Optoelectronic devices

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ET1039 Nanotechnology

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1.INTRODUCTION

Is the study and application of electronic devices that source, control and detect light. It combine electronics and optics.

Optoelectronic devices are electrical-to-optical or optical-to-electrical transducers, or instruments that use such devices in their operation.

Normally they are semiconductor devices. Its operation is based on the wave theory and quantum mechanics (photoelectric effect).

We can distinguish 3 categories:

-Emitters Light.

-Receivers Light.

-Emitters - Receivers Light (optocouplers).

A semiconductor has a conduction band and valence band. Between them there is a band whose width is measured in terms of energy (Eg). When an electron "falls" from the conduction band to the valence band releases the energy that separates the two bands.

According to the quantum theory: $Eg = h * \upsilon$

- υ = frequency of emitted radiation.
- h = Planck constant.

If υ is within the spectrum of light radiation, light emission occurs.
The opposite effect is also possible: a luminous radiation stimulates the electrons from the valence band which acquire the energy needed to overcome the bandgap and "jump" to the conduction band, producing semiconductor input conducting.

2.EMITTERS LIGHT

Among semiconductor devices, those capable of emitting light belong to the category of the diodes.

- Led (Ligth-emitting diode)
- Laser diode.

the essential feature is that the width of the bandgap make the emitted radiation corresponding to light energy. This circumstance depends on the semiconductor material used and the color of the emitted light.

The excitation can be done:

- In DC:
  - Serial connection.
  - Parallel connection.
- Digital excitation.
- By pulse width modulation.

2.1LED

Materials:

Chemical compound	Colour	Wave length (nm)
Gallium arsenide (GaAs)	Infrared	940
Gallium arsenide and aluminum (AlGaAs)	Red and infrared	890
Gallium arsenide phosphide (GaAsP)	Red, orange and yellow	630
Gallium phosphide (GaP)	Green	555
Gallium nitride (GaN)	Green	525
Gallium nitride and Indium(InGaN)	Blue	450
Silicon carbide (SiC)	Blue	480

Vf:

Red = 1.6V

Red high luminosity = 1.9V

Yellow = 1.7 – 2V

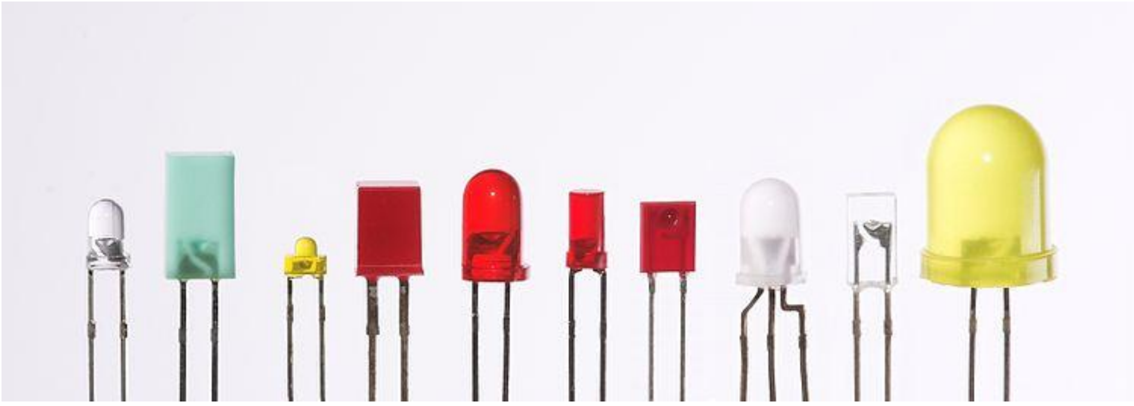
Green = 2.4V

Orange = 2.4V

Bright White = 3.4V

Blue = 3.4V

Blue 430 nm = 4.6V

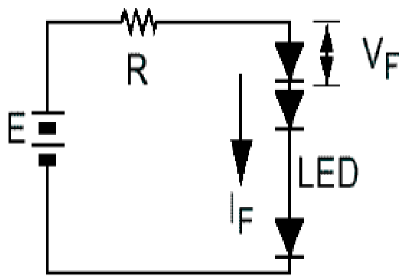


A LED is a two-lead semiconductor light source.

