UNIT III

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SYLLABUS

- Optical Absorption in semiconductors,
- Types of Photo Diodes,
- Principle of photo detection,
- working and structures of p-i-n and APD photo detectors,
- noises in photo detectors,
- SNR,
- detector response time effects,
- comparison of various photo detectors.

LECTURE PLAN

UNIT-III OPTICAL DETECTORS		
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	Types of Photo Diodes, Principle of photo detection	2/328-329
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Introduction

- In case of any communication, there must be a device which can receive the transmitted signal.
- In case of OFC system, the first element of the receive is a photodetector.
- Photodetectors are semiconductor devices that can convert optical signals into electrical signals.

Cond…

- The function of the photodector is to:
  - sense the optical light
  - convert it into electrical variations.
- Hence referred 'O/E Converter.
- Since the optical signal is very weak and distorted signal, so the photodetector *must be able to sense the weak signals & it must be high performance device*.

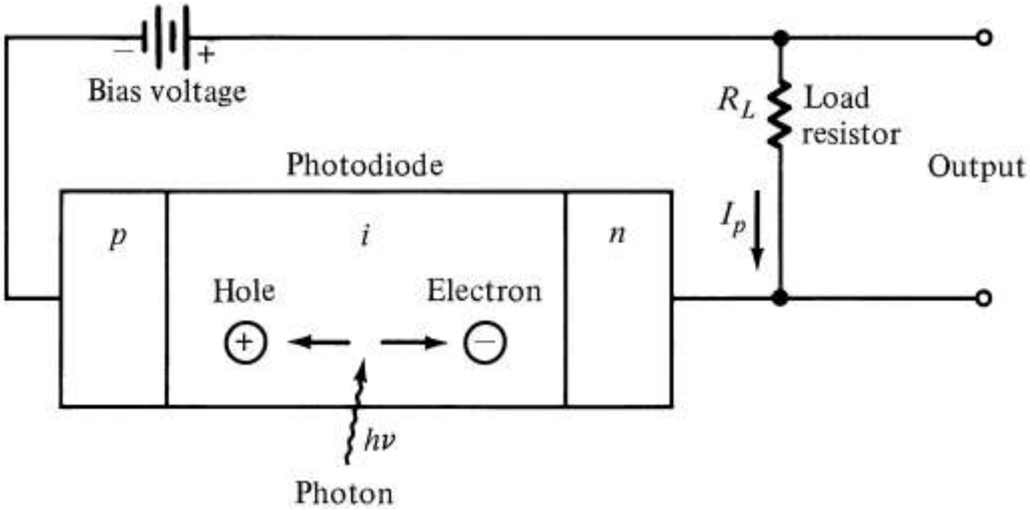
Basic Requirement for the Photodetectors

1. *Good Sensitivity:* it must be able to produce maximum electrical signal for a given amount of optical power, i.e., the quantum efficiency should be high.
2. *Fast Response Time*: to obtain higher bandwidth
3. *Compatible Physical Dimensions*: Small Size for efficient coupling to the fiber.
4. *Highly Stable*: the performance characteristic of the detector must be independent of the ambient conditions.
5. *High Reliability:* so that it can perform its function for a long time continuously.
6. *Low Biasing Voltages or Current*: should not require excessive bias voltage or current.

PHYSICAL PRINCIPLE OF PHOTODIODE

PIN Photodector

- The pin refers to positive intrinsic negative.



