

Technical Report: Comparative Analysis of Photodetectors for Appropriate Usage in Optical Communication Applications

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ABSTRACT

Photodetectors have found useful applications in various power and electronic fields such as in microwave power amplifications and fibre optic data communications. Different types of photodetectors, especially the PIN photodiodes and Avalanche photodiodes, are the most useful photodetectors in microwave and fibre optic communications. In this paper, the authors x-rayed the different types of photodetectors, the photodetectors' principles, the fiber optic communication architecture and principles and finally carried out the comparative analysis of PIN and Avalanche photodiodes.

KEYWORDS: PIN photodiode, Avalanche photodiode, Photodetector, photodiode, Photodetection, fiber optic, microwave, amplifier, optical communication

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INTRODUCTION

Photodetector is a semi-conductor material that has found several useful applications in optical communication applications, home automation and industrial electronics. Photodetectors are also known as photosensors. They are sensors of light or other sources of electromagnetic radiation. Photodetectors convert light energy known as photons into electrical current.

A photodetector has a *p-n junction* that converts light photons or optical signal into current or electrical

signal. The absorbed photons in a photodetector constitute the electron-hole pairs in the depletion region. They are of several types or examples of photodetector- Photodiodes, Phototransistors, Photon multipliers, Photo-resistors.

Photodiodes' constituents may contain optical filters and built-in lenses. They may have large or small surface areas. A photodiode is built or designed to operate in reverse bias. Fig.1.1 shows some of the various photo detector samples in the market.



Fig.1.1. Photodetectors in the market

A photodetector is made up of semiconductor materials and absorbs incident photos and convert them into electrons. Fig.1.2 shows the working principle of a photodetector.

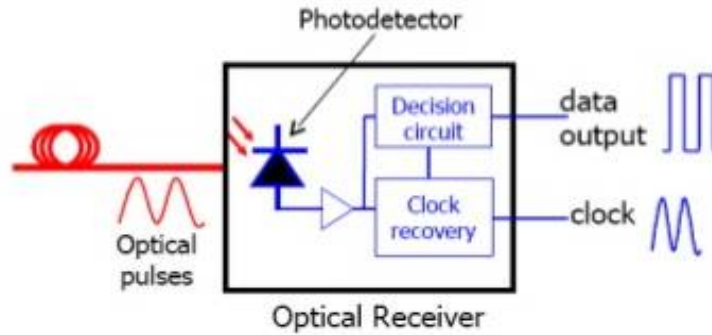


Fig.1.2. A photodetector working principle

A. Principles of Photodetection

Photodetection principle is based on two types of photoelectric effects which are as follow:-

1. External photoelectric effect
2. Internal photoelectric effect

1. External photoelectric effect:

In external photoelectric effect, electrons become free from the metal surfaces by energy absorption obtained by streams of incident photons. *Photomultiplier tube* and *vacuum photodiode* are the implications of external photoelectric effect.

2. Internal photoelectric effect:

In internal photoelectric effect, free charge carriers are generated by absorption of incident photons in semiconductor junction detectors. *PIN photodiodes*, *PN junction photodiodes* and *Avalanche Photodiodes* are typical examples that utilize this effect.

A Photodiode works in the following principle- the reverse-biased photodiode is under luminance (incident photons) represents the energy band gap diagram which is absorbed via the window. The absorbed energy raises a bound electron across the band gap from the valance to the conduction band as depicted Fig.1.3.

A free hole is left in the valence to the conduction band. Under electric field the generated free charge carriers produce the drift current.

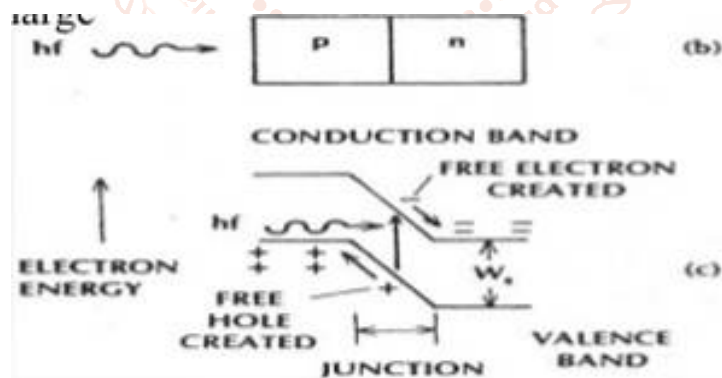


Fig.1.3. Photodiode energy band diagram

B. Photodiode equivalent circuit

The simplified photodiode equivalent model (Fig.1.4) represents the key elements. The irradiance (light intensity) is proportional to current source I_D which is in parallel with diode.

Performance is dependent upon parasitic components R_D and C_D can play an imperative role.

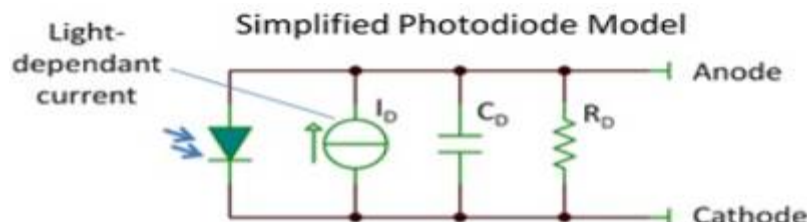


Fig.1.4. Photodiode Equivalent Circuit

C. Modes of Operation of Photodiodes

The operating modes of the photodiode include three modes, namely *Photovoltaic mode*, *Photoconductive mode* and *Avalanche diode mode*.