It is a p–n junction diode, which emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

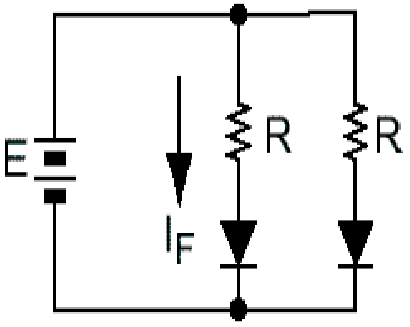
The main types of LEDs are miniature, high-power devices and custom designs such as alphanumeric or multi-color.

LEDs have many advantages over incandescent light sources and fluorescent, such as low power consumption, a longer life, small size, vibration resistance, low emission of heat, do not contain mercury…



Serial excitation of *n* LEDs with a battery in DC.

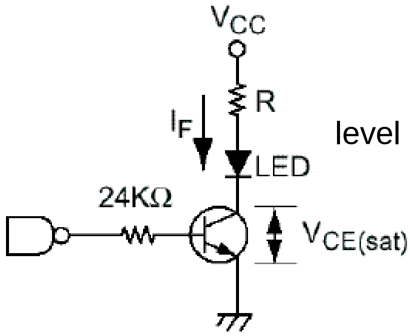
$$If = \frac{E - n\,Vf}{R}$$



Parallel connection of LEDs in DC

$$If = \frac{E - Vf}{R}$$

Digital excitation:



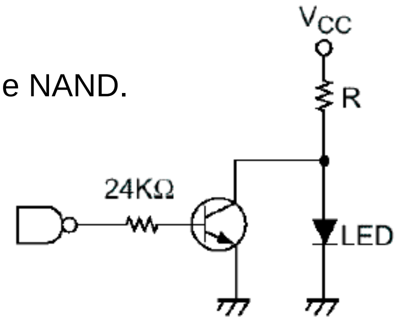
LED activated with the output at the high level of the NAND gate. If NAND gate =ON, LED=ON.

$$If = \frac{Vcc - (Vce(sat) + Vf)}{R}$$

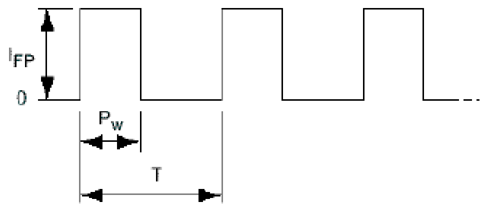
LED activated with the output at the low level of the NAND.

If NAND is OFF, LED = OFF.

$$If = \frac{Vcc - Vf}{R}$$



Excitation PWM:



Ifp = maximum pulse allowed

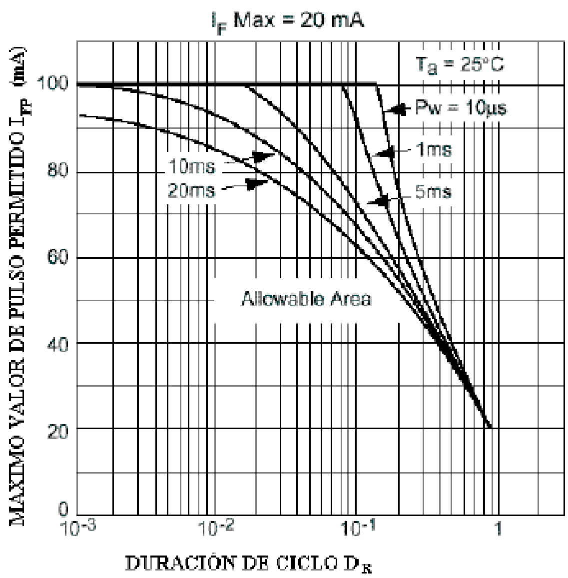
Pw = pulse width

T = period

Dr = duration of the cycle (= Pw/T)

Advantages:

- It allows adjusting the current in a non-dissipative way.
- The current is constant in every pulse, so the chromaticity coordinates are constants for any luminosity.



