(MPM-202)
Optoelectronics and Optical Communication System

UNIT-II (Optical Sources and Detectors)

Lecture-4

by

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SYLLABUS

MPC-202 OPTOELECTRONICS AND OPTICAL COMMUNICATION SYSTEM Credits 4 (3-1-0)

UNIT I: Optical process in semiconductors

Optoelectronic properties of semiconductor: effect of temperature and pressure on bandgap, carrier scattering phenomena, conductance processes in semiconductor, bulk and surface recombination phenomena, optical properties of semiconductor, EHP formation and recombination, absorption in semiconductors, effect of electric field on absorption.

UNIT II: Optical sources and detectors

An overview of optical sources (Semiconductor Laser and LEDs), Optical Detectors: Type of photo detectors, characteristics of photo detectors, noise in photo detectors, photo transistors and photo conductors.

UNIT III: Optical fiber

Structure of optical wave guide, light propagation in optical fiber, ray and wave theory, modes of optical fiber, step and graded index fibers, transmission characteristics of optical fibers, signal degradation in optical fibers; attenuation, dispersion and pulse broadening in different types of optical fibres.

UNIT IV: Fiber components and optoelectronic modulation

Fiber components: Fibre alignments and joint loss, fiber splices, fiber connectors, optical fiber communication, components of an optical fiber communication system, modulation formats, digital and analog optical communication systems, analysis and performance of optical receivers, optoelectronic modulation.

General Characteristics of Photodetectors

➢ There are some important parameters-

i. η → the external Quantum efficiency

ii. R → Responsivity

iii. t_r → Rise time/ Impulse response

iv. P_{Noise} → Noise power/ dark current

As far as we have discussed the external quantum efficiency and responsivity.

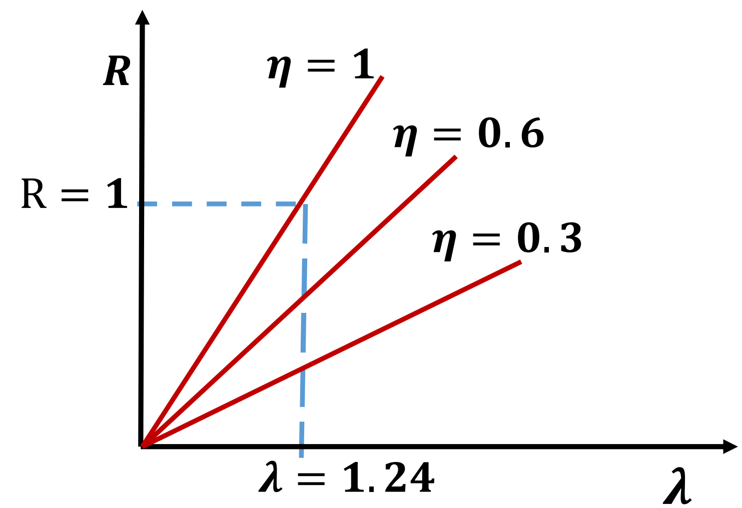
- Today we are going to discuss the **'rise time/impulse response'** in detail.

General Characteristics of Photodetectors

- We had expression for responsivity of a detector given by-

$$\boxed{R = \frac{\eta\,\lambda\,(\mu m)}{1.24}\ \text{(A/W)}}$$

- The plot of responsivity vs λ then we have straight lines for different values of η-

