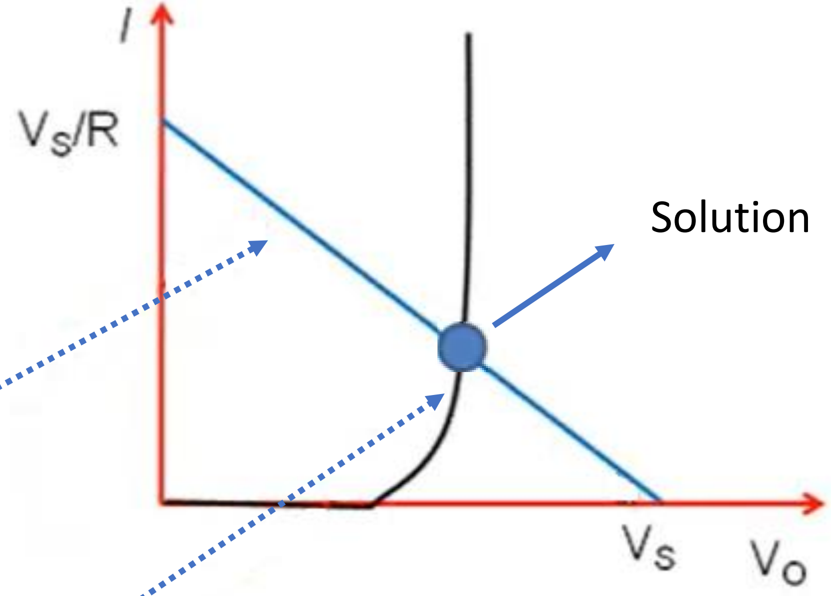
Graphical Method: Method of Load Line

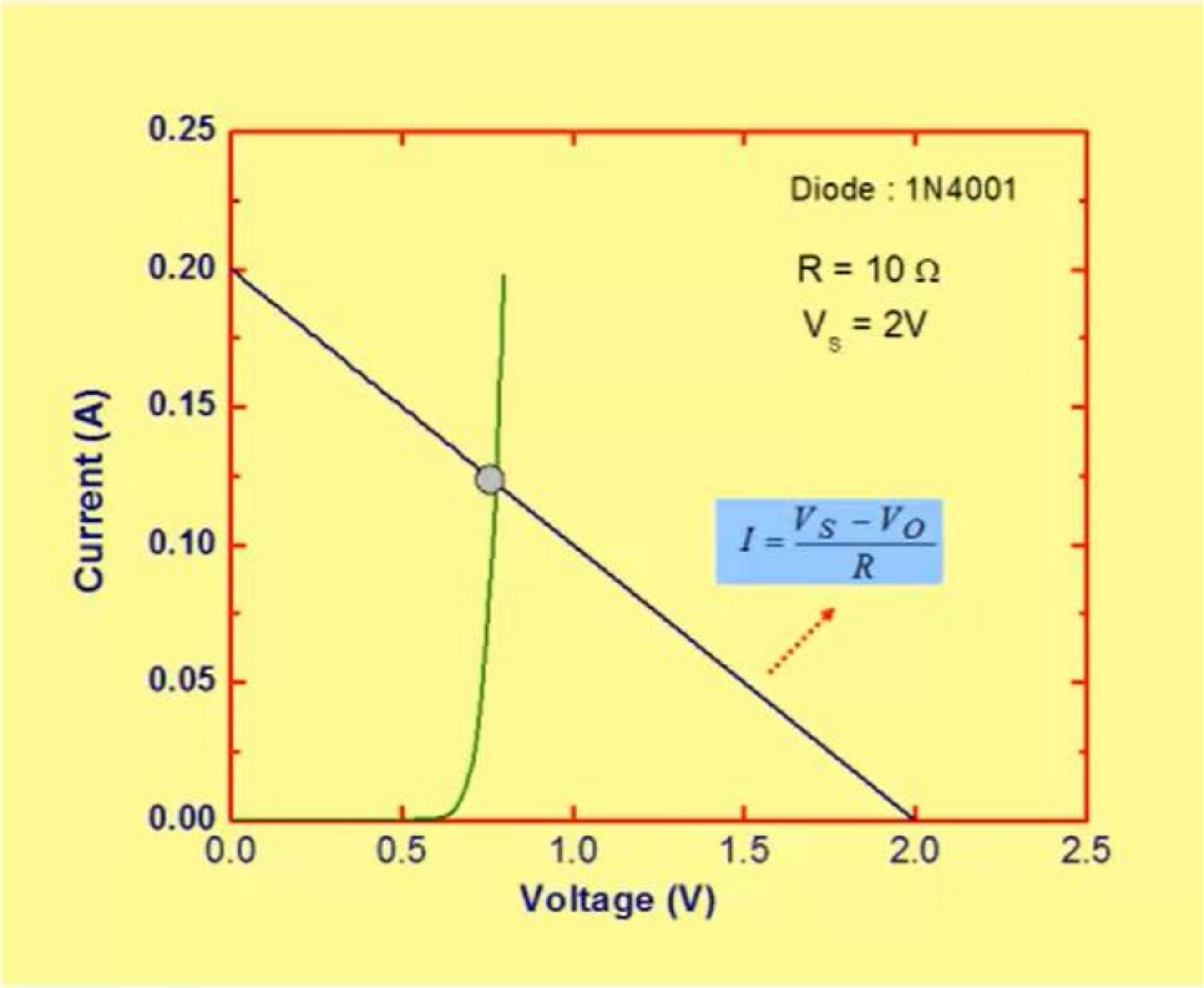


$$V_s = I \times R + V_o$$

$$I = \frac{V_s - V_o}{R}$$

$$I = I_s \times \{\exp(\frac{V_o}{nV_T}) - 1\}$$





$V_O = 0.77V$; $I = 0.12A$