Cond…

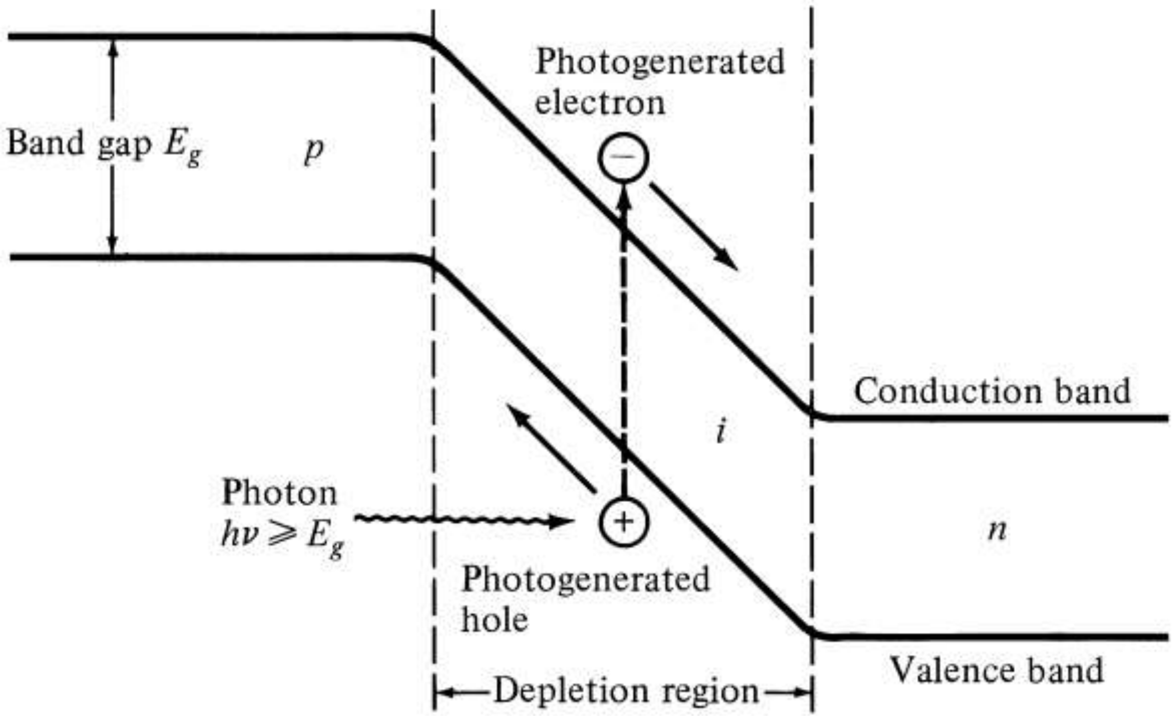
- So, the device consists of 3 layers.
- P and N regions are separated by very lightly n-doped intrinsic (i) region.
- The reverse bias voltage is applied across the device, so that the i region is fully depleted of carriers.

Cond…

- Now, the photon can give its energy and excite an electron from the valance band to the conduction band, *only when the incident photon has an energy greater than or equal to the band gap energy of this semiconductor material*.

Cond...

- This process will generates mobile electron-hole pairs as shown on next slide.
- These electrons and holes are known *photocarriers*, since they are photo-generated charge carriers.


Photogenerated electron
Band gap E_g
p
Conduction band
i
Photon
$h\nu \geq E_g$
n
Photogenerated hole
Valence band
Depletion region

Cond…

- These charge carriers are available to produce a current flow, when a bias voltage is applied across the device.
- The most of the incident light is absorbed in the depletion region, so the photocarriers are generated in this depletion region.

Cond...

- A high electric field is available in the depletion region, so it will cause the carriers to separate.
- These carriers are collected across the reverse bias junction.
- The current will flow because of these carriers.
- The one electron will flow for every carrier pair generated.
- This current is known as *photocurrent*.

Cond...

- Since the charge carriers flow through the material, the electron-hole pair will recombine and hence disappear.
- On average, the charge carriers move a distance L_n or L_p for electrons and holes respectively.

Cond…

- This distance is known as the *diffusion length*.
- The time for recombination or electron or hole is known as *carrier lifetime*.
- The lifetime and the diffusion lengths are related by: $L_n = \sqrt{D_n \tau_n}$ & $L_p = \sqrt{D_p \tau_p}$

Cond…

$$L_n \,\&\, L_p = Diffusion\,length\ \ for\ elctrons\ \&\ holes\ respectively$$

$$\tau_n \,\&\, \tau_p = Carrier\ Lifetime\ \ for\ elctrons\ \&\ holes\ respectively$$

$$D_n \,\&\, D_p = Diffusion\,coeffient\ \ for\ elctrons\ \&\ holes\ respectively$$

- As a photon flux Φ penetrates into a semiconductor, it will be absorbed as it progresses through the material.

