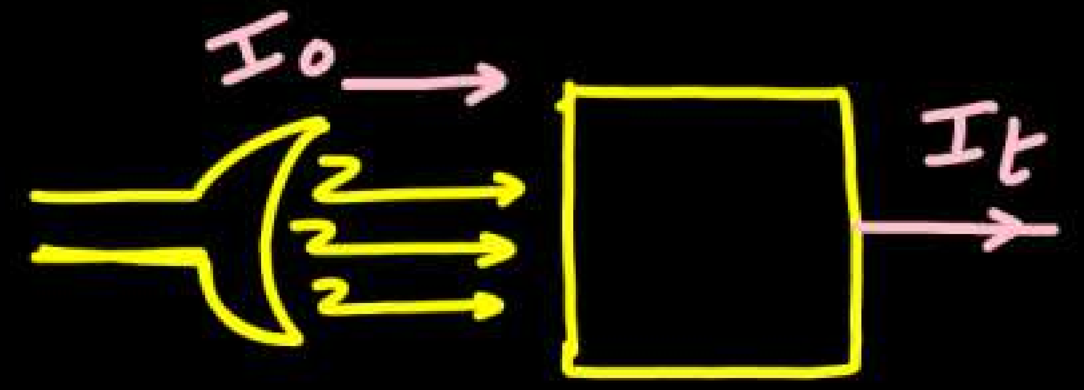
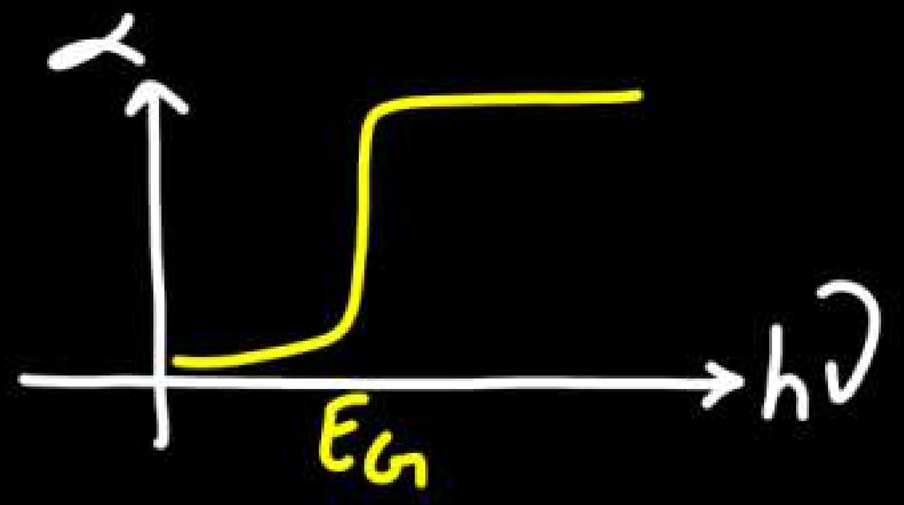
Photo Conduction



Intensity of Incident light $\rightarrow I_o$

Intensity of Transmitted light $\rightarrow I_t$

$I(x) = I_o e^{-\alpha x}$. | $\alpha \rightarrow$ Absorbtion coefficient.



If $\alpha = 0 \rightarrow h\nu < E_G \rightarrow I_t = I_o$

$\hookrightarrow$ No absorbtion

After Generation (G_L), to Propagate them for Conduction $\longrightarrow$ Bias Need to be given (Gradient)

As $I_L = \Delta q A(\mu_n + \mu_p)\bar{E} = G_L \tau_p q A(\mu_n + \mu_p)\bar{E}$

$$\therefore \frac{I_L}{G_L q A L} = \frac{\tau_p}{t_n}\left[1 + \frac{\mu_p}{\mu_n}\right] \longrightarrow \text{Photo Conductor GAIN.}$$

$\left[\because v_d = \frac{L}{t_n}, t_n \rightarrow \text{Transit time}\right]$.

The Rate @ which charge Collected by Contacts to the rate @ which charge is generated with in Photo Conductor.

Photo Diode

→ Photo Conduction.

→ Diode Can be Made up of Either Direct (or) Indirect b.gap.

→ Need Material with large α & $h\nu \geq E_G$ eV.

→ After G_L, If we provide Bias (F·Bias), then $I_D = I_0 \exp\left(\frac{V_D}{V_T}\right)$ will be Dominated than I_L

$\Rightarrow$ Total current @ o/p will be $I_D + I_L \simeq I_D$ $\Rightarrow$ Not photo current.

→ If we provide R·Bias, $I_D = \left[I_0 \exp\left(\frac{-V_D}{V_T}\right) - 1\right] - I_L$

$\Rightarrow I_D \simeq -I_0 - I_L \simeq -I_L \rightarrow$ photo current.

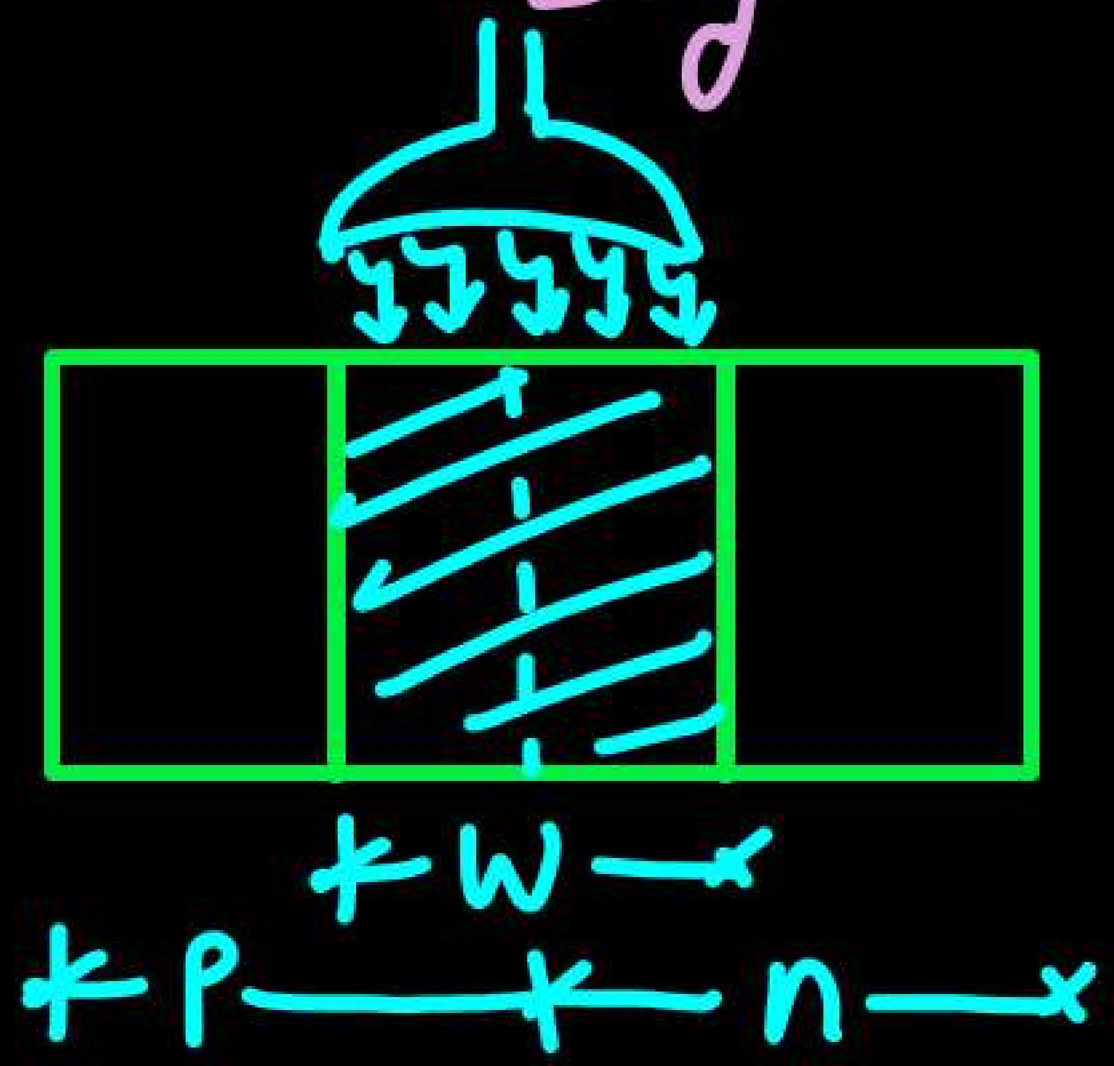
$\therefore$ P.Diodes Must be R·Biased.