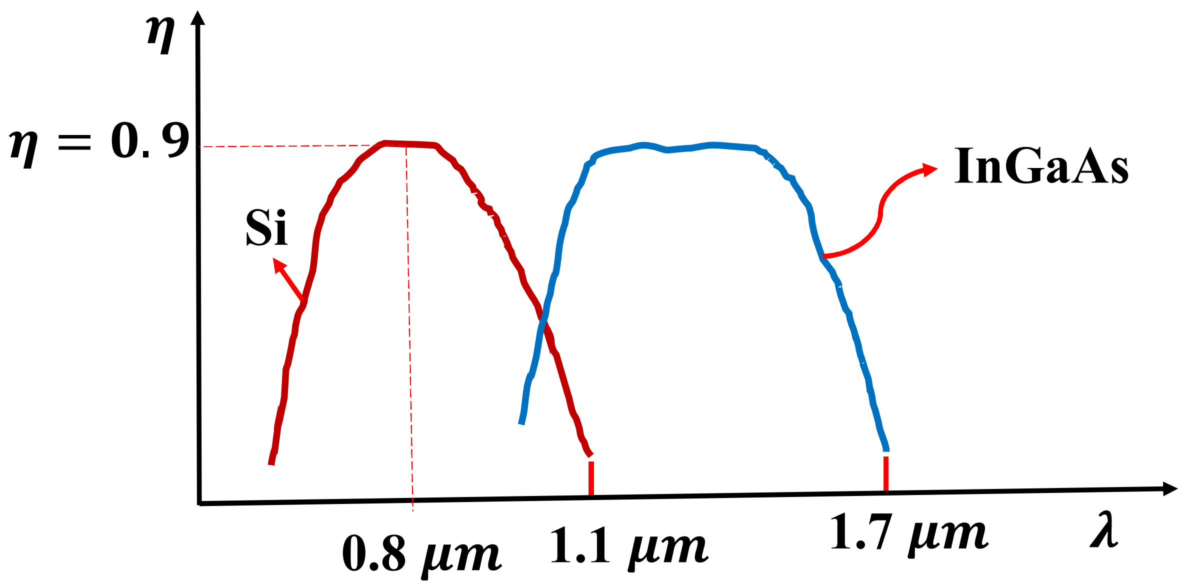


- For $\eta = 1$ and $\lambda = 1.24\ \mu m$ then **R=1.**

- **This is graph assuming that quantum efficiency η is constant but in practical η is not constant.**

General Characteristics of Photodetectors

- The variation of η with respect to wavelength is given by-



- From the above curves for the variation of η with respect to λ we have following observations-

General Characteristics of Photodetectors

- The maximum efficiency for silicon is **0.9** at a wavelength **0.8 μm** and there after it goes down and approaching to **0** at a wavelength **1.1 μm.** The reason that the quantum efficiency goes down at both the ends is-

- **Cut off at longer wavelength**

- *The absorption coefficient goes to zero as the absorbed photons has energy less than the bandgap (or the wavelength is greater with respect to bandgap).*

- Since 1.1 eV is the bandgap of Si, thus below this energy no photons will be absorbed. So, the quantum efficiency of Si goes down to zero at longer wavelength.

- Simillarly InGaAs (which has a lattice match with InP and we can grow

- defect free hetero structures) having bandgap of approximately 0.7 eV so the the quantum efficiency goes down to zero at longer wavelength.

❖ **<u>Cut off at shorter wavelength</u>**

➢ The reason for cutoff of efficiency at shorter wavelength are-

i. Generation of hot carriers-

- When incident photon energy have shorter wave length i.e. when a photon of **energy much higher than the bandgap** is absorbed the electron from V.B. goes to the higher allowed energy state in C.B. which is a **high energy carrier or hot carrier.**