Cond...

- Let, Pin is the optical power level, that falls on the photodector at x = 0 and P(x) is the power level at distance x into the material.
- The incremental distance dx in the semiconductor is given by:

$$dP(x) = -\alpha_s(\lambda)P(x)dx$$

Cond…

- Integrating this relation gives,

$$P(x) = -P_{in} e^{-\alpha_s(\lambda)x}$$

$$\alpha_s \text{ is photon absorption coefficient}$$

- The upper wavelength cutoff is determined by band-gap energy E_g of the material.

Cond…

$$\lambda_c(\mu m) = \frac{hc}{E_g(eV)} = \frac{1.24}{E_g(eV)}$$

- The photocurrent I_P produced by incident light of optical power P_o is given by:

$$I_p = \frac{q}{h\nu} P_{in}(1-\alpha_s w)(1-R_f)$$

Cond…

- Where,
  - R_f is reflectivity at the entrance of the photodiode
  - P_{in} is the optical incident power
  - q is the electron charge
  - hv is the photon energy

Cond…

- Photodector have two quantum efficiency and its response speed.
- These parameters depend on the material band gap, the operating wavelength, and the doping and thickness of the, p, i, and n regions of the device.

Cond…

- The quantum efficiency is the no of electron-hole carrier pair generated per incident is given by:

$$\eta = \frac{no\,of\ electron\,hole\ pair\ generated}{no\,of\ incident\ photons} = \frac{I_p / q}{P_{in} / h\nu}$$

$$R = \frac{I_p}{P_{in}} = \frac{\eta q}{h\nu}$$

Cond…

- R is the responsivity of the photodiode.
- The photocurrent (I_p) is directly proportional to the incident optical power (P_{in}).
- Quantum efficiency varies according to the photon energy.

Avalanche Photodiodes

Problems:

- Example 6.1, 2, 3 4, 6 & 7 from Keiser.

Review Problems

- How is silicon RAPD operated? How does it differ from p-i-n photodiode? What are the advantages and disadvantages?**[UPTU 2009-10]**
- Define quantum efficiency and responsivity of a photo-detector. Calculate the transit time for silicon photodiode which has a saturation of 10^5 ms^{-1}. The depletion layer thickness is 7 μm. **[UPTU 2009-10]**
- Explain the requirements of optical detector to be used for the purpose of optical communication. What are the parameters by which performance of optical detector can be judged?**[UPTU 2010-11]**

Review Problems

- Describe the working and principle of pin photodiode. How its efficiency can be increased. **[UPTU 2010-11]**
- Write short notes **[UPTU 2010-11]**
  - RAPD photo-detector
  - Noise sources in optical fiber communication.
- What is the significance of intrinsic layer in PIN diode? What is the principle of working of PIN diode **[UPTU 2011-12]**
- Define quantum efficiency and responsivity of a photodiode. Determine the wavelength at which quantum efficiency and responsivity are equal **[UTU 2011-12]**

Review Problems

- Discuss the working principle of avalanche photodiode, how it differs from p-i-n photodiode? State the advantages and drawbacks with the use of the RAPD as a detector for optical fiber communications. **[UTU 2011-12]**
- Explain the physical principle of APD. What is the temperature effect on Avalanche Gain? Describe Automatic Gain Control using Op-amp. **[UPTU 2011-12]**
- Explain the working of a P-I-N photodiode. Also explain the factors that limit the speed of response of photodiode **[UTU 2012-13]**
- Explain the impact ionization in avalanche photodiodes. Define photo multiplication factor and cutoff over length of photodiode. **[UTU 2012-13]**

Review Problems

- Discuss the expression for the SNR in an APD receiver. How the signal to noise ratio may be modified to give the optimum avalanche multiplication factor **[UTU 2012-13]**
- Describe surface LED and PIN photodiode always operative in reverse bias region. **[UTU 2012-13]**

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