Photo Diode

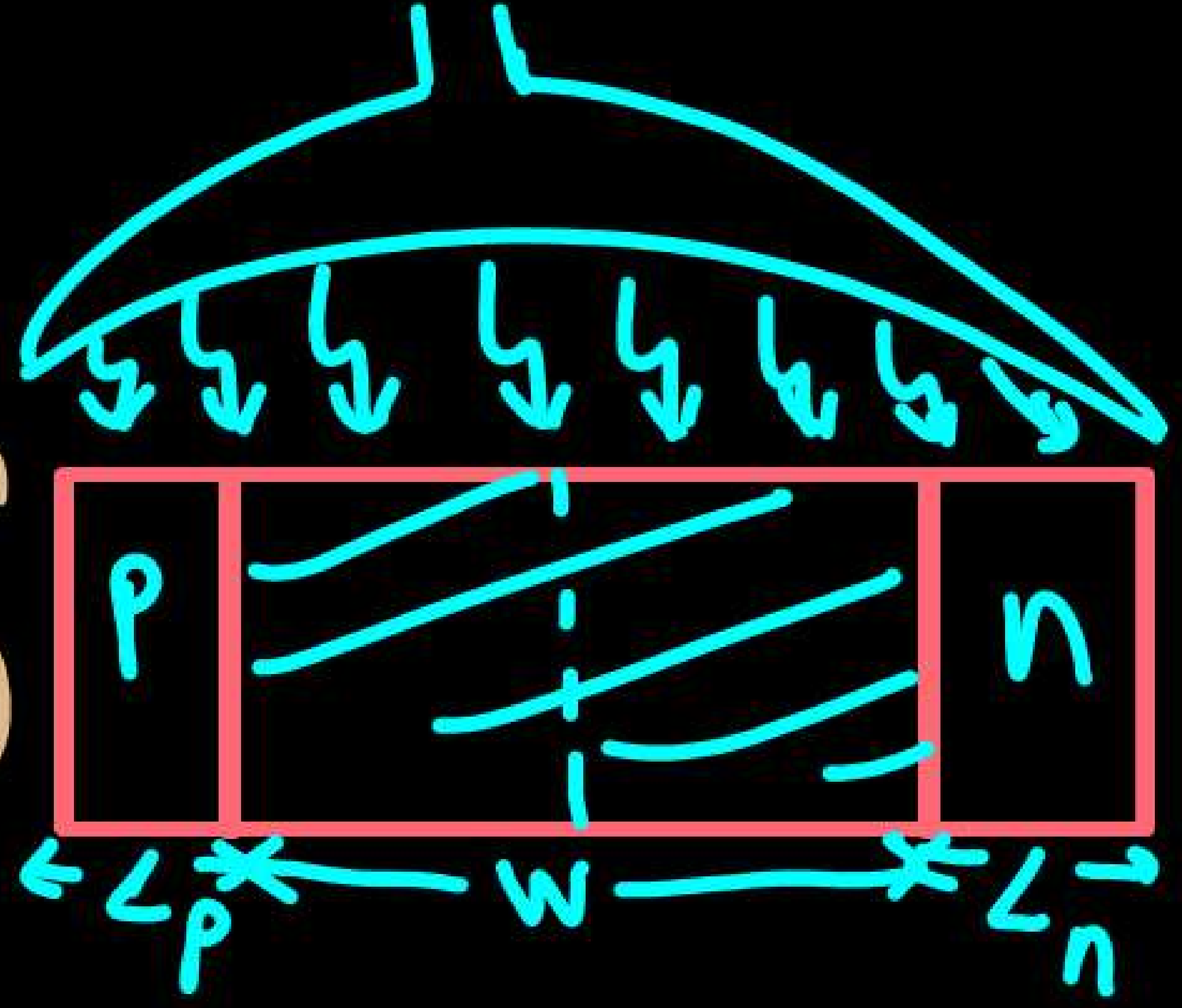
Since $J_{gen.} = q\int_0^W U_L\,dx = qU_LW = qG_LW \rightarrow$ In dep. region.

$\Rightarrow I_{gen.} = I_L = qAG_LW \rightarrow$ where $A \rightarrow$ Area @ which light is injected.

Prompt (or) Primary Current.



If we provide light through out body $\rightarrow$



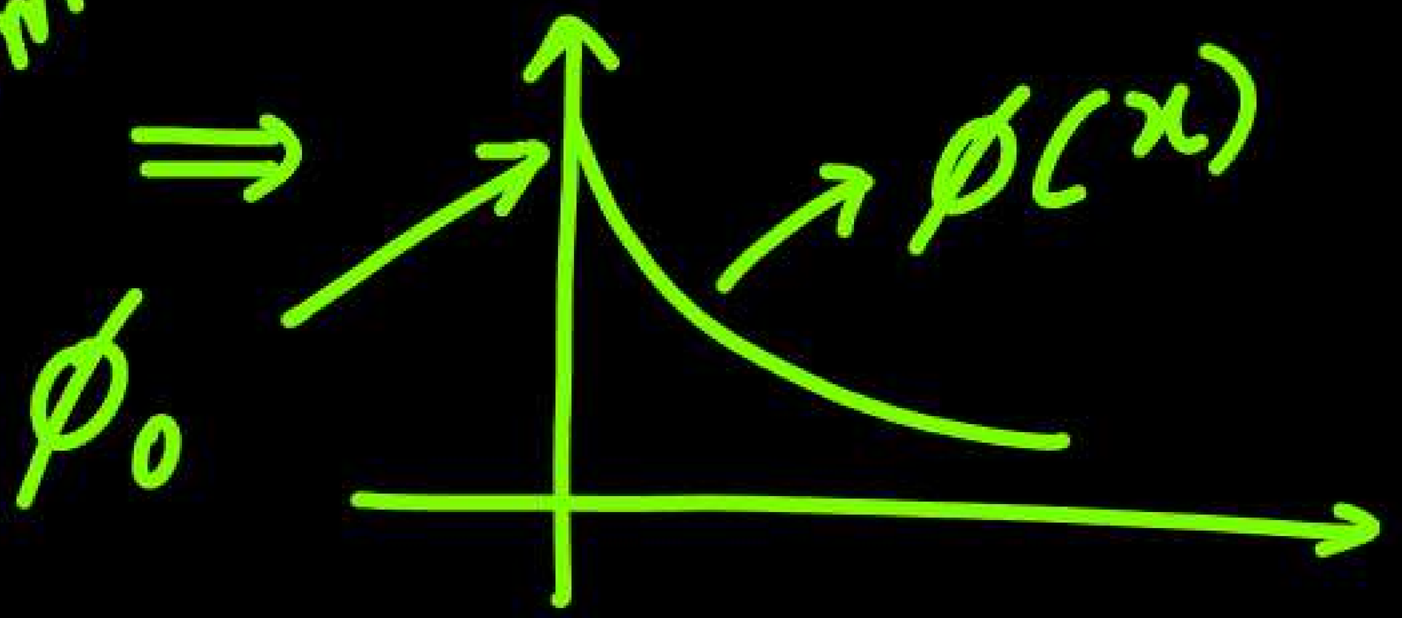
$J_L = qG_LW + qG_LL_p + qG_LL_n$

But in R. Bias, $W >>> (L_n + L_p)$

$\Rightarrow J_L \simeq qG_LW.$

All the Above Analysis → when ∃ G_L under Uniform Generation of Light.

In GATE Exam, if Examiner specified Non Uniform G_L ⟹



$$\Rightarrow G_L = \alpha \phi_0 \exp(-\alpha x)$$
$$= \alpha \phi(x)$$

where $\phi(x) \rightarrow$ Photo flux.