Photovoltaic Mode: This mode is also known as zero bias mode, in which a voltage is produced by the lightened photodiode. It gives a very small dynamic range and non-linear necessity of the voltage formed. A photodiode that operates in this mode is usually used as *solar* or *photo-voltaic cell*.

Photoconductive Mode: The photodiode used in this photoconductive mode is more usually *reverse biased*. The reverse voltage application will increase the depletion layer's width, which in turn decreases the response time and the junction capacitance. This mode is too fast and displays electronic noise.

Avalanche Diode Mode: Avalanche diodes operate in a *high reverse bias condition*, which permits multiplication of an avalanche breakdown to each photo produced electron-hole pair. This leads to an internal gain in the photodiode, which slowly increases the device response.

D. Basic requirements of a Photodetector for a good performance

The basic requirements or properties of a Photodetector to perform well are summarized as follow:

1. Sensitivity at the required wavelength.
2. Efficient conversion of photos to electrons.
3. Responsivity or fast response to operate at high frequencies.
4. Low noise for reduced errors.
5. Sufficient area for efficient coupling to optical fiber.
6. High reliability.
7. Low cost.
8. Rise time.

Other significant photodetector parameters include the following:-

1. Quantum Efficiency : It is the ratio of primary electron-hole pairs created photon to the photon incident on the diode material.
2. Detector Responsivity: This is the ratio of output current to input optical power. Hence, this is the efficiency of the device. The unit of responsivity is amperes per watt.
3. Spectral Response Range: This is the range of wavelength over which the device will operate. The spectral response refers to the curve of detector responsivity as a function of wavelength.
4. Noise Characteristics: This is the level of noise produced in the device. This is critical to the operation of the device at low levels of input light.
5. Response Time: This is a measure of how quickly the detector can respond to variation in the input light intensity.
6. Rise Time : This is the time for the detector output current to change from 10 to 90% of its final value when the optic input power variation is a step.
7. Gain: The Avalanche Photo Device (APD) have more gain than PIN diode due to the effect of impact ionisation as it is operated at high electric field.

E. Significance of Photodiodes

Photodiodes are unique among light photodetectors in that when illuminated, they generate an output which is proportional to light level. Their characteristics and features can be summarised as follows:-

1. Low cost visible and near-IR photo detector
2. Excellent linearity in output photocurrent according to light intensity
3. Fast response times
4. Available in a wide range of packages
5. Low noise
6. Mechanically rugged yet compact and light weight.
7. Available as duals, quads or as linear arrays.
8. Usable with almost any visible or near infrared light source such as LEDs, neon, fluorescent, incandescent bulbs, lasers, flame sources, sunlight, etc.

F. Applications of PIN Photodiodes and Avalanche Photodiodes

PIN Photodiode, an example of photodiode, is the most widely used in the following domain or applications:

- Audio CD players

- DVD Players
- Computer CD drives
- Optical Communication Systems
- Nuclear radiation detectors

Avalanche Photodiode (APD):

Avalanche Photodiode (APD) level of gain is of importance for high voltage requirements. They are used in the following domains:-

- Laser range finders
- Fast receiver modules for optical data communications
- High speed Laser scanner (2D bar code reader)
- PET scanner
- Speed gun
- Microscopy and particle detection

Photodetector is the fundamental element of optical receiver, followed by amplifiers and signal conditioning circuitry.

Some other photodiodes are utilised in some applications as follow:-

- Optical position sensors
- Beam alignment
- Laser range finders
- Photography
- Analytical Instrumentation
- Spectroscopy
- Medical Imaging Instruments
- Surface characterisation

G. Classification or types of Photo detectors

There are basically two types of Photodetectors as used in optical communication applications. They types are as follow:

1. Photoconductive detector
2. Junction photodetector

1. Photoconductive detector

Photoconductive photodetector is widely known as *LDR (Light Dependent Resistor)* or *photoresistors*. It detects the presence of light and its intensity. On light incidence, the electrical conductivity and hence resistance of this device changes from several mega ohms (in dark condition) to few kilo ohms in light condition and thereby detects the presence of light and its intensity.

Light dependent resistors, LDRs or photoresistors are often used in circuits where it is necessary to detect the presence or the level of light. They can be described by a variety of names from *light dependent resistor*, *LDR*, *photoresistor*, or even *photo cell*, *photocell* or *photoconductor*.

Although other devices such as *photodiodes* or *photo-transistor* can also be used, LDRs or photoresistors are particularly convenient electronic components to use. They provide large change in resistance for changes in light level.

In view of their low cost, ease of manufacture, and ease of use LDRs have been used in a variety of different applications. At one time LDRs were used in photographic light meters, and even now they are still used in a variety of applications where it is necessary to detect light levels.

It is relatively easy to understand the basics of how an LDR works without delving into complicated explanations. It is first necessary to understand that an electrical current consists of the movement of electrons within a material.

Good conductors have a large number of free electrons that can drift in a given direction under the action of a potential difference. Insulators with a high resistance have very few free electrons, and therefore it is hard to make them move and hence a current to flow.

An *LDR* or *photoresistor* is made any semiconductor material with a high resistance. It has a high resistance because there are very few electrons that are free and able to move - the vast majority of the electrons are locked into the crystal lattice and unable to move. Therefore in this state there is a high LDR resistance.

As light falls on the semiconductor, the light photons are absorbed by the semiconductor lattice and some of their energy is transferred to the electrons. This gives some of them sufficient energy to break free from the crystal lattice so that they can then conduct electricity; this results in a lowering of the resistance of the semiconductor and hence the overall LDR resistance. Fig.1.5 depict a typical leaded light dependent resistor, its basic structure and symbol while Fig.1.6 shows a typical leaded light dependent resistor. Fig.1.7 depicts the circuit symbols of light dependent resistor, LDR.