Applications of LEDs:

We can distinguish 4 main types of applications for LEDs

- Indicators and signs.
  Visual signs where light goes more or less directly from the source to the humane eye, to convey a message or meaning. A clear example are the traffic signals.

- Lighting or illumination.
  Light is reflected from objects to give visual reponse of these objects. The development of high-efficiency and high-power LEDs has give us the possibility to use LEDs in illumination.
  Are used as street lights and in other architectural lighting, like parking garages. In 2007 the italian Village of Torraca was the first place to convert its entire illumination system to LEDs. Another case of use is in the mining operations, as cap lamps.
  Nowadays, big companies are doing energetic studies of their installations in order to save money, and a part of that study is estimate how much money would they save by converting the illumination system to LEDs.

- Measuring and interacting with processes involving no human vision. Machine vision systems often require bright and homogeneous illumination, so features of interest are easier to process. Barcode reader are the most common example of machine vision, and many low cost products use red LEDs instead of lasers.

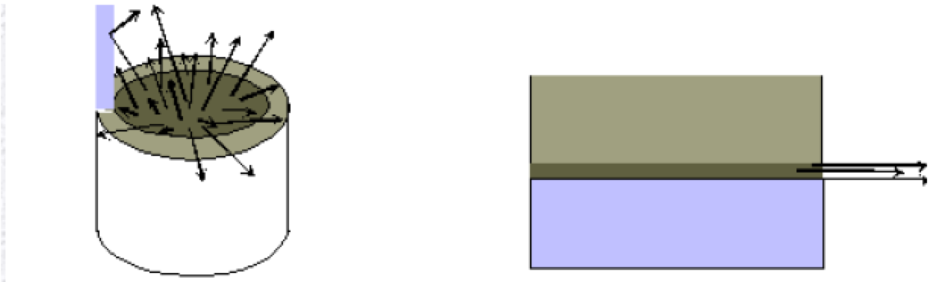
- Narrow band light sensors where LEDs operate in a reverse-bias mode and respond to incident light, instead of emitting light.

2.2 LASER DIODE

LASER diode (*Light Amplification by Stimulated Emission of Radiation*) is an electrically pumped semiconductor laser in which the active laser medium is formed by a p-n junction of a semiconductor diode similar to that found in a light-emitting diode.
Is electrically a P-i-n diode. The active region of the laser diode is in the intrinsic (I) region, and the carriers (electrons and holes) are pumped into that region from the N and P regions.

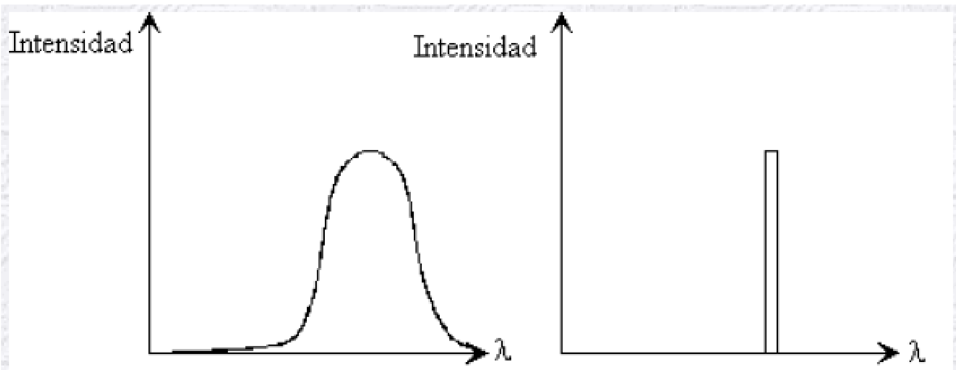
2.2.1 Advantages over LEDs

- The light emission is guided in one direction: A LED emits photons in many directions. A laser diode, however, guides the preferential light in only one direction.