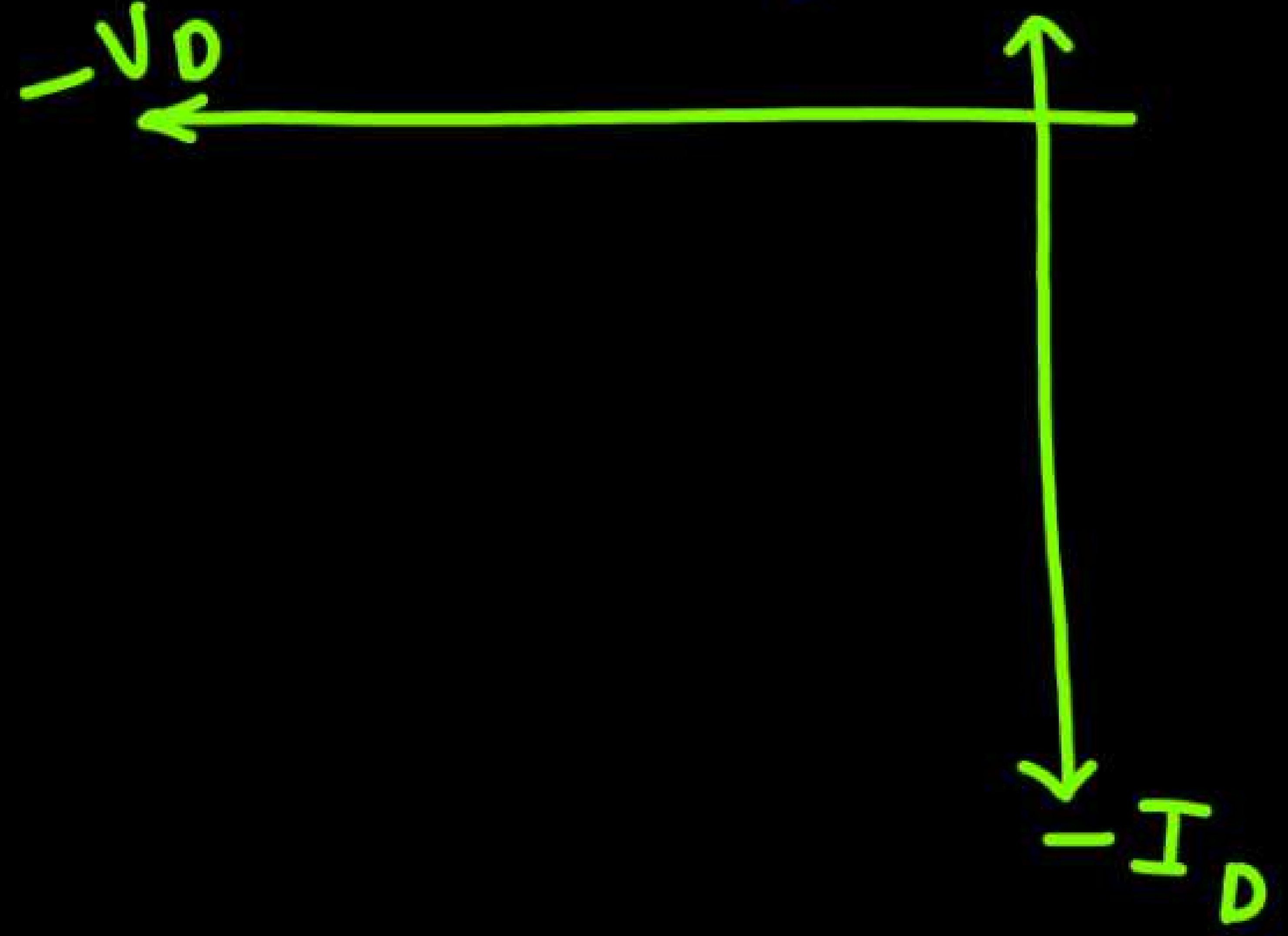
$$\phi(x) = \frac{I_\nu(x)}{h\nu}$$

$I_\nu(x) \rightarrow$ Irradiance (W/cm^2).

$$\therefore J_L = q \phi_0 [1 - e^{-\alpha x}]$$

Photo Diodes

$$I_D = I_0\left(\exp\left(\frac{-V_D}{\eta V_T}\right)-1\right) - I_L \Rightarrow I_D \simeq -I_0 - I_L.$$



If Intensity of Light Doubled, then

$I_L \longrightarrow$

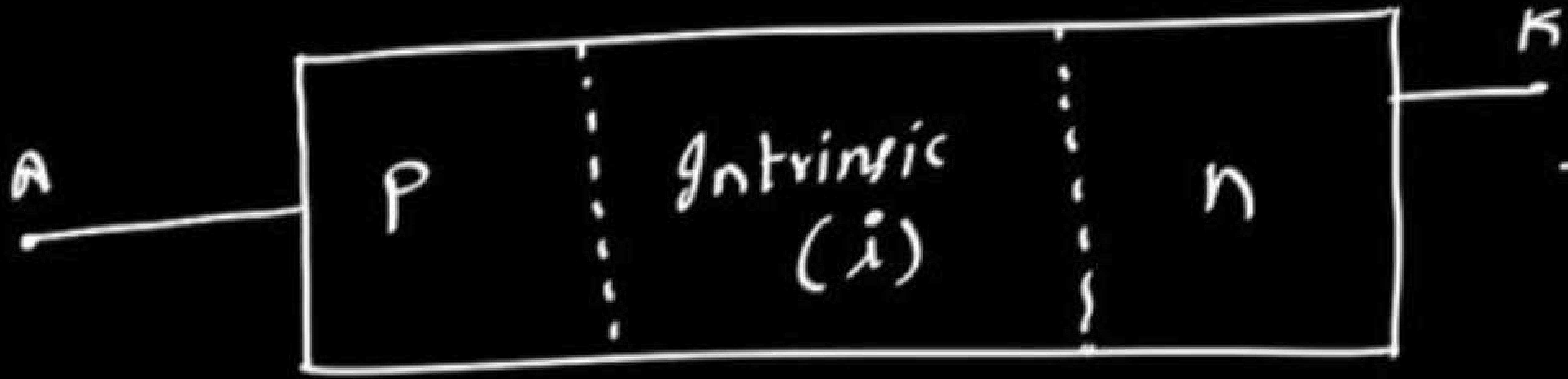
o/p $\longrightarrow I_L$

I/p $\longrightarrow (P_{in})_{Light}$

$\longrightarrow$ Sensitivity (or) Responsivity $\longrightarrow$ higher W $\Rightarrow$ higher irradiance $\Rightarrow$ Higher Responsiv.

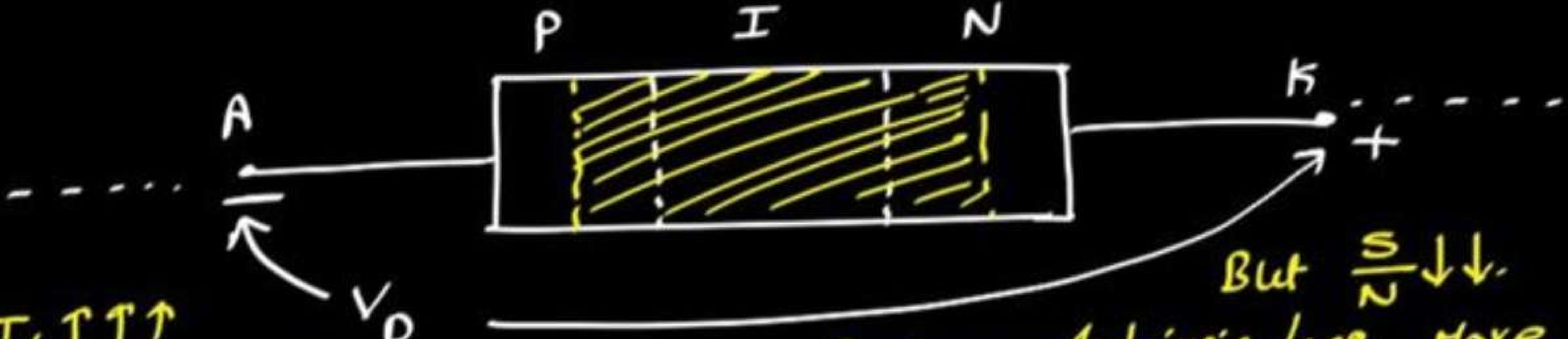
$$\therefore R = \frac{I_L}{(P_{in})_{opt}} \; A/W.$$

So, To produce Wide $\omega_{dep.}$ $\longrightarrow$ [$\because$ higher dop. $\Rightarrow$ lesser w.
$\therefore$ lesser dop. $\Rightarrow$ higher w.
$\therefore$ Zero dop. $\Rightarrow$ Infinite dep. width]



$\longrightarrow$ PIN Photo Diode.

Now Apply R-Bias $\rightarrow$



$\Rightarrow G_L \uparrow\uparrow\uparrow$

$\Rightarrow I_D \uparrow\uparrow\uparrow$

$\Rightarrow R \uparrow\uparrow\uparrow \Rightarrow I_L \uparrow\uparrow\uparrow$

$\Rightarrow$ Efficiency $\uparrow\uparrow$.

But $\frac{S}{N}\downarrow\downarrow$.

Because Intrinsic has More Thermal Noise.

Then what to Do?

$\therefore$ Practically Intrinsic is replaced with lightly doped p-region (or) lightly doped n-region.

$\therefore$ PIN Diode $\xrightarrow[\text{practically}]{}$ pp^-n / pn^-n

$\therefore$ Conversion Efficiency for photo Diode.

Quantum Efficiency : $\eta_e = Q_e = \dfrac{\text{Number of E.H.P. generated}}{\text{Number of Incident photons}}$.

$$= \frac{I_L/q}{P_{in}/h\nu} = \frac{I_L(h\nu)}{P_{in}\,q} = R\left[\frac{h\nu}{q}\right]$$

$$\therefore R = \frac{Q_e\, q}{h\nu}.$$

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$$\therefore \frac{I_{opt}}{P_{opt}} = \frac{\eta_e q}{hc/\lambda}$$

$$\Rightarrow I_{opt} = \frac{\eta_e q}{hc/\lambda} \times P_{opt}$$

$$\Rightarrow I_{opt} = \frac{\eta_e q}{hc/\lambda} \times \frac{P_{opt}}{A} \times A$$

irradiance (W/m^2)

$$\Rightarrow I_{opt} = \frac{\eta_e q}{hc/\lambda} \cdot I_{\gamma} \cdot A$$

In Many cases, $I_p \rightarrow$ Primary photo current $\rightarrow$ May not be suitable to produce Needed current to drive load (or) Next state $\Rightarrow$ we Need gain (or) Multiplication $\Rightarrow$ Need Avalanche Photo Diode.