The process is progressive, and as more light shines on the LDR semiconductor, so more electrons are released to conduct electricity and the resistance falls further.



Fig.1.5: Typical leaded light dependent resistor, basic structure and symbol



Fig.1.6: Typical leaded light dependent resistor

The LDR symbol used in circuits is based around the resistor circuit symbol, but shows the light, in the form of arrows shining on shown in Fig.1.7. By this, it follows the same convention used for photodiode and phototransistor circuit symbols where arrows are used to show the light falling on these components. The light dependent resistor or photo resistor circuit symbols are shown for both the newer style resistor symbol, i.e. a rectangular box and the older zig-zag line resistor circuit symbols. The working principle of LDR is shown in Fig.1.8.

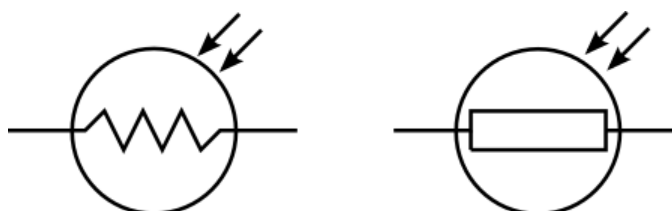


Fig.1.7: light dependent resistor symbol

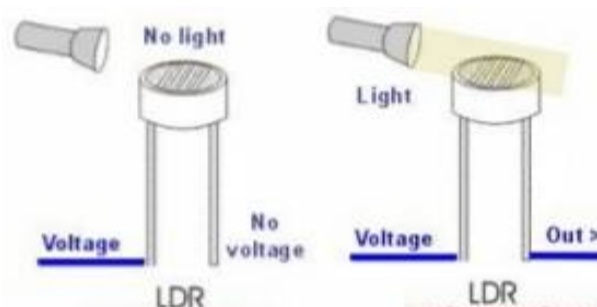


Fig.1.8. Light Dependent Resistor (LDR) working principle

2. Junction Photodetector

There are several types of Junction Photodetectors. They include the following:-

- P-n junction photodiode
- PIN photodiode
- Avalanche photodiode
- Schottky photodiode
- Phototransistor

P-n Junction Photodiode:

In general, p-n junction, as depicted in Fig.1.9, like current rectification, can also be used for light detection purpose.

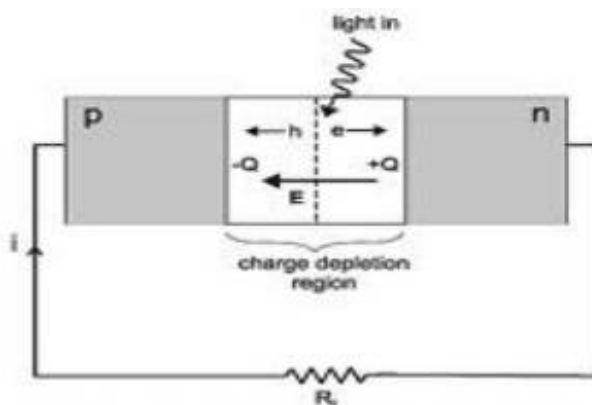


Fig.1.9. P-n junction photodiode

The PIN Photodiode:

The Pn junction photodiode has two drawbacks:

1. Depletion layer capacitance is not sufficiently small to allow Photodetection at high modulation frequencies (RC time constant limitation).
2. Narrow SCL (at most a few microns). Long wavelengths incidence photons are absorbed outside SCL, low QE.

The PIN photodiode can reduce these two problems. The PIN diode derived its name from the fact that it has three main layers. Rather than just having a P-type and an N-type layer, it has three layers such as:

- P-type layer
- Intrinsic layer
- N-type layer

The working principle of the PIN diode exactly same as a normal diode. The main difference is that the depletion region, because that normally exists between both the P and N regions in a reverse biased or unbiased diode is larger. In any PN junction diode, the P region contains holes as it has been doped to make sure that it has a majority of holes. Likewise the N-region has been doped to hold excess electrons. The layer between the P and N regions includes no charge carriers as any electrons or holes merge. As the depletion region of the diode has no charge carriers it works as an insulator. The depletion region exists within a PIN diode, but if the PIN diode is forward biased, then the carriers come into the depletion region and as the two carrier types get together, the flow of current will starts. Figs.1.10, 1.11 and 1.12 show the structure of PIN photodiode, *Reverse-biased PIN Photodiode* and *PIN photodiode circuit* respectively. Fig.1.13. represents the energy band diagram of PIN photodiode.

Applications of PIN Diodes:

The main applications of PIN mainly include the following areas:-

- *The PIN diode is used as a high voltage rectifier.* The intrinsic layer in the diode offers a partition between the both the layers, permitting higher reverse voltages to be tolerated
- *The PIN diode is used as an ideal radio frequency switch.* The intrinsic layer among the P and N layers increases the space between them. This also reduces the capacitance between both the regions, thus raising the level of isolation when the PIN diode is reverse biased.
- *The PIN diode is used as a photodetector* to convert the light into the current which takes place in the depletion layer of a photo diode, rising the depletion layer by inserting the intrinsic layer progresses the performance by increasing the volume in where light change occurs.

- This diode is an ideal element to give electronics switching in applications of electronics. It is mainly useful for RF design applications and also for providing the switching, or an attenuating element in RF attenuators and RF switches. The PIN diode is capable to give much higher levels of consistency than RF relays that are frequently the only other alternative.

