(MPM-202)
Optoelectronics and Optical Communication System

UNIT-II (Optical Sources and Detectors)

Lecture-3

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.

Photodetectors

- **Photodetectors**
  - **Photoemissive** (incident photon results in emission of electron)
    - **e.g. Photo-multiplier tube (PMT)**
  - **Photo-conductive** (the incident photon changes the conductivity of the detector i.e. detectors based on change in conductivity)
    - **Photoconductor**
    - **Photodiodes**
      - Solar Cells
      - PIN
      - Avalanche Photo Diode (APD)
    - **Phototransistor**

- There is also an another class of photo detectors called **'thermopiles'** whose temperature changes by absorption of incident radiation and is particularly used for high energy pulse detection

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

- For detection of light the external Quantum efficiency and responsivity are more important while for high speed communication the rise time/ impulse response and noise power are more important.

General Characteristics of Photodetectors

1.The External Quantum Efficiency (η)

- The quantum efficiency refers to the fractional number of carriers generated per incident photon.

- Let ϕ be the photon flux (number of photon incident per unit time) and P_{opt} is the power then

$$\phi = \frac{P_{opt}}{h\nu} \quad (1)$$

- The quantum efficiency is defined as-

$$\eta = \frac{Carrier\ flux\ (e-h\ pair)\ generated\ which\ contribute\ to\ photo\ generated\ current}{Incident\ photon\ flux}$$

General Characteristics of Photodetectors

Thus, we have

$$\boldsymbol{\eta = \frac{\left(^{i_p}/_{e}\right)}{\left(^{P}/_{h\nu}\right)}} \qquad \textbf{(2)}$$

where $\boldsymbol{i_p}$ is the photo current and 'e' is the charge on one electron

- Since all the electron-hole pairs generated need not to contribute in photocurrent.
- Thus, $\mathbf{0 < \boldsymbol{\eta} < 1}$, as every incident photon will generate one e-h pair at best.
- The expression for $\boldsymbol{\eta}$ in eq. (2) is in terms of incident flux and photocurrent.

General Characteristics of Photodetectors

2. Responsivity (R)

- In case of photodetector responsivity is defined as

$$R = \frac{i_p}{P_{Optical}} \; Ampere/Watt \qquad (3)$$

- From eq. 2 put the value of $\frac{i_p}{P_{Optical}}$ in eq (3),

$$R = \frac{i_p}{P_{Optical}} = \frac{\eta\, e}{h\nu} \qquad (4)$$

$$\boxed{R = \frac{\eta\, \lambda\,(\mu m)}{1.24}\ (\text{A/W})} \qquad (5)$$

General Characteristics of Photodetectors

- From eq. 5 we conclude that as wavelength is a fixed quantity,thus

$$R \propto \eta \qquad (7)$$

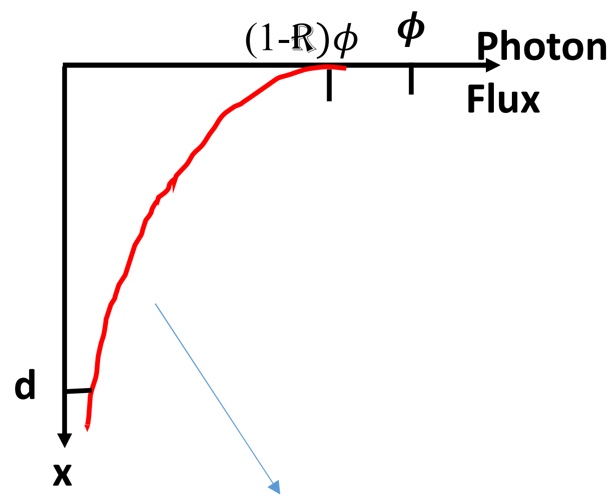
- So to maximize responsivity that means (from eq. 3) to get maximum photo current for a given optical power we have to **maximize the quantum efficiency.**
- **So how to maximize η and what does η depend on??**

How to maximize η and on what does η depend on??

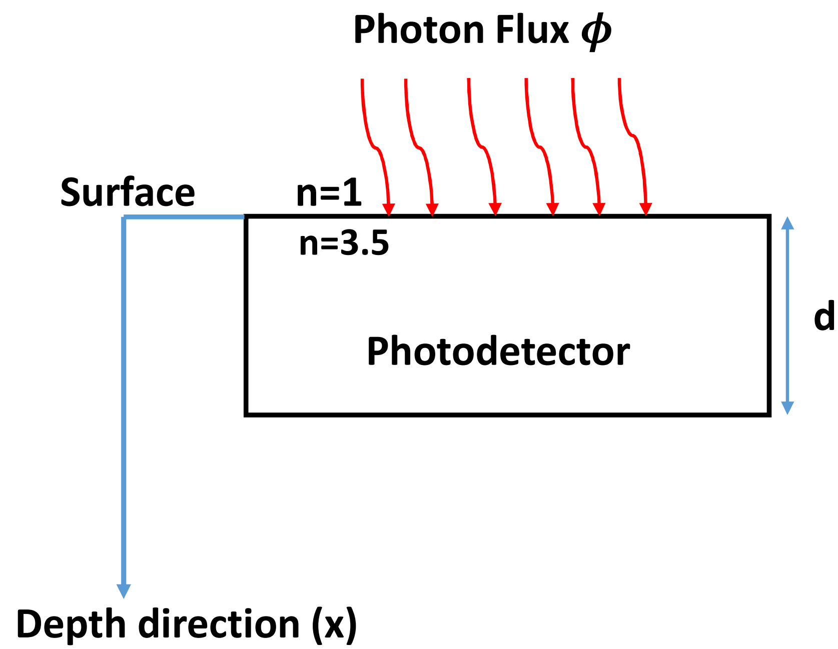
General Characteristics of Photodetectors