Emisión fotónica en diodo LED   Emisión fotónica en diodo LASER

- Laser light emission is monochromatic: Photons emitted by a laser have similars wavelengths. In contrast, in the light emitted by LEDs, there are photons with wavelengths so much higher than other ones.



Espectro emitido por un LED   Espectro emitido por un LASER

2.2.2 Types:

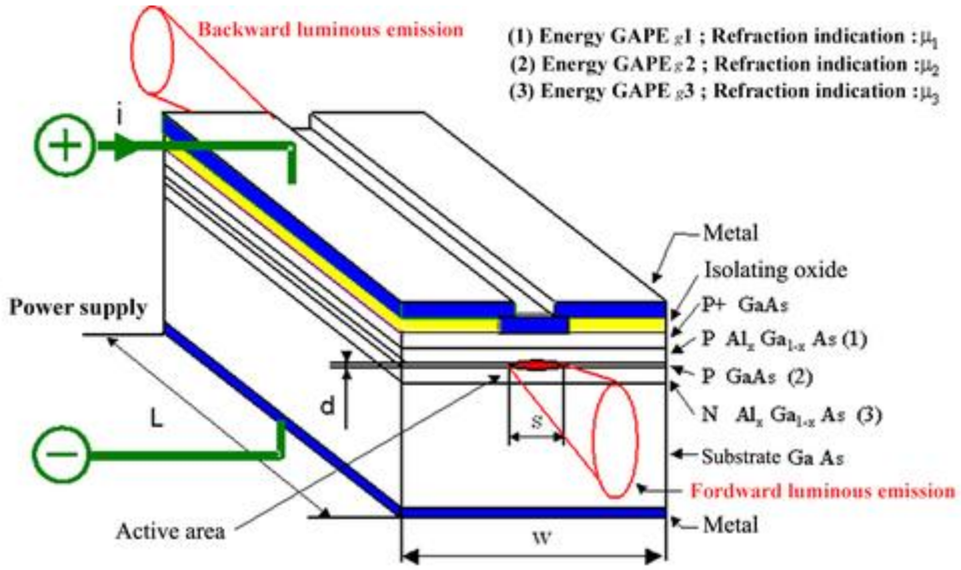
The simple laser diode structure is extremely inefficient. Such devices require so much power that they can only achieve pulsed operation without damage.

- <u>Double heterostructure lasers.</u>

A layer of low bandgap material is intercaled between two layers of hhigher bandgap material. Normally gallium arsenide (GaAs) with aluminium gallium arsenide (AlxGa(1-x)As)

Junctions between different bandgap amterials are called heterostructures.

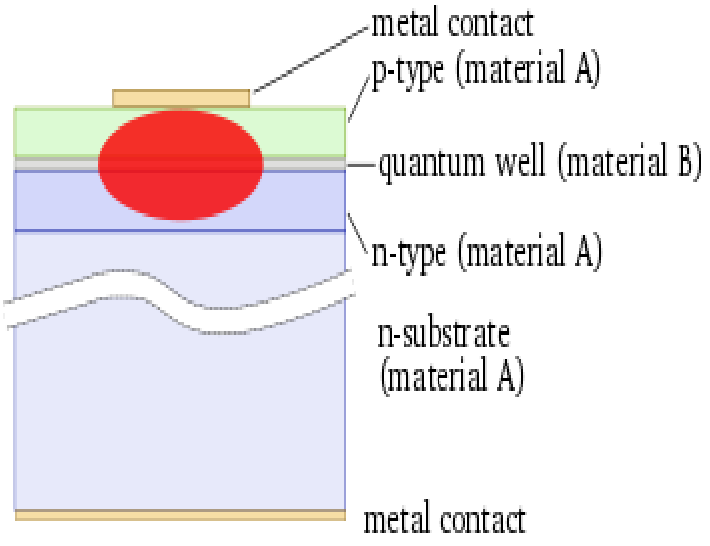
The main advantage is that the region where free electrons and holes co-exist (active region) is confined to the thin middle layer. Which means that some of the electron-hole pairs can contribute to amplification. In addition, since light is reflected from the heterojunction it is confined to the region where the amplification takes place.