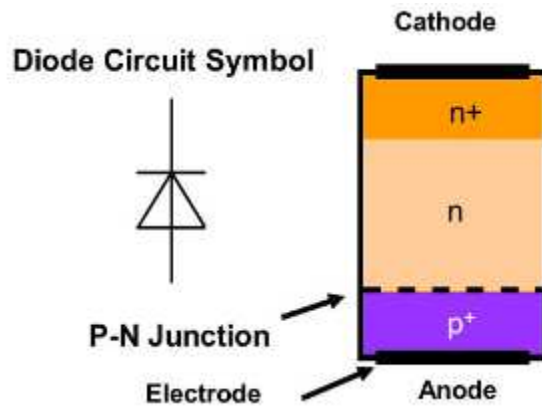


Fig.1.10. Structure of PIN Diode

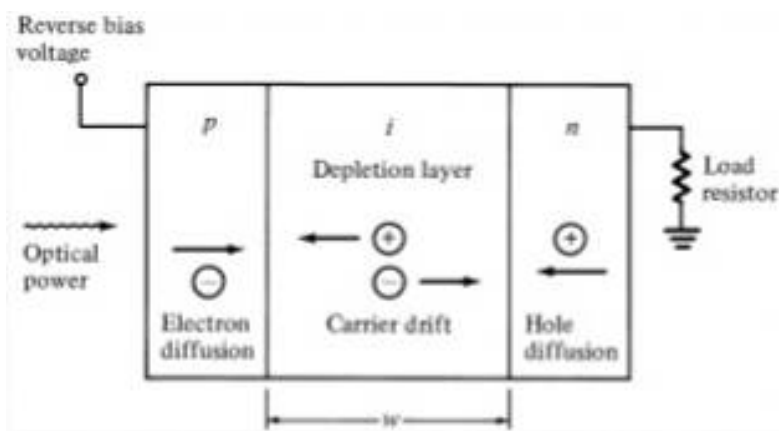


Fig.1.11. Reverse-biased PIN Photodiode

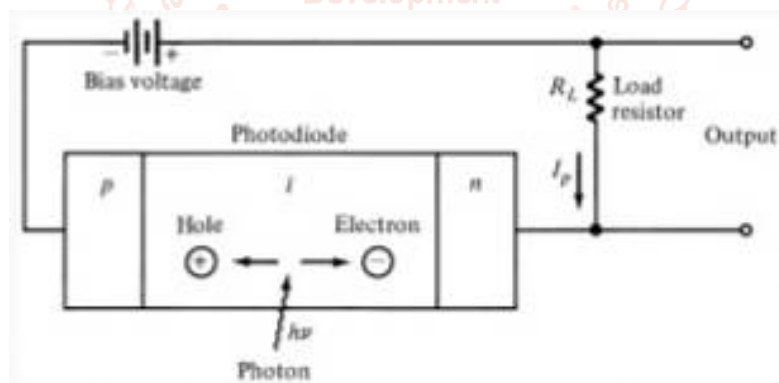


Fig.1.12. PIN photodiode circuit

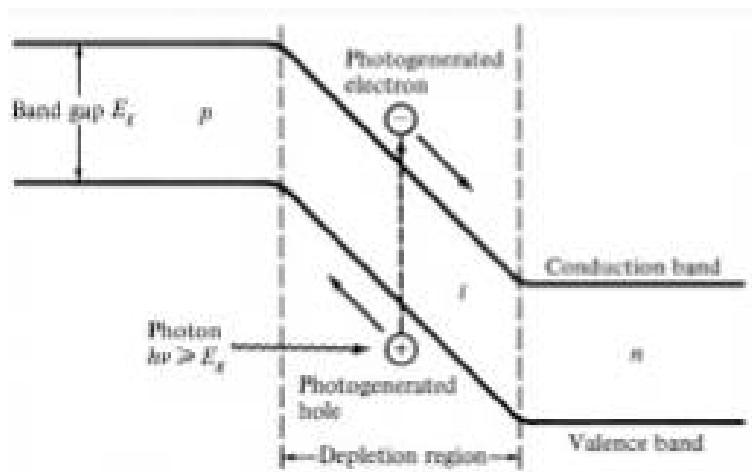


Fig.1.13. Energy Band diagram of PIN photodiode

Avalanche Photodiode (APD):

The Avalanche Photodiode (APD) is another n+I-p+ which provides very high gain 200 and can detect even very low-level of light due to several reasons. This detector is widely used in dedicated optical communication. The thickness of I-region is very large compared with the other region of the device, so incoming light quickly passes through n+ and p layers and spend major time in this region creating large electron and hole pairs. This is known as absorption region of the device. See Fig.1.14.

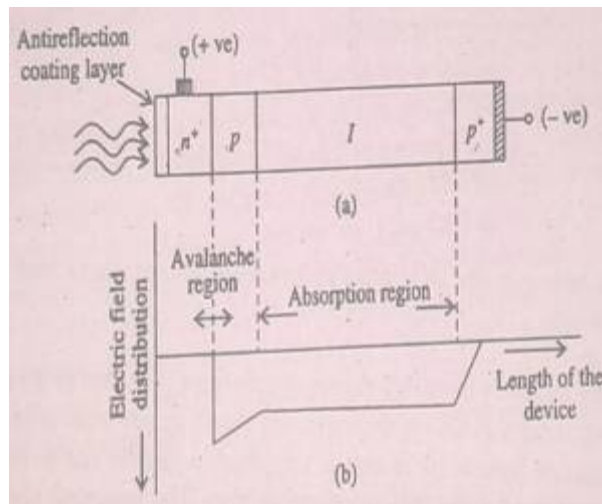


Fig.1.14. Working principle of Avalanche Photodiode

Schottky photodiode:

Schottky photodiode is one of the simple metal semiconductor junctions. The advantage of this type of photodiode is its high speed which arises from the fact that it is a majority carrier device. And its depletion layer is one sided only (n side). The Schottky photodiode is shown in Fig.1.15.