- Let us consider on a photodetector with thickness ‘d’ there incident a photon flux and ‘x’ be the depth direction from the surface.
- The refractive index of air and semiconductor are taken as 1.0 and 3.5.
- ℝ is the reflectivity and R is responsivity.
- If ℝ is the reflectivity then (ℝ.ϕ) will be reflected back from the surface i.e. 30% is reflected back so only (1-ℝ)ϕ i.e. 70% light will enter the material.

General Characteristics of Photodetectors



Inside the medium the intensity of photon flux is exponentially decaying as the absorption coefficient (α) of the material decreases as the depth increases [$I = I_0 e^{-\alpha}$].And after d it becomes constant in air.



ℝ is the reflectivity and R is responsivity.

General Characteristics of Photodetectors

- Let I_0 is **incident intensity** and $\mathrm{I} = I_0 e^{-\alpha d}$ is **coming out** of the material therefore **absorbed energy** in the material is $= I_0 - I_0 e^{-\alpha d} = I_0(1 - e^{-\alpha d})$ **and** the fraction i.e. absorbed is $(1 - e^{-\alpha d})$.

Therefore the **fractional number of photons** which are **absorbed**

$$= (1-\mathbb{R})\phi . (1 - e^{-\alpha d}) \qquad (8)$$

- Among the absorbed photon, some may give their energy to lattice and generate phonons, some absorbed photon may be absorbed in the traps. So if **N** number of photons which are absorbed only **N**ζ $(zeta)$ will contribute to external current.

General Characteristics of Photodetectors

- So ζ $(zeta)$ comprises of two parts-

a) All absorbed photons may not generate e-h pairs.

b) Some of the generated e-h pairs may immediately recombine.

Therefore the **fractional absorbed photon flux which contributes in external current** is given by

$$= (1-\mathbb{R})\phi . (1-e^{-\alpha d}) . \zeta \qquad (9)$$

- Therefore from the definition of quantum efficiency-

$$\eta = \frac{Carrier\ flux\ (e-h\ pair)\ generated\ which\ contribute\ to\ photo\ generated\ current}{Incident\ photon\ flux}$$

General Characteristics of Photodetectors

- Thus, from eq. (9), the expression of quantum efficiency is given by-

$$\eta = \frac{(1-\mathbb{R})\phi.\,(1-e^{-\alpha d}).\,\zeta}{\phi}$$

$$\Rightarrow \eta = (1-\mathbb{R}).\,(1-e^{-\alpha d}).\,\zeta \qquad (10)$$

- This expression of quantum efficiency shows that η depends on reflectivity '$\mathbb{R}$' , absorption coefficient 'α' , thickness 'd' and the factor zeta 'ζ'.
- Thus η can be optimized and will have **maximum value 1 i.e. 100%** efficiency of the device if $\mathbb{R}=0$, $e^{-\alpha d} = 0$ and $\zeta = 1$ can be obtained (from eq. 10).

General Characteristics of Photodetectors

- So, for making $\mathbb{R}=0$ we have to make a anti-reflection coating at the surface. But one can make anti-reflection coating for a particular wavelength and $\mathbb{R}=0$ will be when anti-reflection coating is done for all the wavelengths.
- For $\boldsymbol{e^{-\alpha d}=0}$, $\boldsymbol{\alpha d}$ has to be large i.e. either $\boldsymbol{\alpha}$ or $\boldsymbol{d}$ or both has to be large.
- One has to select proper $\boldsymbol{d}$ value for the sufficient light absorption like if one want to absorb 90% of light then

$$\left(1-e^{-\alpha d}\right)=0.9$$

$$\Rightarrow\ e^{-\alpha d}=0.1$$

Let $\boldsymbol{\alpha = 20,000\ cm^{-1}}$

$$\Rightarrow \boldsymbol{d=\frac{1}{\alpha}\ln 10=\frac{2.303}{20{,}000\ cm^{-1}}=\frac{2.303}{2}\ \mu m\sim 1\ \mu m}$$

General Characteristics of Photodetectors

- For $\zeta = 1$, i.e. we have to generate electron hole pair and make them alive so that they may contribute to external current for this one can do following things-

i. Apply an appropriate bias so that the generated carriers immediately starts moving away from each other (which minimizes the recombination) and contribute in external current.

ii. Minimize the defects and traps in the material as they act as recombination centers.

Thus ζ can be maximized by very careful fabrication of the high quality (defect free or minimum defect) material.

Conclusion

- η is not a fixed quantity.
- η depends on reflectivity '$\mathbb{R}$' , absorption coefficient 'α' , thickness 'd' and the factor zeta 'ζ'.
- Thus η can be optimized and will have **maximum value 1 i.e. 100%** efficiency of the device if $\mathbb{R}=0$, $e^{-\alpha d} = 0$ and $\zeta = 1$ can be obtained (from eq. 10).
- In similar way responsivity $\mathbb{R}$ is optimized by optimizing η

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


THANK YOU