➢ Quantum well lasers

If the middle layer is thin enough, it acts as a quantum well.

The efficiency of a quantum well laser is greater than that of a bulk laser because the density of states function of electrons in the quantum well system has an abrupt edge that concentrates electrons in energy states that contribute to laser action.



Lasers containing more than one quantum well layer are known as*multiple quantum well* lasers.

➢ Quantum cascade lasers

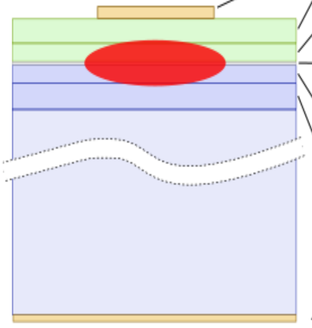
In a quantum cascade laser, the difference between quantum well energy levels is used for the laser transition instead of the bandgap. This enables laser action at relatively long wavelengths, which can be tuned simply by altering the thickness of the layer. They are heterojunction lasers.

➢ Interband cascade lasers

A Interband cascade laser (ICL) is a type of laser diode that can produce coherent radiation over a large part of the mid-infrared region of the electromagnetic spectrum.

- <u>Separate confinement heterostructure lasers</u>

The thin layer in the simple quantum well diode is too small to effectively confine the light. To compensate, another two layers are added on, outside the first three. These layers have a lower refractive index than the centre layers, and hence confine the light effectively. Such a design is called a separate confinement heterostructure (SCH) laser diode.



- <u>Distributed bragg reflector lasers</u>

Is a type of single frequency laser diode. It is characterized by an optical cavity consisting of an electrically or optically pumped gain region between two mirrors to provide feedback.
One of the mirrors is a broadband reflector and the other mirror is wavelength selective so, that gain is favored on a single longitudinal mode, resulting in lasing at a single resonant frequency.

- <u>Distributed feedback lasers</u>

Is a type of single frequency laser diode. To stabilize the lasing wavelength, a diffraction grating is etched close to the pn junction of the diode. This grating acts like an optical filter, causing a single wavelength to be fed back to the gain region and lase.

DFB lasers are widely used in optical communication applications where a precise and stable wavelength is critical.

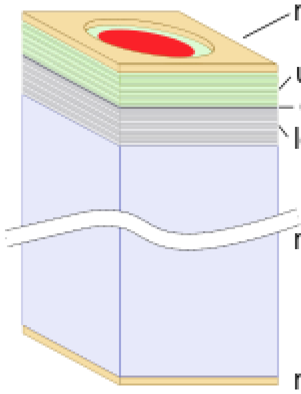
- <u>Vertical-cavity surface-emitting lasers (VSCELs).</u>

Have the optical cavity axis along the direction of current flow rather than perpendicular to the current flow.

The active region length is very short compared with the lateral dimensions so that the radiation emerges from the surface of the cavity. The reflectors at the ends of the cavity are dielectric mirrors.

There are several advantages to producing VCSELs when compared with the production process of edge-emitting lasers. Edge-emitters cannot be tested until the end of the production process. If the edge-emitter does not work, whether due to bad contacts or poor material growth quality, the production time and the processing materials have been wasted.

But there is a disadvantage: because of the high mirror reflectivities, VCSELs have lower output powers when compared to edge-emitting lasers.



- <u>Vertical external-cavity surface-emitting lasers (VECSELs)</u>

Similar to VCSELs. In VCSELs, the mirrors are typically grown epitaxially as part of the diode structure, or grown separately and bonded directly to the semiconductor containing the active region. VECSELs are distinguished by a construction in which one of the two mirrors is external to the diode structure. As a result, the cavity includes a free-space region.

- <u>External-cavity diode lasers</u>

Are tunable lasers which use mainly double heterostructures diodes of the AlxGa(1-x)As type. The first external-cavity diode lasers used intracavity etalons and simple tuning Littrow gratings. Other designs include gratings in grazing-incidence configuration and multiple-prism grating configurations.

