SNS COLLEGE OF TECHNOLOGY

Coimbatore-35
An Autonomous Institution

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Approved by AICTE, New Delhi & Affiliated to Anna University, Chennai

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

OPTICAL AND MICROWAVE ENGINEERING

III YEAR/ VI SEMESTER

UNIT 4-OPTICAL DETECTORS-PIN –APD characteristics

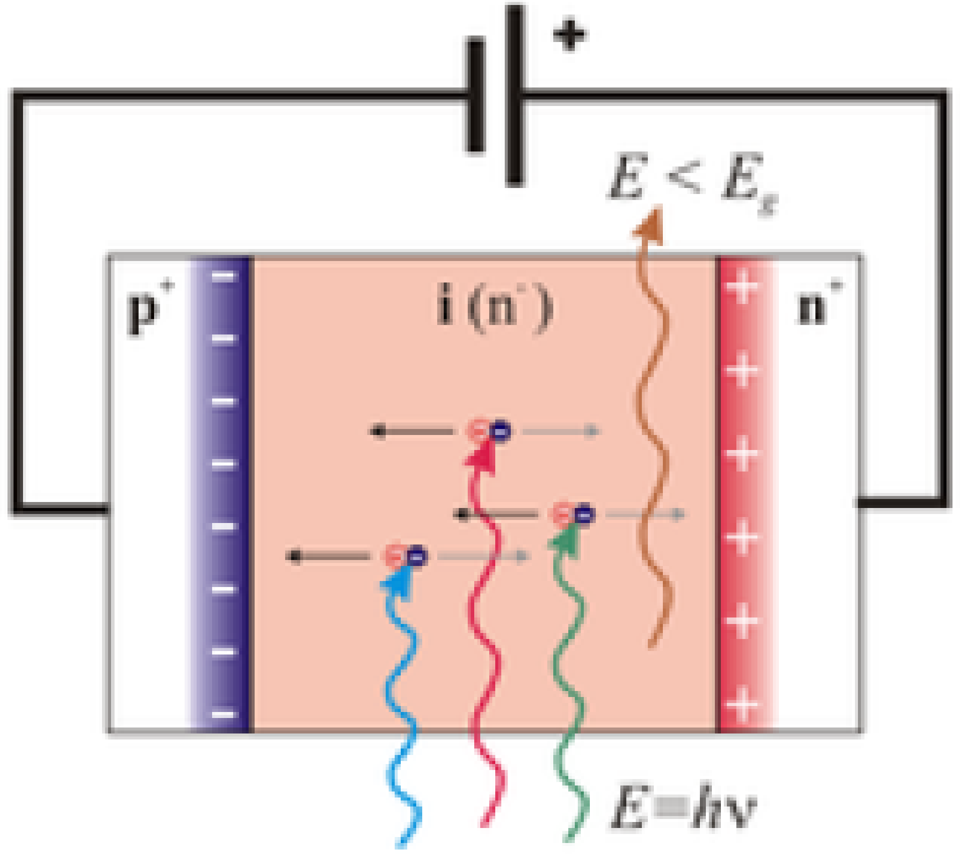
OPTICAL DETECTORS

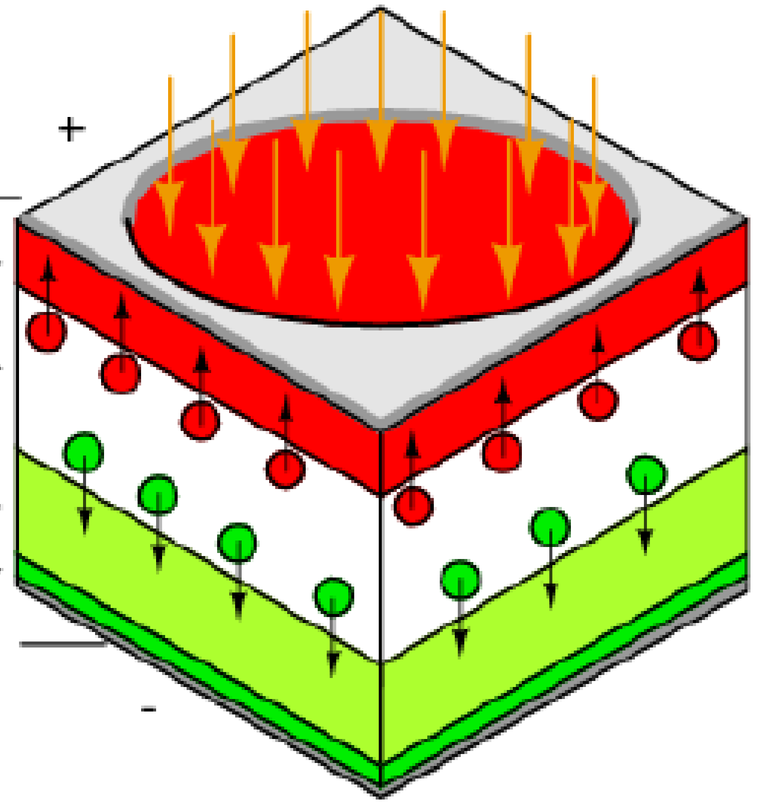
Photodetectors find applications in the area of medical, automotive, safety and analytical equipments, cameras, communications, astronomy and industry.