General Characteristics of Photodetectors

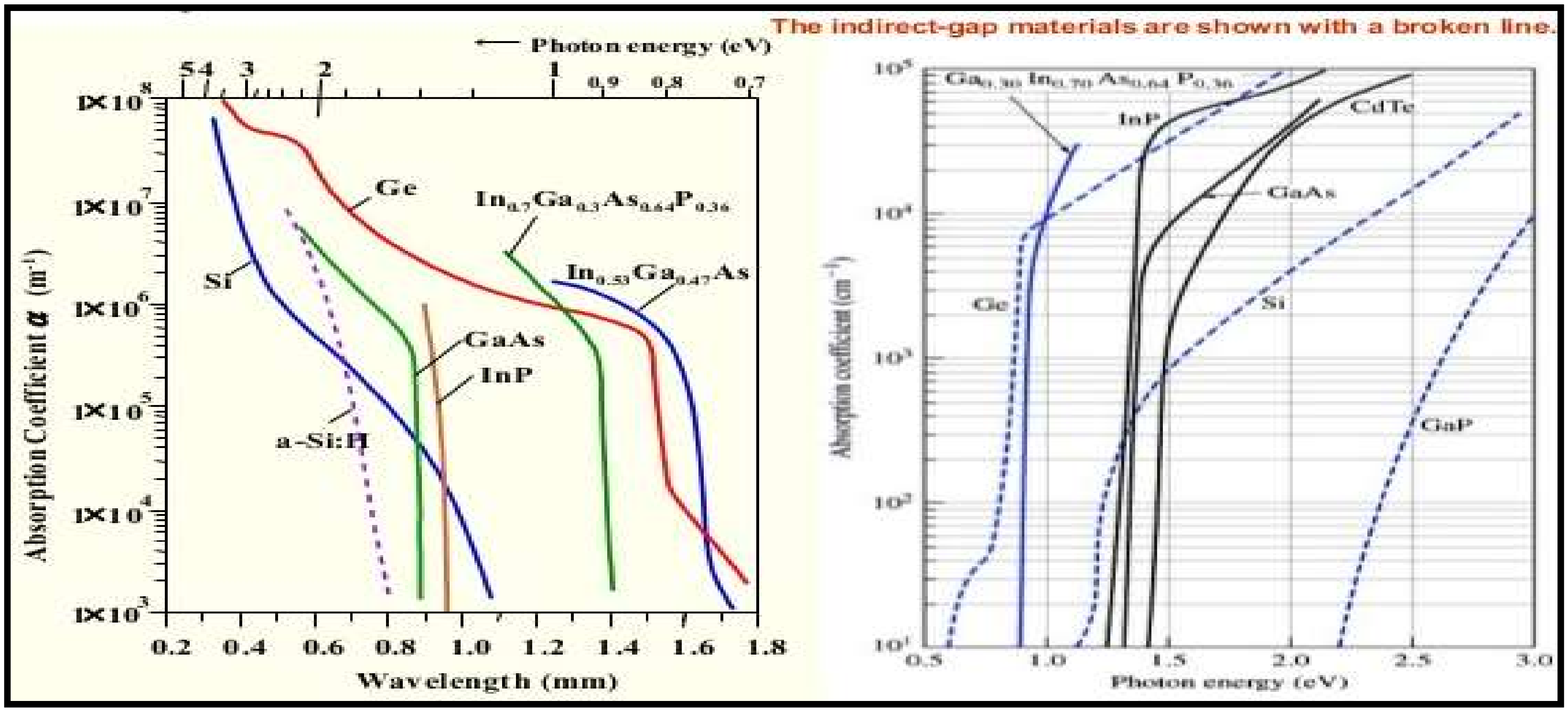
- The high energy carrier or hot carrier at higher level in the C.B. comes to the minima of C.B. by **thermalization process** i.e. dissipating its energy in form large number of **phonons** and the recombines **non-radiatively.**

- Thus the generation of hot carriers at shorter wavelength results in is no any photocurrent or e-h pair contribute in external current and hence the efficiency is dropping down at shorter wavelength.

General Characteristics of Photodetectors

ii. Absorption Near the Surface

- Since at **lower wavelength or for higher energies** the absorption coefficient is high as shown in figure-