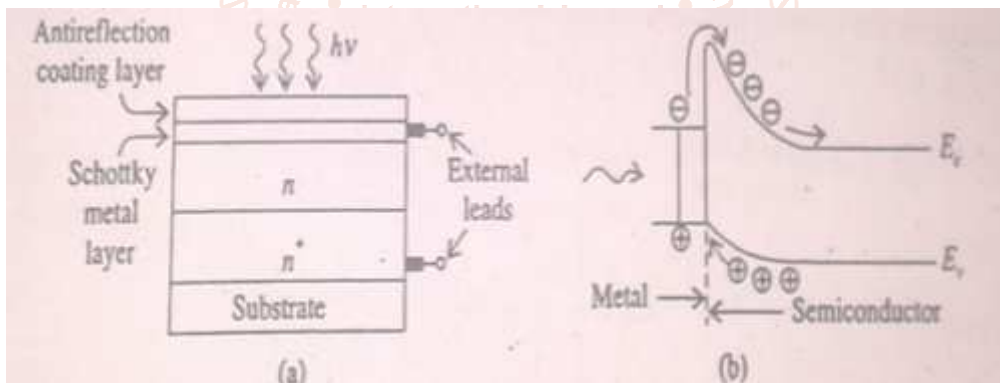


Fig.1.15. Schottky Photodiode

Phototransistor:

This is a special class of photodetector like the *Avalanche Photodiode*. Phototransistor, as shown in Fig.1.16, provides high gain; the device on receiving a weak signal amplifies it internally and then passes on its output terminal.

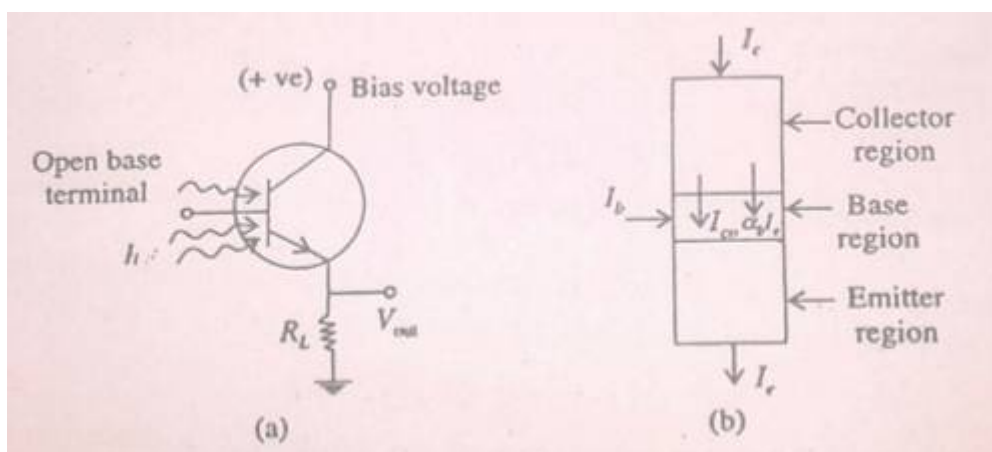


Fig.1.16. Phototransistor photodiode working principle

2.1. FIBER OPTIC COMMUNICATION SYSTEM

A. Fiber Optic Communication System

The fiber optic communication is the ideal choice for gigabits and beyond gigabits transmission of data. This type of communication is used to transmit voice, video, telemetry and data over long distances and local area networks (LAN) or computer networks at very fast speed. A fiber optic communication system uses light wave technology to transmit the data over a fiber by changing electronic signals into light.

Some exceptional characteristic features of this type of communication system like large bandwidth, smaller diameter, light weight, long distance signal transmission, low attenuation, transmission security, and so on make this communication a major building block in any telecommunication infrastructure. The subsequent information on fiber optic communication system highlights its characteristic features, basic elements and other details. Fig.2.1 depicts the basic fiber optic communication system [1].

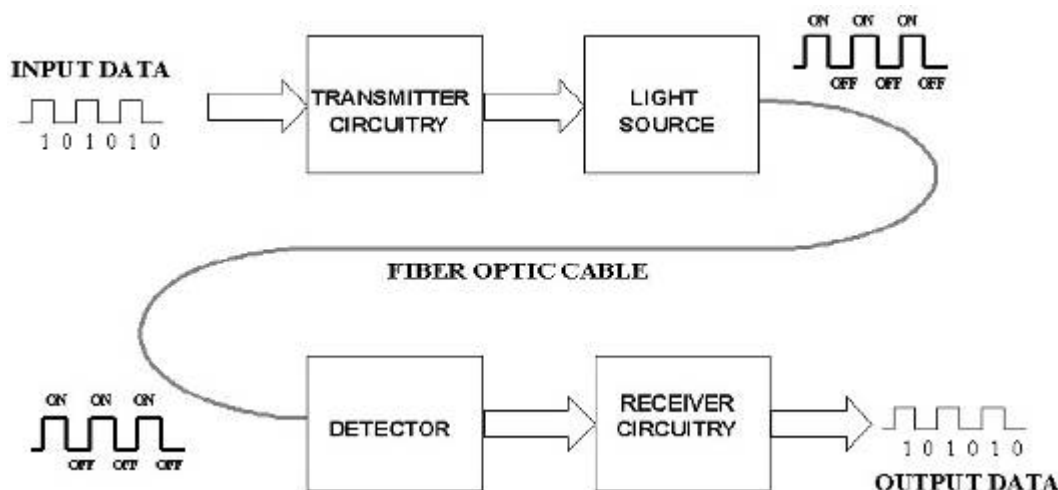


Fig.2.1. The basic fiber optic communication system[1]

Three Basic Elements of a Fiber Optic Communication System:

There are three main basic elements of fiber optic communication system. They are:-

- Compact Light Source
- Low loss Optical Fiber
- Photo Detector

Accessories like connectors, switches, couplers, multiplexing devices, amplifiers and splices are also essential elements in this communication system.