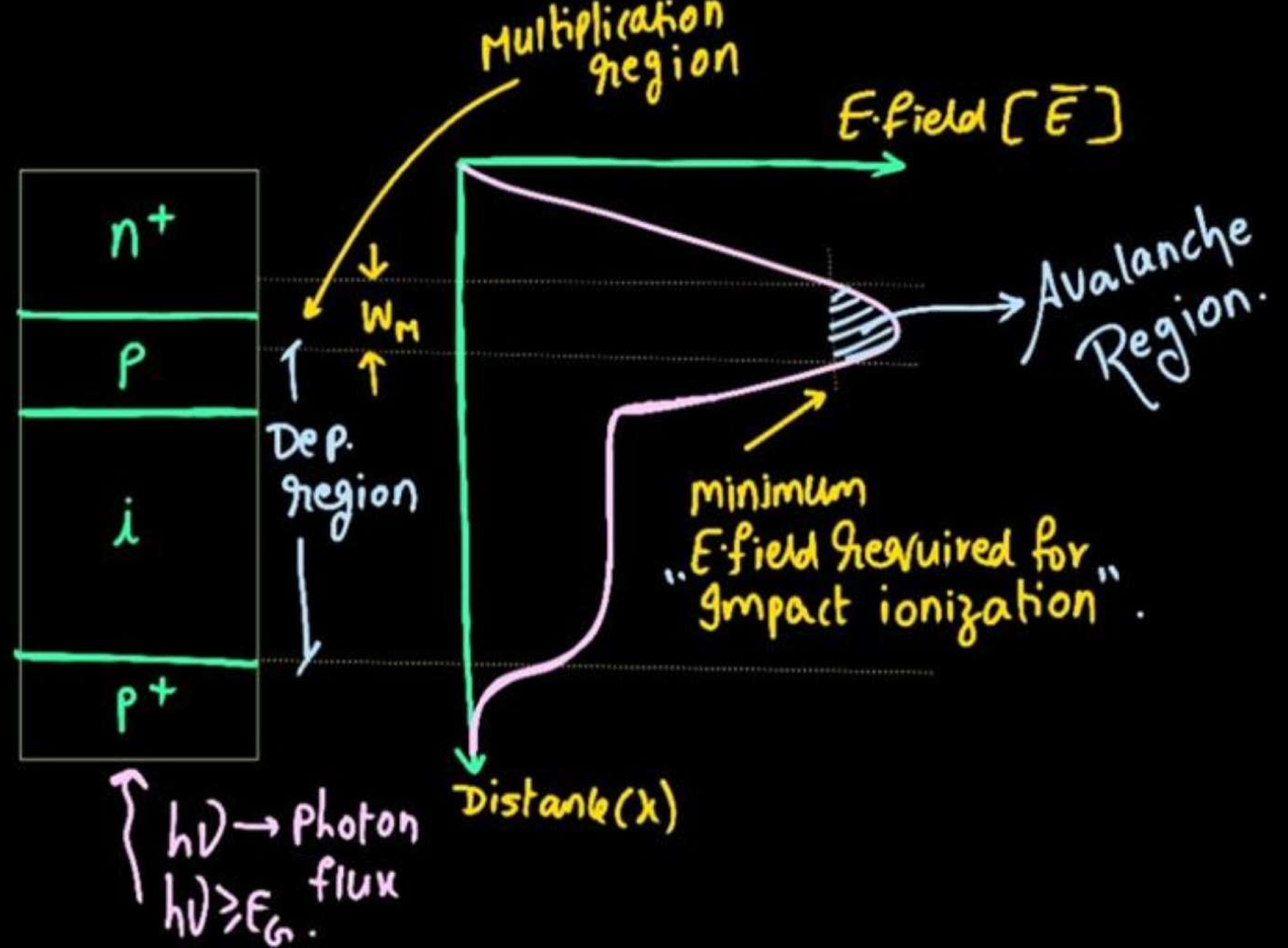
Responsivity of APD $\rightarrow$

$$R_{APD} = (R)M = \left(\frac{\eta_e q}{h\nu}\right)M.$$

Where, $M = \dfrac{I_M}{I_p}$, $I_M \rightarrow$ Average Multiplied photo current.

$I_p \rightarrow$ Un multiplied Photo current.

APD



Multiplication region
E-field [$\bar{E}$]
n^+
W_M
p
Dep. region
i
p^+
Avalanche Region.
minimum "E-field required for impact ionization".
Distance(x)
$h\nu \rightarrow$ photon flux
$h\nu \geq E_G$.

To get a better Response time, we go for PIN Diode.

PIN Photo Diode
- → Due to Intrinsic ∃ Very Wide Depletion Region.
- → $\lambda \rightarrow$ Range ($500 \rightarrow 1600\,nm$).
- → More better than pn Diode (large I_{λ}).
- → But Due to Intrinsic ∃ Noise $\Rightarrow \frac{S}{N} \downarrow\downarrow$
- → Not suits for low light Applications & $V_R \leq 3V$.
- → p^+nn^+, p^+pn^+.

Schottky Photo Diode

→ Hot carrier, Metal - SC Diode.

→ ∃ a barrier. ⇒ due to least barrier, Electrons & holes Can be Easily Seperated ⇒ fast Switching, Wide Band Applications.

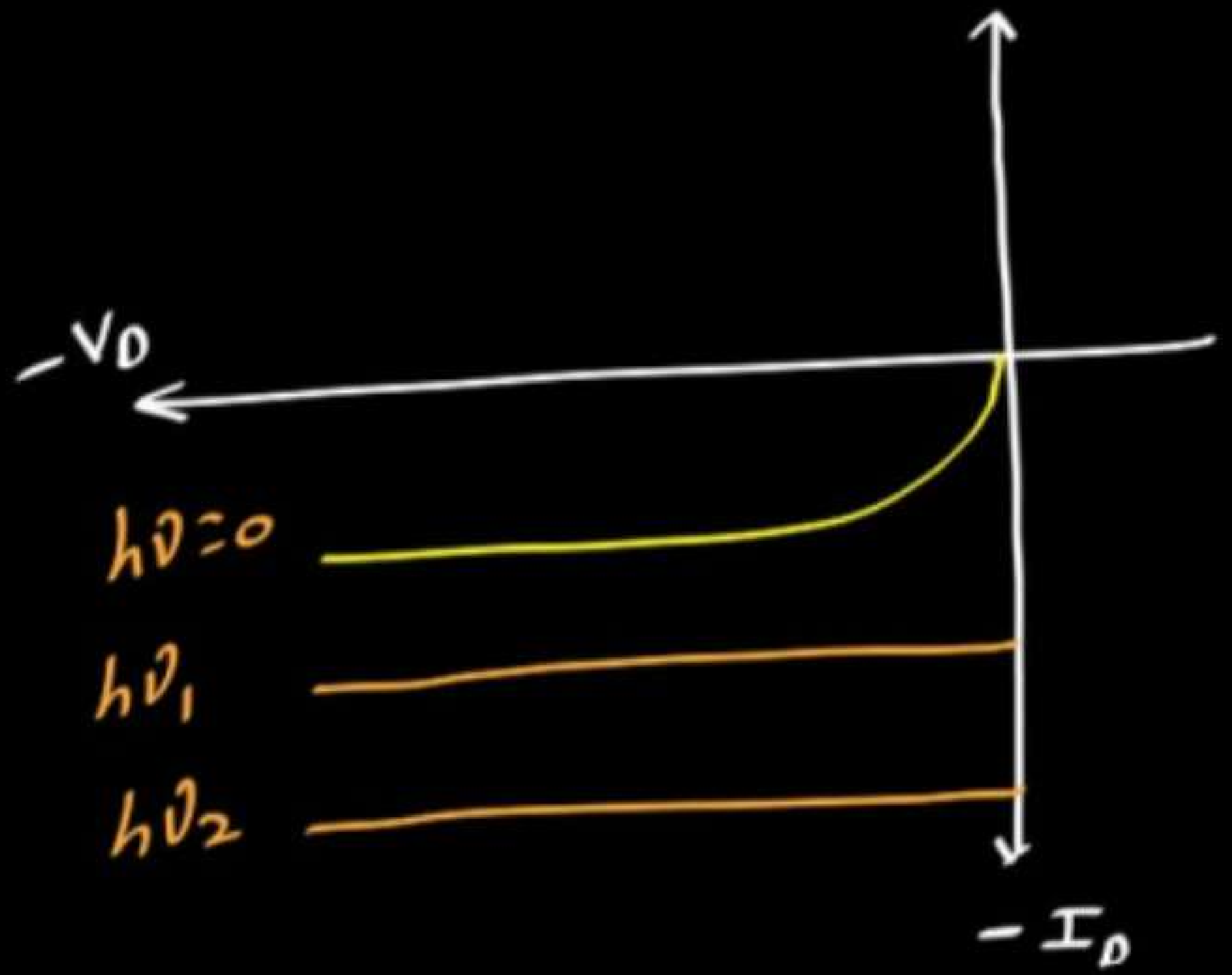
→ $C_D \cong 0$.