General Characteristics of Photodetectors

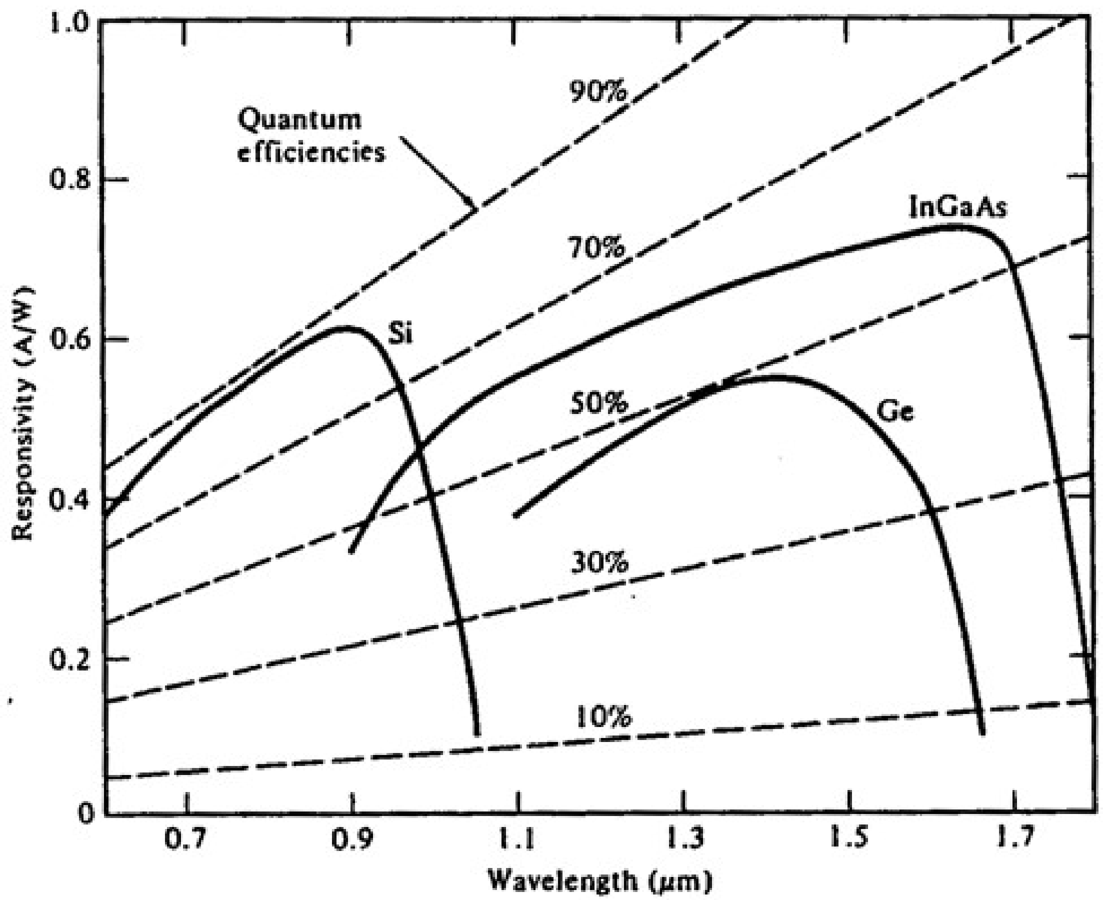
- This higher value of α at shorter wavelength results in the absorption of incident photons close to the surface and absorption coefficient is given by $e^{-\alpha d}$ so if **α is very large** then **d should be very small** means all the light is absorbed in the very thin layer of the surface.

- In many devices surface is not a very good place to absorb the incident photons as there are surface states due to **dangling bonds (incomplete bonds)** at the surface.

- These act as traps in the forbidden gap which results in carrier recombination thus decrement in η is absorbed at lower wavelength.

General Characteristics of Photodetectors

- Thus the practical curve of responsivity as a function of wavelength is shown below-