1. Compact Light Source

The light emitting diodes are used for short distances and low data rate applications due to their low bandwidth and power capabilities. The Laser diode structure is of two types the Can and Frame types as shown in Fig.2.2. Two such LEDs structures include Surface and Edge Emitting Systems. The surface emitting diodes are simple in design and are reliable, but due to its broader line width and modulation frequency limitation edge emitting diode are mostly used. Edge emitting diodes have high power and narrower line width capabilities.

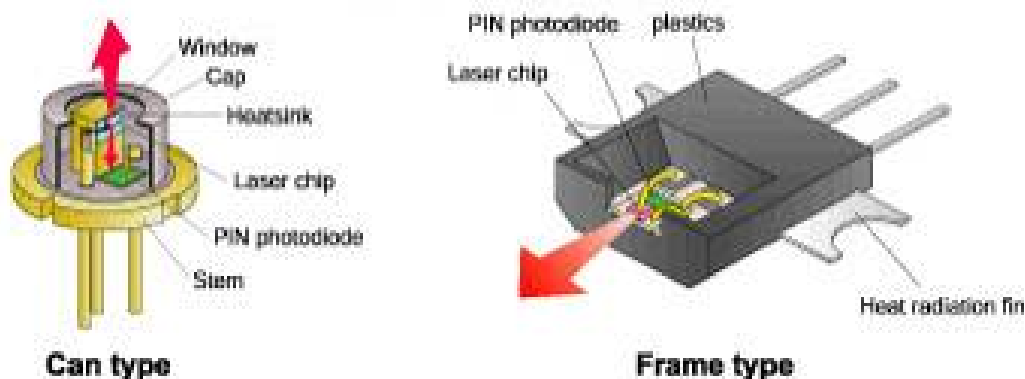


Fig.2.2. the Laser Diode Structure

For longer distances and high data rate transmission, Laser Diodes are preferred over LED due to its high power, high speed and narrower spectral line width characteristics. But these are inherently non-linear and more

sensitive to temperature variations. Nowadays many improvements and advancements have made these sources more reliable. Table 2.1 depicts the comparison/differences between the Laser Diodes and LED according to the variation in the properties. Both these sources are modulated using either direct or external modulation techniques.

Table 2.1. The LED versus Laser Diodes

Characteristic	LED	Laser
Output power	Lower	Higher
Spectral width	Wider	Narrower
Numerical aperture	Larger	Smaller
Speed	Slower	Faster
Cost	Less	More
Ease of operation	Easier	More difficult

2. Low Loss Optical Fiber

Optical fiber is a cable, as shown in Fig.2.3, which is also known as cylindrical dielectric waveguide made of low loss material. An optical fiber also considers the parameters like the environment in which it is operating, the tensile strength, durability and rigidity. The Fiber optic cable is made of high quality extruded glass (si) or plastic, and it is flexible. The diameter of the fiber optic cable is in between 0.25 to 0.5mm (slightly thicker than a human hair).

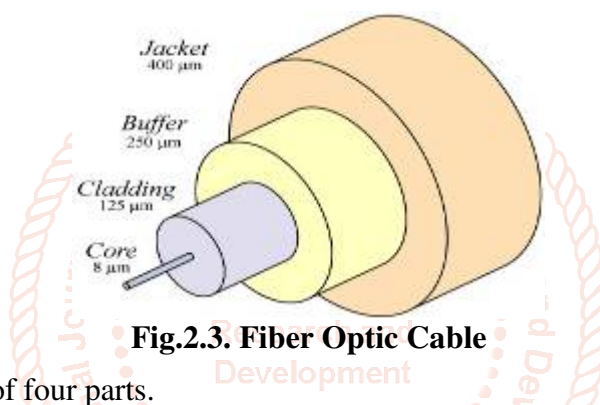


Fig.2.3. Fiber Optic Cable

A Fiber Optic Cable consists of four parts.

- Core
- Cladding
- Buffer
- Jacket

Core:

The core of a fiber cable is a cylinder of plastic that runs all along the fiber cable's length, and offers protection by cladding. The diameter of the core depends on the application used. Due to internal reflection, the light travelling within the core reflects from the core, the cladding boundary. The core cross section needs to be a circular one for most of the applications.

Cladding:

Cladding is an outer optical material that protects the core. The main function of the cladding is that it reflects the light back into the core. When light enters through the core (dense material) into the cladding (less dense material), it changes its angle, and then reflects back to the core.

Buffer:

The main function of the buffer is to protect the fiber from damage and thousands of optical fibers arranged in hundreds of optical cables. These bundles are protected by the cable's outer covering that is called jacket.

Jacket:

Fiber optic cables jackets are available in different colors that can easily make us recognize the exact color of the cable we are dealing with. The color yellow clearly signifies a single mode cable, and orange color indicates multimode.