$C_T \rightarrow$ V.V.V. Small.

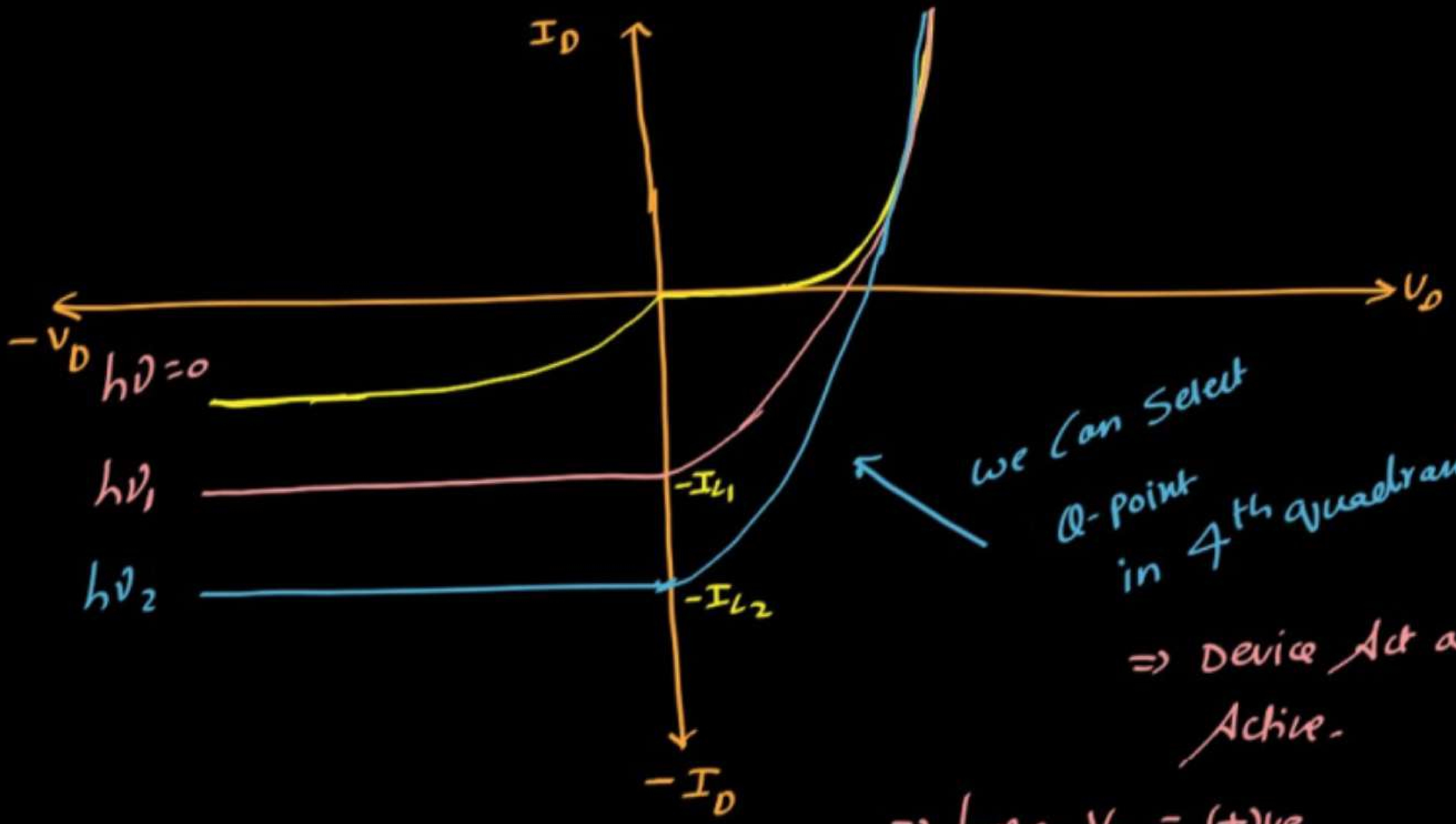
Metals → Platinum, Tungten, etc.,

Since characteristics of Photo Diode is →

Since we know for photo diode →



Now Just for Testing purpose, Apply a Small Forward Voltage, by keeping Same light.



we can select Q-point in 4^{th} quadrant.

$\Rightarrow$ Device Act as Active.

$\Rightarrow$ here $V_D = (+)ve$
& $I_D = (-)ve$.

$$\Rightarrow \quad I_D = I_0\left[\exp\left(\frac{+V_D}{\eta V_T}\right)-1\right] - I_L$$

$\longrightarrow$ This is Not a Photo Diode.

Because for photo Diode,

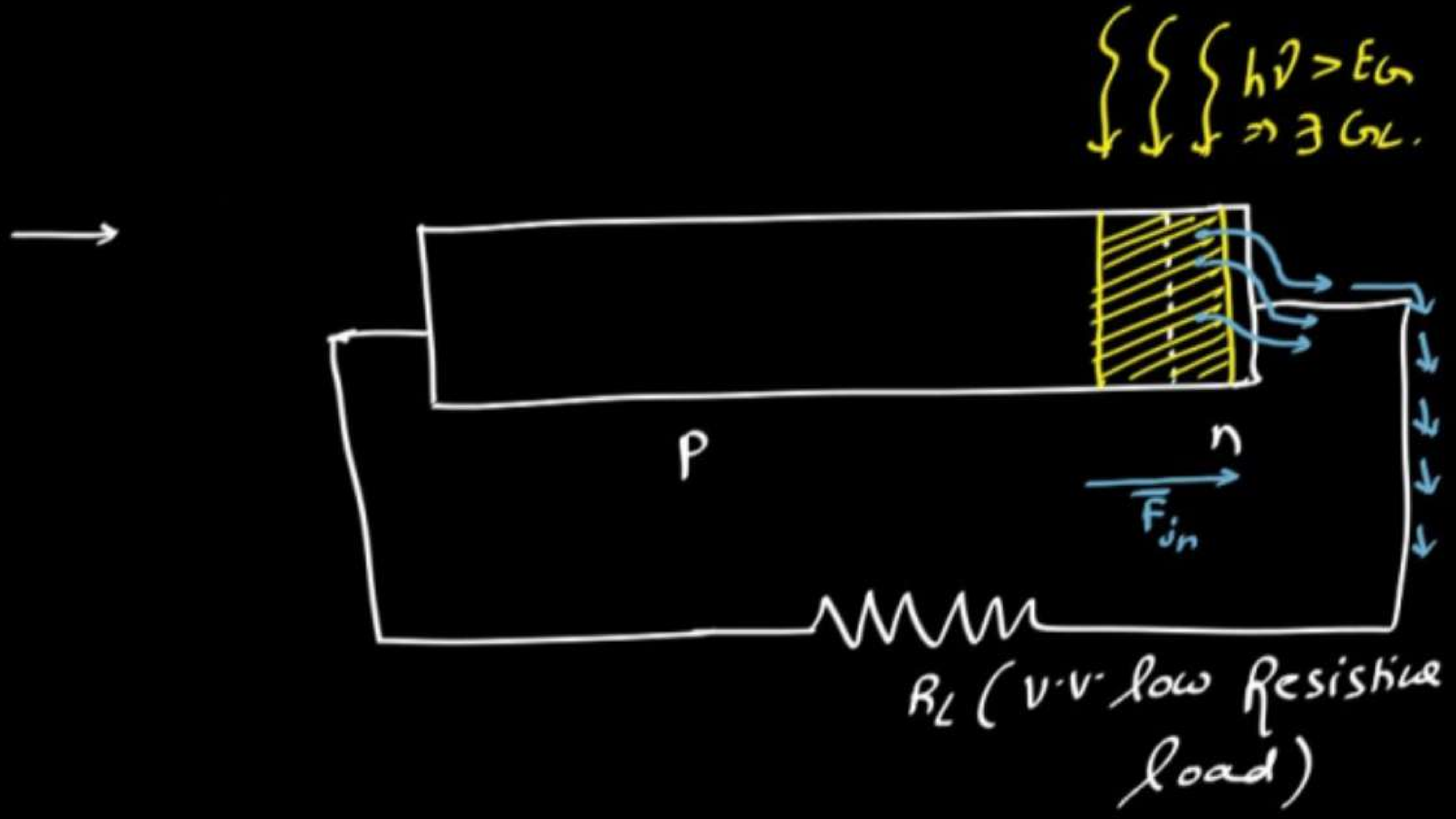
Q - Point $\longrightarrow$ 3rd quadrant.

$$I_D = I_0\left[\exp\left(\frac{-V_D}{\eta V_T}\right)-1\right] - I_L.$$

$\Rightarrow$ To produce this response $\longrightarrow$ we Need a Special Construction

$\longrightarrow$ Solar Cell.

(Photo Voltaic Cell) (PV cell).