General Characteristics of Photodetectors

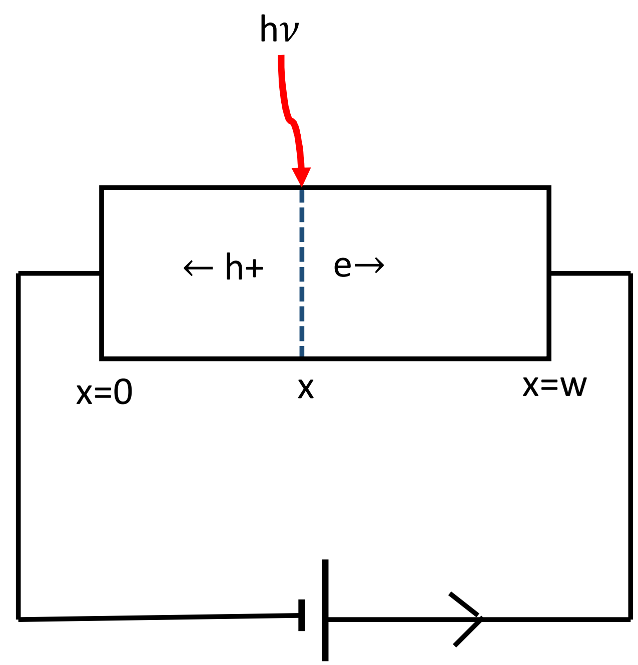
3. Impulse Response

- Impulse respond refers to the response of the detector to an input impulse.
- Impulse is an instantaneous pulse.
- We want to know that if one photon at an instant 't' incidents on the device then how would the current in the external circuit look like.
- The current in the circuit is given by **'Remo's Theorem'.**
- **Remo's Theorem states that-** "If a charge **q** moves in a medium with velocity **v(t)** i.e. of length **'w or l'** then the current **i(t)** in an external circuit is given by

General Characteristics of Photodetectors

$$\boldsymbol{i(t) = -\frac{q}{w} v(t)} \qquad \textbf{(11)}$$

- Let us consider a photodetector of width **'w'** and the bias is applied to the photo conductor
- Then the total current due to electron and hole motion is given by



$$\boldsymbol{i(t) = i_e(t) + i_h}$$

$$\boldsymbol{i(t) = -\frac{(-e)v_e}{w} + \left(-\frac{e(-v_h)}{w}\right)}$$

$$\boldsymbol{i(t) = -\frac{e}{w}(v_e + v_h)} \qquad \textbf{(12)}$$

General Characteristics of Photodetectors

- Here $\boldsymbol{v_e}$ and $\boldsymbol{v_h}$ are the drift velocity of electron and holes respectively.

- Since $\boldsymbol{v_e = \mu_e E}$ and $\boldsymbol{v_h = \mu_h E}$ where $\boldsymbol{\mu_e}$ and $\boldsymbol{\mu_h}$ are the mobilities of electrons and holes respectively and **E** is the applied electric field.

- Thus the output current depends on drift velocity of carriers and thus on their mobilities.

- The mobilities of carriers for some useful semiconductor materials are tabulated here-

General Characteristics of Photodetectors

Material	Electron mobility	Hole mobility
Si	1500	450
Ge	3900	1900
GaAs	6500	400
InP	4600	150
InGaAs	**14000**	**400**

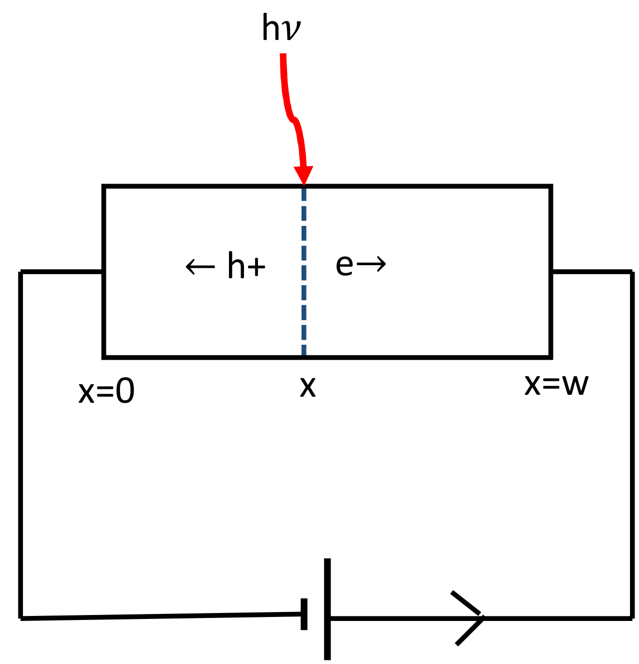
- Since electron mobility is much larger than the hole mobility so the current due to electron will be larger than that of hole.

- If there is creation of an electron and hole in the material then they will move in opposite to each other due to applied bias and we will have external current due to the motion of carriers inside the material as far as they are collected by the electrodes.