2.2.3 Applications:

- Data communications fiber optics.
- Optical interconnections between integrated circuits.
- Laser printers.
- Scanners and digitizers.
- Sensors.
- Dental laser treatment.
- Body hair removal.
- Laser display
- Odontology

3.RECEIVERS LIGHT

Are those components that vary an electrical parameter depending on the light. All components photodetectors are based on the same principle. If we build a component with a semiconductor material so that light can impinge on the material, the light generated electron hole pairs.

We will discuss now about three different types of light receptors:

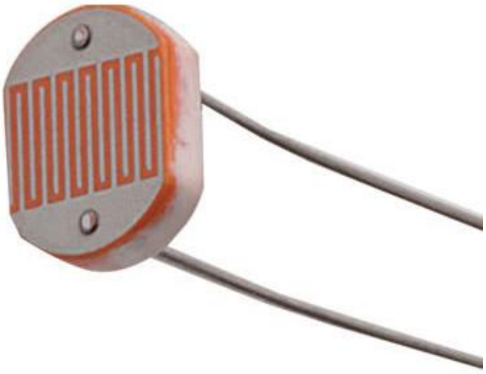
- Photoresistor.
- Photodiode.
- Phototransistor.

3.1 Photoresistor

Is a light-controlled variable resistor. The resistance of a photoresistor decreases with increasing incident light intensity. A photoresistor can be applied in light-sensitive detector circuits, and light- and dark-activated switching circuits.

If incident light on a photoresistor exceeds a certain frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electrons (and their hole partners) conduct electricity, thereby lowering resistance. The resistance range and sensitivity of a photoresistor can substantially differ among dissimilar devices.

A photoelectric device can be either intrinsic or extrinsic. An intrinsic semiconductor has its own charge carriers and is not an efficient semiconductor. In intrinsic devices the only available electrons are in the valence band, and hence the photon must have enough energy to excite the electron across the entire bandgap.



Extrinsic devices have impurities, also called dopants, added whose ground state energy is closer to the conduction band; since the electrons do not have as far to jump, lower energy photons are sufficient to trigger the device.

3.1.1 Applications

Most of the applications are based on photoresistors actuating a relay or a lamp. The practical applications of the photoresistors include switches and alarms activated by light or darkness, light barrier, reflection smoke alarms, etc.

Main applications of photoresistors are the lighting systems, being the most popular example the light activation system in companies when the night falls.

When the ambient light drops below a certain level, a relay is actuated, closing the corresponding switch.

Although less popular, there are also more applications, such as camera light meters, clock radios, outdoor clocks, solar street lamps and solar road studs, etc.

3.2 Photodiode.

Is a semi-conductor device, with a p-n junction and an intrinsic layer between p and n layers. It produces photocurrent by generating electron-hole pairs, due to the absorption of light in the intrinsic or depletion region. The photocurrent thus generated is proportional to the absorbed light intensity.

When photons of energy greater than 1.1 eV hit the diode, electron-hole pairs are created. The intensity of photon absorption depends on the energy of photons – the lower the energy of photons, the deeper the absorption is. This process is known as the inner photoelectric effect.

If the absorption occurs in the depletion region of the p-n junction, these hole pairs are swept from the junction - due to the built-in electric field of the depletion region. As a result, the holes move toward the anode and the electrons move toward the cathode, thereby producing photocurrent.

3.2.1 Modes.

Photodiodes can operate in different modes, photovoltaic mode, photoconductive mode and avalanche mode:

- Photovoltaic mode – It is also known as zero bias mode, in which a voltage is generated by the illuminated photodiode. It provides a very small dynamic range and non-linear dependence of the voltage produced.

- Photoconductive mode - The diode used in this mode is more commonly reverse biased. The application of reverse voltage increases the width of the depletion layer, which in turn reduces the response time and capacitance of the junction. This mode is very fast, and exhibits electronic noise.