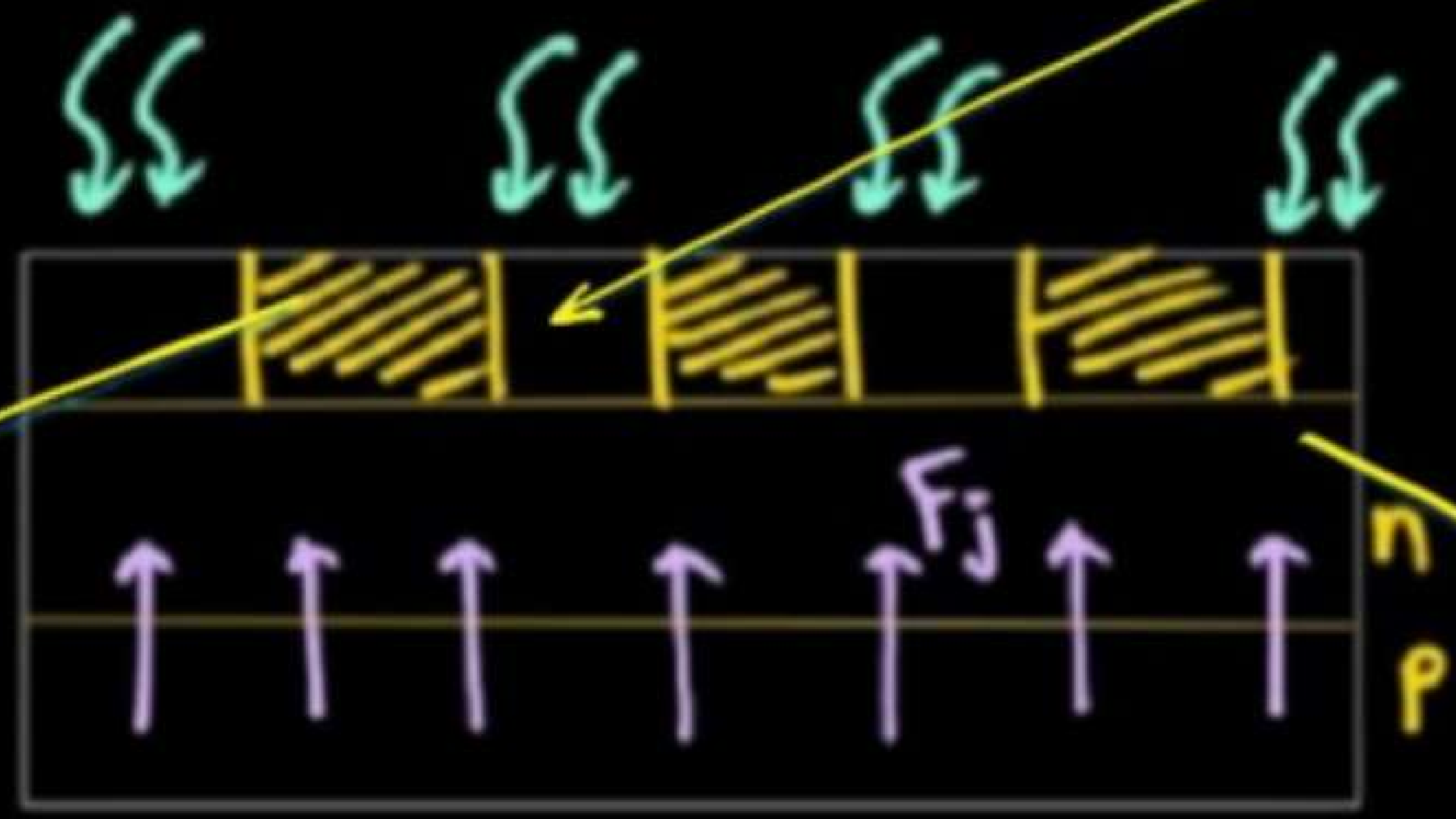
with out bias ∃ current.

∴ Solar cell don't need any External bias,

But it behaves as F. Bias.

Anti Reflecting Coating to Accomodate light inside Semiconductor.

Metal Contacts

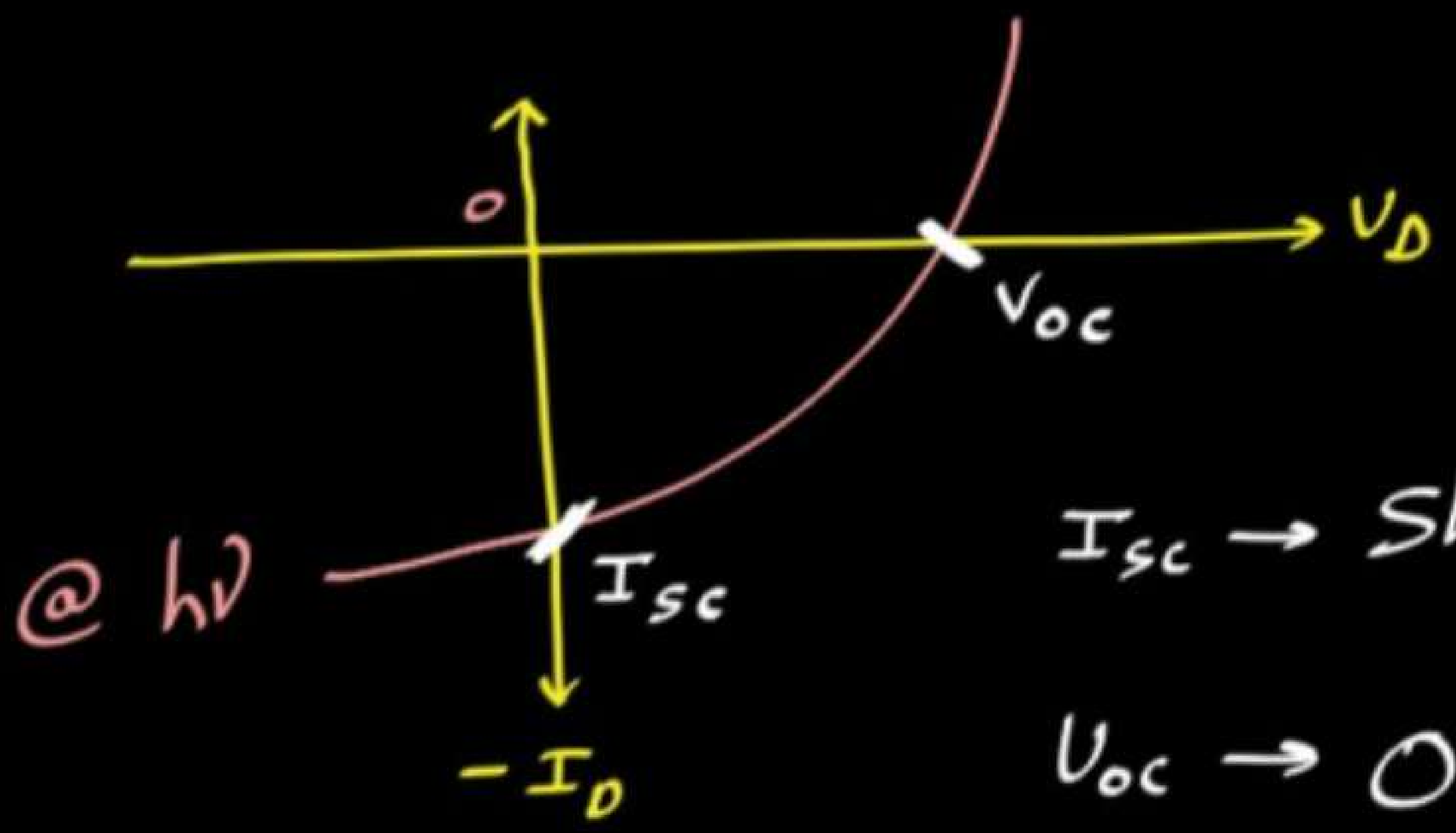


Advisable to be Very thin
$\Rightarrow$ Easy to Accumulate Carriers Out of n-Region.

$$\therefore \quad I_D = I_o\left\{\exp\left(\frac{+V_D}{\eta V_T}\right)-1\right\} - I_L \longrightarrow \text{Solar cell.}$$

$$I_D = I_o\left\{\exp\left(\frac{-V_D}{\eta V_T}\right)-1\right\} - I_L \longrightarrow \text{photo diode.}$$

$\therefore$ @ a particular light intensity $\rightarrow$



$I_{sc} \rightarrow$ Short Circuited current

$V_{oc} \rightarrow$ Open Circuited voltage.