General Characteristics of Photodetectors

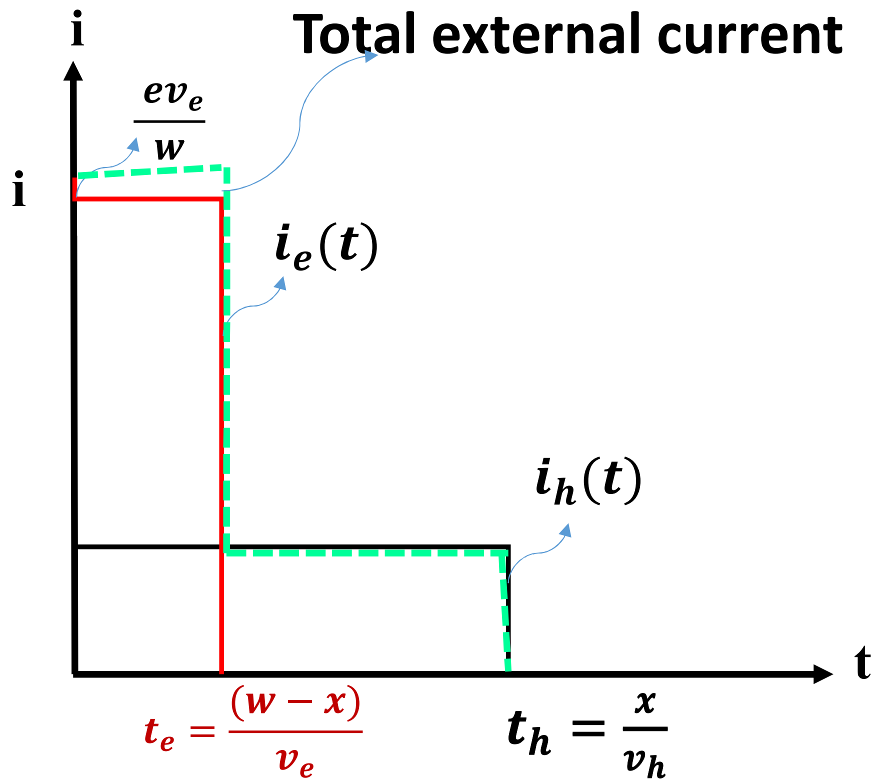
- The generated electron travels a distance of (w-x) with velocity $\boldsymbol{v_e}$ in time $\boldsymbol{t_e}$ then upto time $\boldsymbol{t_e = \frac{(w-x)}{v_e}}$ we will have external current due to electron.

- Similarly, the generated hole travels a distance of (w-x) with velocity $\boldsymbol{v_h}$ in time $\boldsymbol{t_h}$ then upto time $\boldsymbol{t_h = \frac{x}{v_h}}$ we will have external current due to electron.



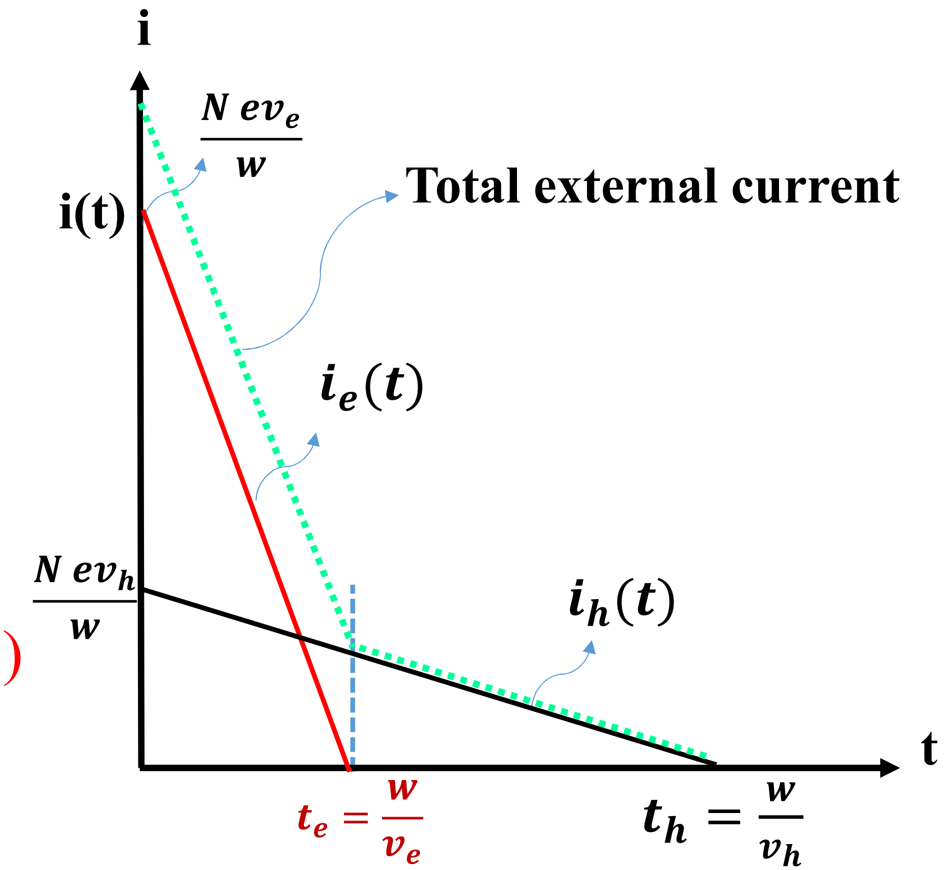
General Characteristics of Photodetectors