Types of Optical Fibers:

Single-Mode Fibers: Single mode fibers are used to transmit one signal per fiber; these fibers are used in telephone and television sets. Single mode fibers have small cores.

Multi-Mode Fibers: Multimode fibers are used to transmit many signals per fiber; these signals are used in computer and local area networks that have larger cores.

3. Photo Detectors

The purpose of photo detectors is to convert the light signal back to an electrical signal. Two types of photo detectors are mainly used for optical receiver in optical communication system: *PIN photo diode* and *avalanche photo diode*. Depending on the application's wavelengths, the material composition of these devices vary. These materials include silicon, germanium, InGaAs, etc.

B. Photodetectors in Optical Communication

According to [2], the fiber optics transmission involves transmission of signals in the form of light from one point to the other. Furthermore, a fiber optic communication network consists of transmitting and receiving circuitry, a light source and detector devices. An optical detector is a device that converts light signals into electrical signals, which can then be amplified and processed.

Photodetectors can dictate or determine the performance of a fiber optic communication link. A photodetector acts as an optical receiver in fiber optic communication system. Two purposes of a photodetector in a fiber optic communication system include the following:-

1. For terminal reception of the communication link at the transmitter end,
2. For photoelectric conversion of the relay system.

Out of the different types of Photodetectors, the two most commonly used suitable for fiber optic communication system are:-

- PIN Photodiode and
- Avalanche Photodiode (APD).

C. Photoelectric detection and optical receiver

According to authors in [2], at the transmitting end of the optical fiber communication system, the light source is modulated with a low-frequency baseband electrical signal, and then the modulated light signal is transmitted via the optical fiber. Due to factors such as attenuation and dispersion of optical fibers, when a dimmed signal is transmitted to the receiving end, it becomes weak and has waveform distortion. The role of the optical receiver is to detect the weak light signal first, then convert it into an electrical signal, and then restore to the original baseband signal through amplification, shaping, regeneration, and decoding. Therefore, the core component of the optical receiver is a *photodetector*. In the entire optical fiber communication system, the photoelectric detection device mainly has two purposes: one is for *terminal reception of the communication system*, and the upper part of the Fig.2.4 is the schematic diagram of terminal receiving of the digital optical fiber communication system; the second is photoelectric conversion for the relay station. After the signal processing continues to transmit, the lower part (see Fig.2.4) depicts the relay station's photoelectric conversion process.

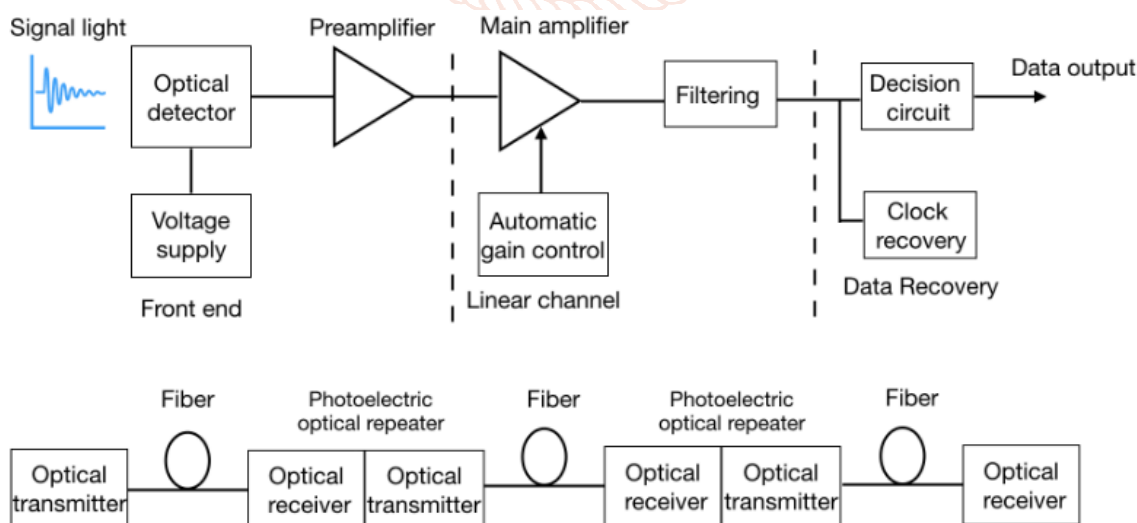


Fig.2.4. Working Process Diagram of Optical Communication System [2]

D. Photoelectric detection principle

The photodetector is an optoelectronic device made by utilizing the photoelectric effect of a semiconductor. It converts the change of the optical signal into the change of the photocurrent, and reflects the change rule of the information. According to different conversion parameters, the semiconductor photodetector has two basic

types: photoconductive type and photodiode type. The conductance of the photoconductive type detector changes with the change of luminous flux. The photodiode is always operated in the reverse bias state. It belongs to the inner photoelectric effect device, and the incident photon does not directly bombard photoelectrons, but merely raises the internal electrons from the lower energy level to the higher energy level. The differential resistance of the photodetector does not change with the luminous flux, and the generated photocurrent is proportional to the luminous flux. Both types of semiconductor photodetection devices have very fast response speeds, but have their own characteristics and different uses. In optical fiber communication systems, the most widely used photodetector is a photodiode because of the small size and long life of such detectors.

3.1. COMPARATIVE ANALYSIS BETWEEN PIN PHOTODIODE AND AVALANCHE PHOTODIODE PHOTODETECTORS

A. Comparison between PIN photodiode and Avalanche Photodiode (APD) as used in Fiber Optic Communication

According to the [3], PIN photodiodes and Avalanche Photodiodes (APD) are used as receivers to facilitate fiber optic networks. Often, they provide extremely high-speed internet access or receive telephone and digital television signals. The chief overall advantage of optical technology is its high data transfer rate; PIN and APD receivers are both designed for such applications. However, there have different or distinct technologies.