$\therefore$ @ $V_D = 0V$, $I_D = I_{sc}$ | @ $I_D = 0$, $V_D = V_{oc}$

$\therefore$ Since, $\quad I_D = I_0\left[\exp\left(\frac{V_D}{\eta V_T}\right)-1\right] - I_L$

@ $I_D = 0$

$\Rightarrow V_D = V_{oc}$

$0 = I_0\left[\exp\left(\frac{V_{oc}}{\eta V_T}\right)-1\right] - I_L$

$\Rightarrow \boxed{V_{oc} = \eta V_T \log_e\left[1 + \frac{I_L}{I_0}\right]}$

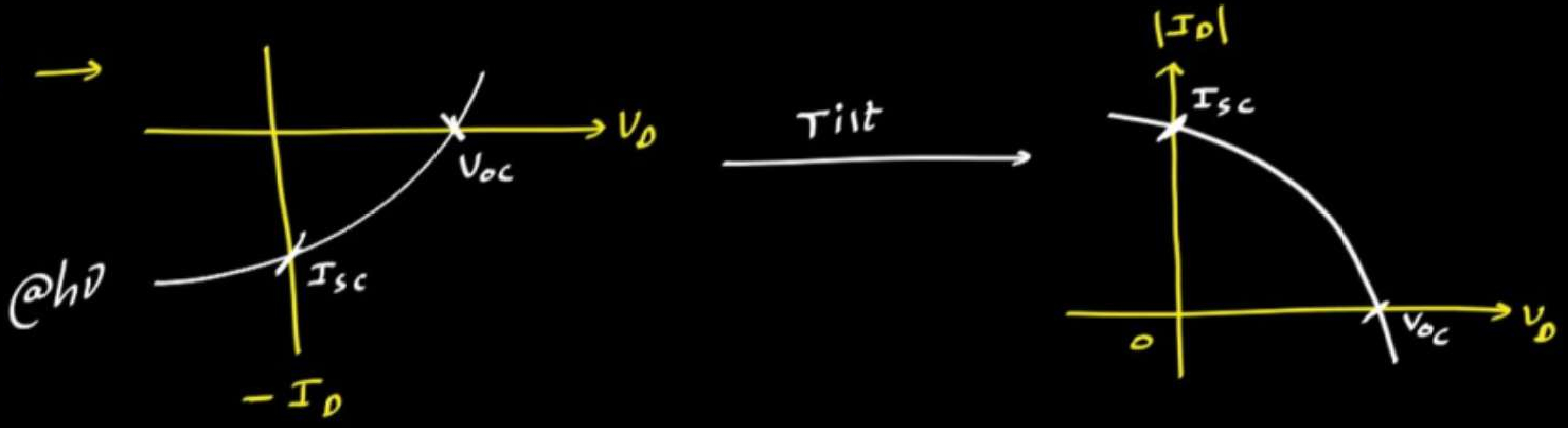
@ $V_D = 0$

$\Rightarrow I_D = I_{sc}$.

$\Rightarrow I_{sc} = I_0\left[1-1\right] - I_L$.

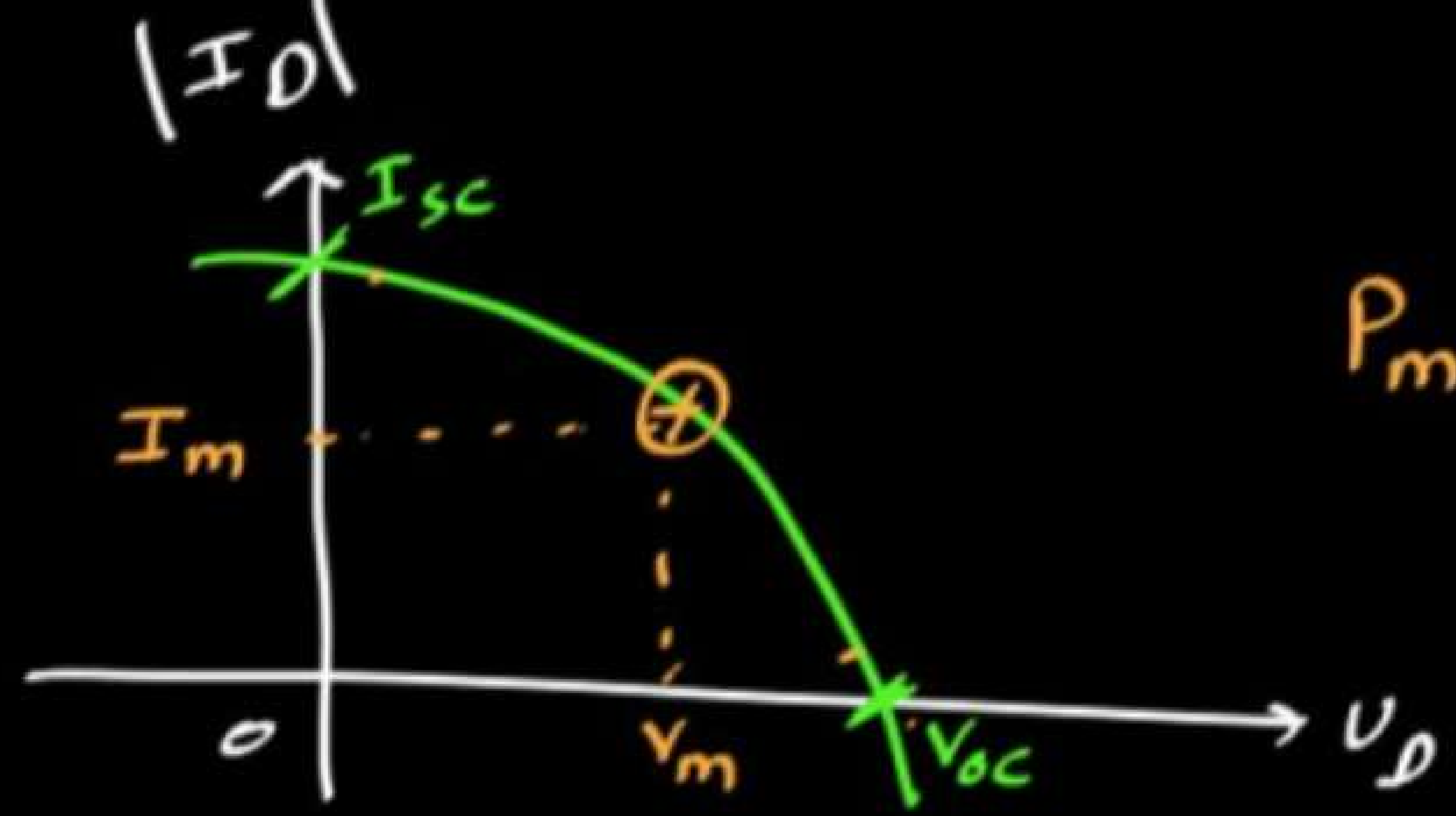
$\therefore I_{sc} = -I_L$.

Now →



Since Solar Cell is Active ⇒ Acting as a Source

⇒ Deliver power ⇒ Need to find Maximum power.



$P_m \rightarrow$ Max. power delivered to load

$= V_m I_m$.

But Solar cell

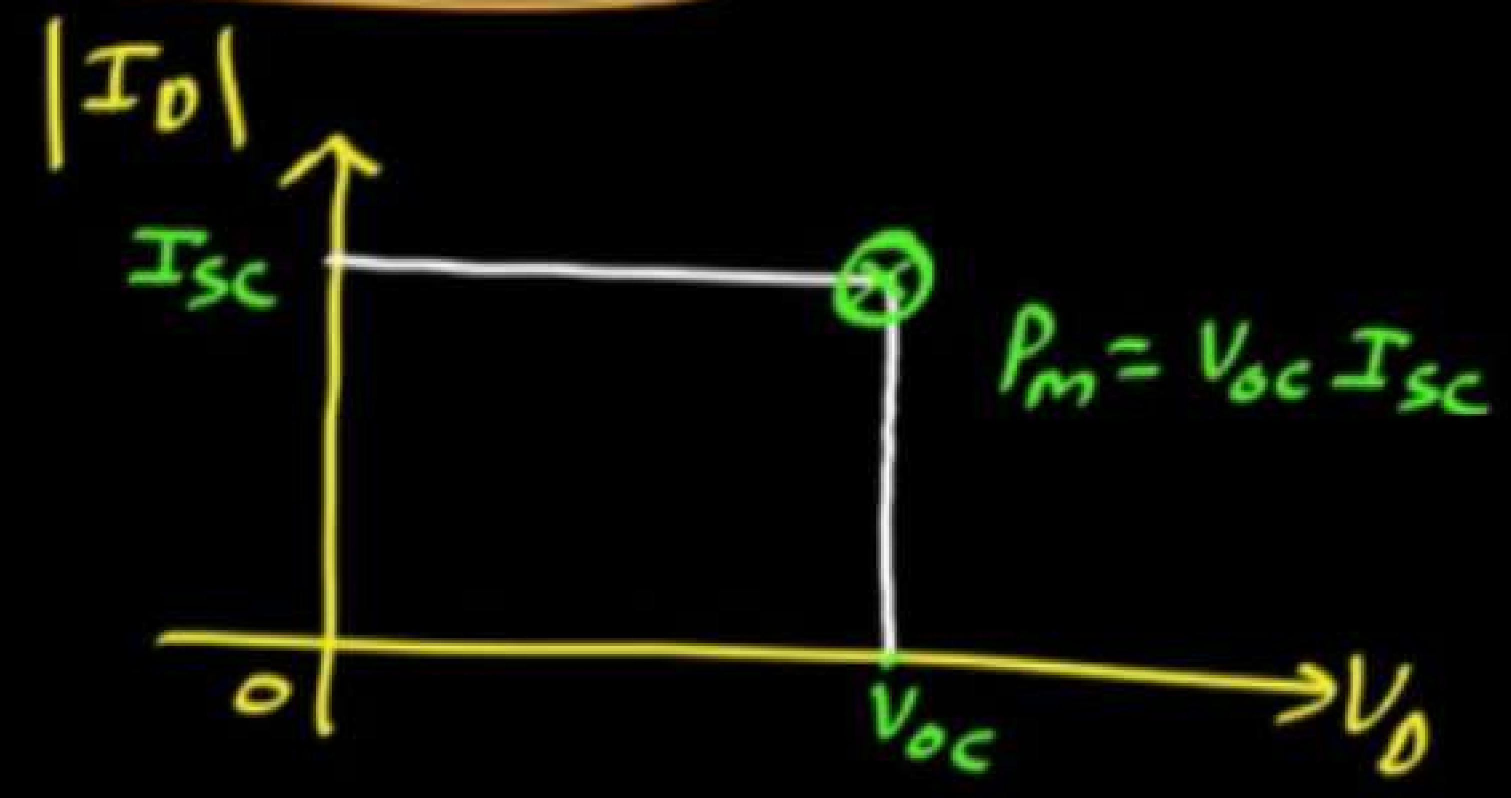
Can provide $V_{oc} I_{sc}$.