- Therefore the plot of external current with time is shown below-



General Characteristics of Photodetectors

- And for large number of photons incidenting on entire detector then the graph between i(t) and t is shown below-



- The impulse response depends on two factors-

i. The transit time of carriers

(i.e. If we want a high speed detector, The velocity of the carriers should be as large as possible and t_e should be equal to t_h and also small w means small area detector so that we get small t_e and t_h)

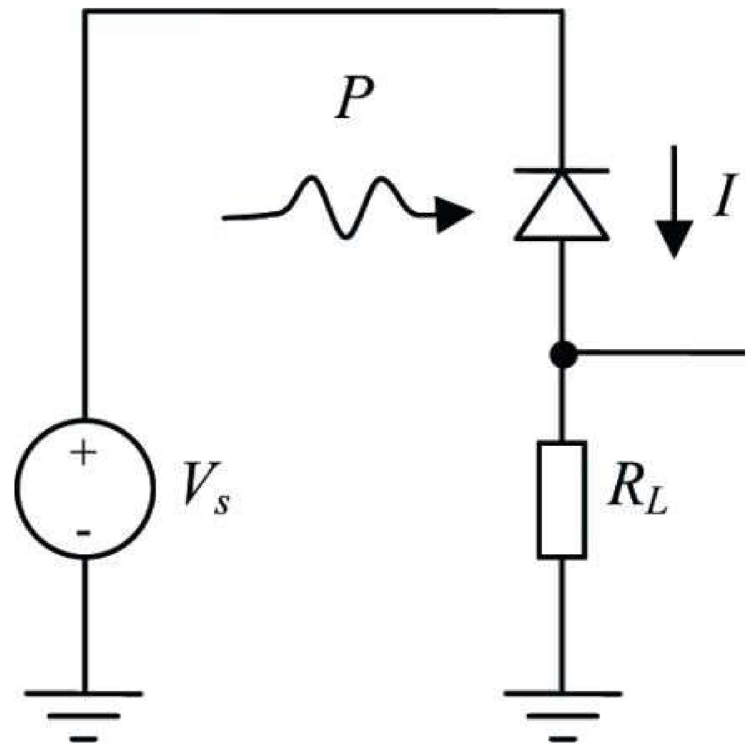
$$t_e = \frac{w}{v_e} \text{ and } t_h = \frac{w}{v_h}$$

General Characteristics of Photodetectors

ii. The RC time constant in the circuit

(i.e. In a standard detector circuit there is a load resistance **'R_L'** and junction capacitance **'C'** then the ***speed of response or rise time*** is determined by the RC-time constant)

$$\boxed{\tau = R_L C} \qquad (13)$$



- The rise time or speed of response for a given load is specified in the photodetector datasheet of a device and is fixed.
- But the transit time can be minimized in a photodetector by taking very small area of device and large drift velocity of carriers.


THANK YOU