Avalanche photodiodes (APDs) are widely used in laser-based fiber optic systems to convert optical data into electrical form. They are high-sensitivity, high-speed semiconductor light sensors.

The main advantage of the APD is that it has a greater level of sensitivity compared to PIN photodiode. The avalanche action increases the gain of the diode many times, providing much higher sensitivity. However, an APD requires a higher operating voltage. In addition, the term avalanche refers to the output being non linear; as a result, APDs also produce a higher level of noise than a PIN diode.

Also APDs, unlike PIN devices, need a high reverse bias condition to work. That permits avalanche multiplication of the holes and electrons created by the initial electron-hole pairs. APDs have an internal region where electron multiplication occurs by application of an external reverse voltage. The resultant gain in the output signal means that low light levels can be measured at high speed.

For silicon, an APD diode will typically require between 100-200 V, and with that voltage they will provide a current gain effect of roughly 100 V, resulting from the avalanche effect. Some diodes that use specialized manufacturing processes enable much higher bias voltages of up to 1,500 V to be applied. The gain levels increase when higher voltages are applied, therefore the gain of these avalanche diodes can rise to the order of 1,000. That provides an advantage in solutions where sensitivity is important.

Typical applications for APDs are laser rangefinders and long-range fiber optic telecommunication, as well as positron emission tomography and particle physics. APD arrays are increasingly commercially available.

The avalanche photodiodes are not as widely used as their PIN counterparts. They are generally used where the level of gain is important and because of the high voltages required and lower reliability, they are often less convenient to use than PIN.

A PIN diode is a type of diode that has a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region. There is where it derived its name PIN.

Because of their applications for ohmic contacts, the p-type and n-type regions are typically heavily doped. The main difference between a PIN diode and an ordinary p-n diode is the wide intrinsic region in the PIN diode p-n junction. Because of this, PIN diode is inferior to the normal p-n diode as a rectifier. PIN diode is very suitable for attenuators and RF switches because of its wide intrinsic region. It is equally very suitable as photodetectors and applied very much in high-voltage power electronics applications, such as a high-voltage rectifier. Higher reverse voltages are tolerated in PIN diode because its intrinsic region provides a greater separation between the p and n regions.

PIN diodes are applied in RF scenarios where the capacitance levels are low. The switching and variable resistance properties of PIN diodes make them well adapted in switching and variable attenuator applications.

The comparative differences between Avalanche Photodiode and PIN photodiode are summarized in Table 3.1.

TABLE 3.1. Comparative differences between Avalanche Photodiode and PIN photodiode

S/N	PIN photodiodes	Avalanche Photodiodes
1.	It uses a lower reverse biased voltage.	It uses a higher reverse biased voltage.
2.	It produces a lower level of noise	It produces a higher level of noise
3.	It requires a lower operating voltage	It requires a higher operating voltage
4.	It is a passive microwave diode (not used in power generation or amplification)	It is an active microwave diode.
5.	It operates at a maximum frequency of 100MHz as a rectifier and up to 150 GHz maximum as a microwave diode.	It operates at a frequency in excess of 200 GHz as a microwave diode.
6.	It does not exhibit negative resistance characteristics unlike the Avalanche Photodiode, Tunnel diode, IMPATT and TRAPATT diodes.	It exhibits negative resistance characteristics like the Tunnel diode, IMPATT and TRAPATT diodes.
7.	It is not used in power generation or amplification.	It is used on power generation or amplification.
8.	It provides a lower sensitivity in fiber optic communication systems.	It produces a much higher sensitivity because of avalanche action (about 10-150 times higher than PIN photodiode) in fiber optic communication systems
9.	It has a slower response time (5 ns).	It has a much faster response time (2 ns).
10.	It cannot be used as for higher pulse modulation rates in fiber optic communication systems than the APD.	It can be used for higher pulse modulation rates for reception in fiber optic communication systems than the PIN photodiodes.
11.	It has a better linear output.	It has a non-linear output.
12.	It has a wider usage and applications.	It a narrower usage and applications and are used only where level of gain is important.
13.	It is easier and more convenient to use.	It is less convenient to us because of higher voltage requirement and less reliability.
14.	It is used as weaker rectifier, attenuator, RF switches, photodetectors and high-voltage power electronics applications, such as a high-voltage rectifier.	It is used in laser rangefinders and long-range fiber optic telecommunication, as well as positron emission tomography and particle physics

Similarities between PIN photodiode and Avalanche Photodiode:

The similarities between the two photodiodes are as follow:-

1. They are both used in microwave power switching, limiting and modulation.
2. They are made from the same semi-conductor materials.
3. They both operate in reverse-biased mode.
4. They are both used in fiber optic communication in optical receiver as photodetector.

SUMMARY AND CONCLUSION

Photodetectors such as Avalanche Photodiodes (AVDs) and PIN photodiodes are very important Photodetectors in fiber optic communication systems as well as other wide range applications. Both of them operate at different working principles and can be used or applied in fiber optic communication system as optical receivers and relay processing elements.

They have different differences in operation and applications. PIN photodiode operates at a lower reverse biased voltage compared to APD which operates at a higher reverse biased voltage. PIN photodiode/photodetector is easier and more convenient to use compared to APD but APD has a much higher sensitivity because of avalanche action. PIN photodiode is much reliable and does not require a very high operating voltage like the APD. APD is always applied where higher gain is desirable.

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