Types of Photodetectors

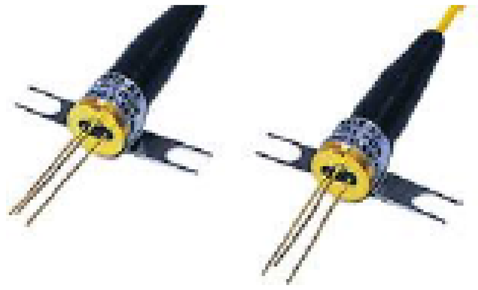
- Photodiode, Photodiode Array, Light Dependent Resistor
- Avalanche Photodiode
- Photomultiplier Tube, Microchannel Plate, Image Intensifier
- Position Sensitive Detector
- CCD

PIN Photodiode





PIN photodiode.



The P-Intrinsic-N structure increases the distance between the P and N conductive layers, decreasing capacitance, increasing speed. The volume of the photo sensitive region also increases, enhancing conversion efficiency. The bandwidth can extend to 10's of GHz. PIN photodiodes are the preferred for high sensitivity, and high speed at moderate cost.

P-i-N PHOTODIODE

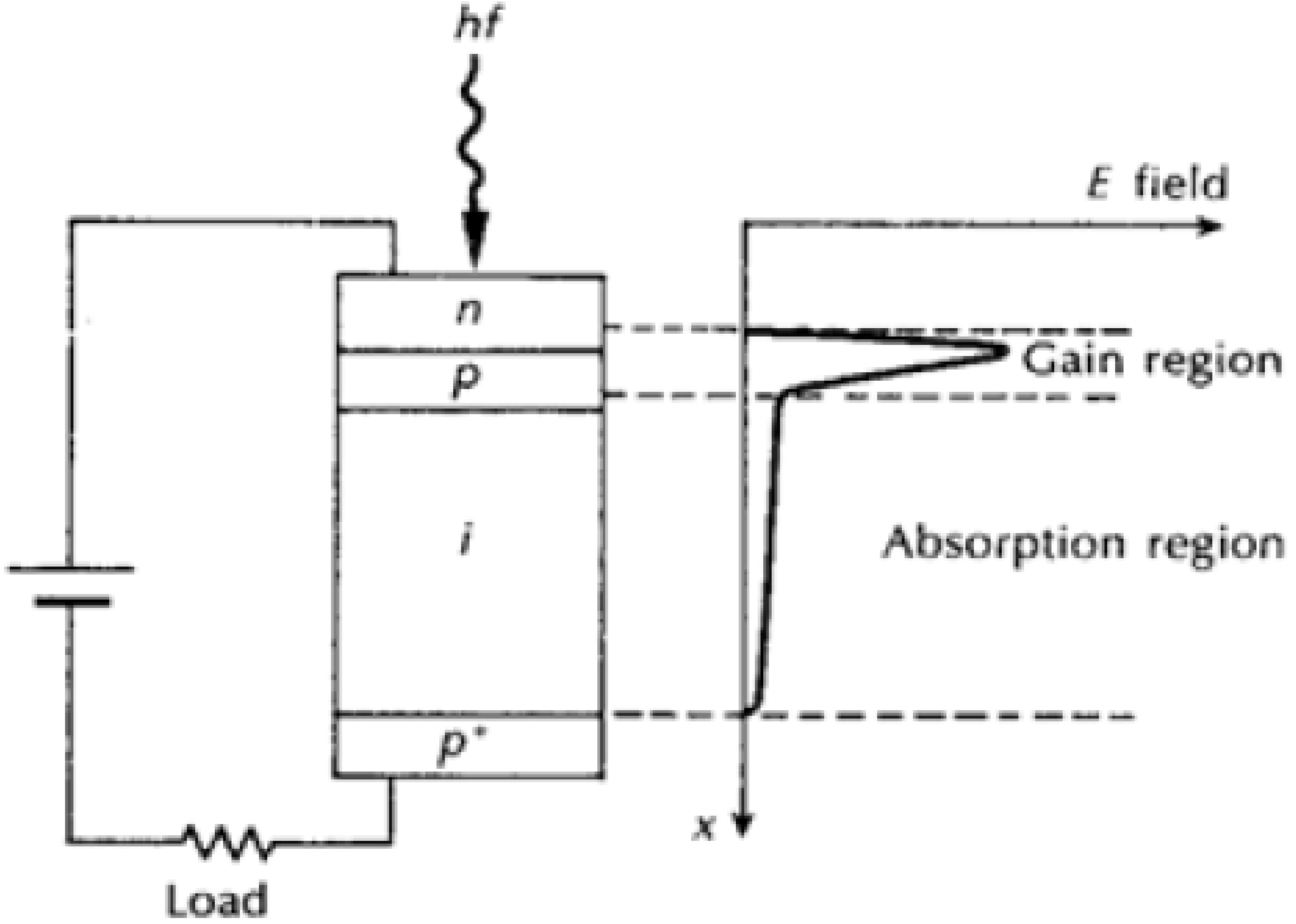
- A typical P-i-N photodiode consists of a highly-doped transparent *p*-type contact layer on top of an undoped absorbing layer (i) and an *n*-type highly doped contact layer on the bottom.