But

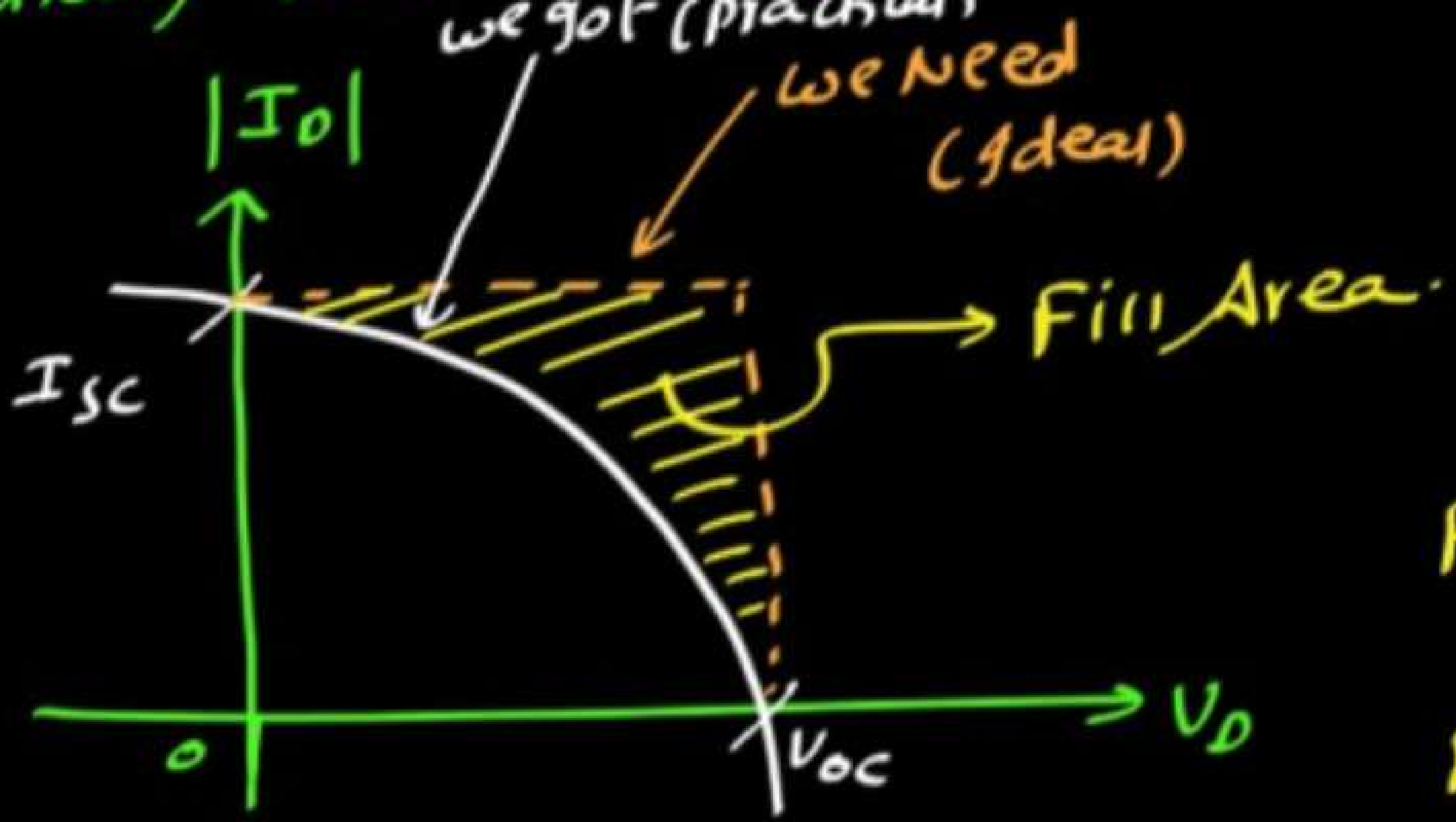
To provide $V_{oc} I_{sc}$

as power to load,

we need



But practically that is Not possible.



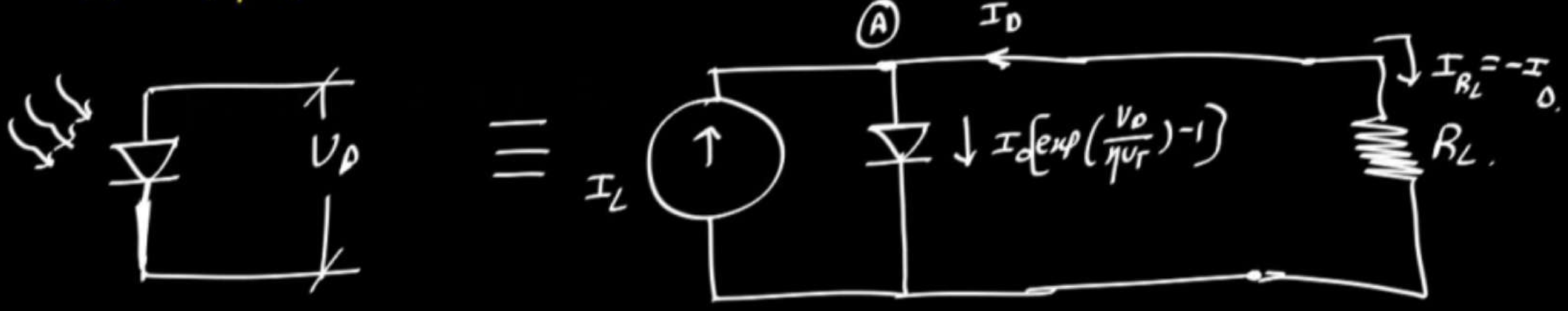
$$F.F. = \frac{I_m V_m}{I_{sc} V_{oc}}$$

↓

Fill factor.

$$\therefore \text{Conversion Efficiency, } \%\eta = \frac{(P_o)_{Electric}}{(P_{in})_{opt}} = \frac{V_m I_m}{(P_{in})_{opt}} = \frac{FF(I_{sc}V_{oc})}{(P_{in})_{opt}} \times 100.$$

∴ The power delivered to load →



$$\text{KCL @ A} \rightarrow \quad I_L + I_D = I_o\left[\exp\left(\frac{V_D}{\eta V_T}\right)-1\right]$$

$$\therefore I_D = I_o\left[\exp\left(\frac{V_D}{\eta V_T}\right)-1\right] - I_L \rightarrow \text{Satisfying Solar cell.}$$

∴ Above c/k is Equivalent c/k of Solar cell.

$$P = VI = VI_{R_L} = V[-I_D].$$

$$\therefore\ P = I_L V - I_0\left[\exp\left(\frac{V}{\eta V_T}\right) - 1\right] V$$

Since to find V_{max} $\longrightarrow$ from C/K Analysis, we know that, diff. power with Voltage & Equate it to Zero.

$$\Rightarrow \frac{dP}{dV} = 0.$$

$$\Rightarrow \quad I_L - I_0\left[\exp\left(\frac{V_m}{V_T}\right)-1\right] - I_0 V_m\left[\frac{1}{V_T}\right]\exp\left(\frac{V_m}{V_T}\right) = 0.$$

$$\Rightarrow \boxed{\left[1+\frac{V_m}{V_T}\right]\exp\left(\frac{V_m}{V_T}\right) = 1+\frac{I_L}{I_0}}.$$