- This diode is evolved mainly from one basic requirement: light should be absorbed in the depletion region of the diode to ensure that the electrons and holes are separated in the electric field and contribute to the photocurrent, while the transit time must be minimal.

- This implies that a depletion region larger than the absorption length must exist in the detector. This is easily assured by making the absorbing layer undoped. Only a very small voltage is required to deplete the undoped region.

- An added advantage is that the recombination/generation time constant is longest for undoped material, which provides a minimal thermal generation current.

Avalanche Photodiodes (APD) – Photodetector with Internal gain



Avalanche photodiode showing high electric field region

- Photodiode with Internal gain: Internally multiply the primary signal photocurrent before it enters the input circuitry of the amplifier.
- Increases receiver sensitivity: the photocurrent is multiplied before encountering the thermal noise associated with the receiver circuit.
- For carrier multiplication, the photogenerated carriers must traverse a region where a very high electric field is present.

- In the high field region, a photogenerated electron or hole can gain enough energy so that it ionizes bonds in the valence band upon colliding with them. This is known as Impact Ionization

- The newly created carriers are also accelerated by the high electric field, gaining enough energy to cause further impact ionization. This phenomenon is the Avalanche Effect

- Create an extremely high electric field region (approximately 3×10^5 V/cm)

- Requires high reverse bias voltages (100 to 400 V) in order that the new carriers created by impact ionization

- Carrier multiplication factors as great as 10^4 may be obtained

- When carriers are generated in undepleted material, they are collected somewhat slowly by the diffusion process. This has the effect of producing a long 'diffusion tail' on a short optical pulse.
- When the APD is fully depleted by employing high electric fields, all the carriers drift at saturation-limited velocities.
- The response time for the device is limited by three factors:
  - the transit time of the carriers across the absorption region (i.e. the depletion width)
  - the time taken by the carriers to perform the avalanche multiplication process
  - the RC time constant incurred by the junction capacitance of the diode and its load
- At low gain the transit time and RC effects dominate giving a definitive response time and hence constant bandwidth for the device
- At high gain the avalanche build-up time dominates and therefore the device bandwidth decreases proportionately with increasing gain

- The rise time between 150-200ps and fall time of 1ns or more are quite common and this *limits the overall response of the device*

- Multiplication factor M is a measure of the internal gain provided by the APD and is defined as

$$M=I_M/I_P$$

where I_M is the average value of the total multiplied output current and I_P is the primary photocurrent.

- The avalanche mechanism is a statistical process, and not every carrier pair generated in the APD experiences the same multiplication. Thus, the measured value of M is expressed as an average quantity which is as great as 10^4 .

Advantages & Drawbacks of APDs

Advantages

- Provides an increase in sensitivity of between 5 dB to 15dB over p-i-n photodiodes i.e. detection of very low level light signals.

- Wider dynamic range as a result of their gain variation with response time and reverse bias

Drawbacks

- Fabrication difficulties due to their more complex structure and hence increased cost.

- The random nature of the gain mechanism which gives an additional noise contribution.

- Often high bias voltages required (50 to 400 V)

- The variation of the gain (multiplication factor) with temperature i.e. temperature compensation is necessary to stabilize the operation of the device.

Photodetectors

- APD vs *p-i-n* diode

Typical Performance Characteristics of Photodetectors

	Silicon		Germanium		InGaAs	
Parameter	**PIN**	**APD**	**PIN**	**APD**	**PIN**	**APD**
Wavelength range (nm)	400–1100		800–1800		900–1700	
Peak (nm)	900	830	1550	1300	1300 (1550)	1300 (1550)
Responsivity R (A/W)	0.6	77–130	0.65–0.7	3–28	0.63–0.8 (0.75–0.97)	
Quantum efficiency (%)	65–90	77	50–55	55–75	60–70	60–70
Gain	1	150–250	1	5–40	1	10–30
Excess noise factor	—	0.3–0.5	—	0.95–1	—	0.7
Bias voltage (V)	45–100	220	6–10	20–35	5	<30
Dark current (nA)	1–10	0.1–1.0	50–500	10–500	1–20	1–5
Capacitance (pF)	1.2–3	1.3–2	2–5	2–5	0.5–2	0.5
Rise time (ns)	0.5–1	0.1–2	0.1–0.5	0.5–0.8	0.06–0.5	0.1–0.5

ASSESSMENT TIME!

List the applications of optic fibers
In medical field.

THANK YOU