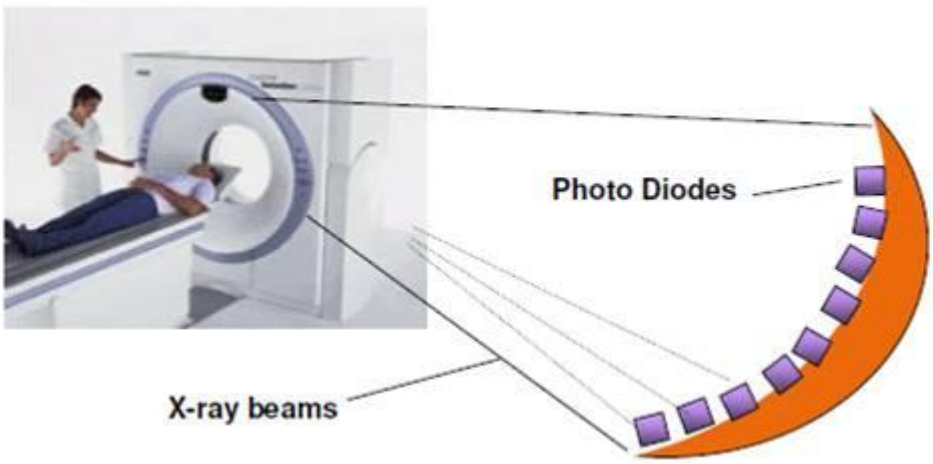
- Avalanche diode mode - Avalanche photodiodes are operated in a high reverse bias condition, which allow multiplication of an avalanche breakdown to each photo-generated electron-hole pair. This results in internal gain within the photodiode, which gradually increases the responsivity of the device

3.2.2 Applications.

They may be used to generate an output which is dependent upon the illumination (analog; for measurement and the like), or to change the state of circuitry (digital; either for control and switching, or digital signal processing).

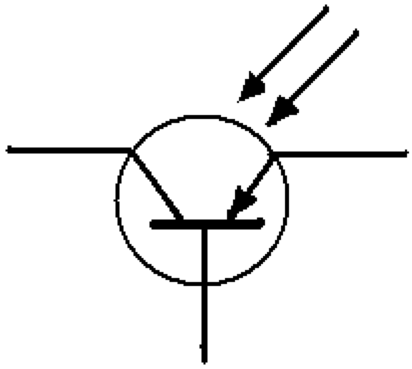
Find application in the following:

- Cameras
- Medical devices
- Safety equipment
- Optical communication devices
- Position sensors
- Bar code scanners
- Automotive devices
- Surveying instruments



3.3 Phototransistor

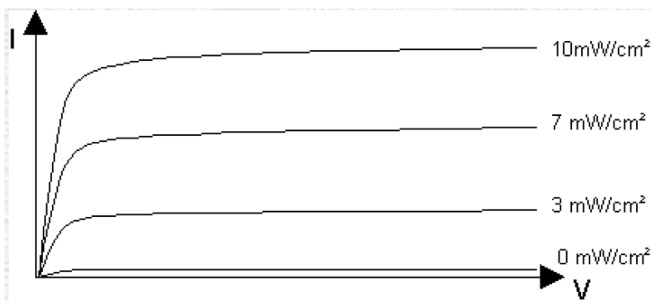
A phototransistor is a light-sensitive transistor. A common type of phototransistor, called a photobipolar transistor, is in essence a bipolar transistor encased in a transparent case so that light can reach the base–collector junction.



The light radiation is incident on the collector base junction when it operates in the normal active region. At this juncture the electron hole pairs are generated, causing electrical current.

The operation of a phototransistor is characterized by the following points:

- A phototransistor operates, generally without base terminal (Ib = 0) although in some cases there phototransistors that have a terminal base available to work as a normal transistor.
- The sensitivity of a phototransistor is higher than a photodiode, since the small photogenerated current is multiplied by the gain of the transistor.
- Operating curves of a phototransistor are analogous curves to BJT transistor, replacing the base intensity for power per unit area incident on the phototransistor.



Operating curves of a phototransistor

3.3.1 Applications:

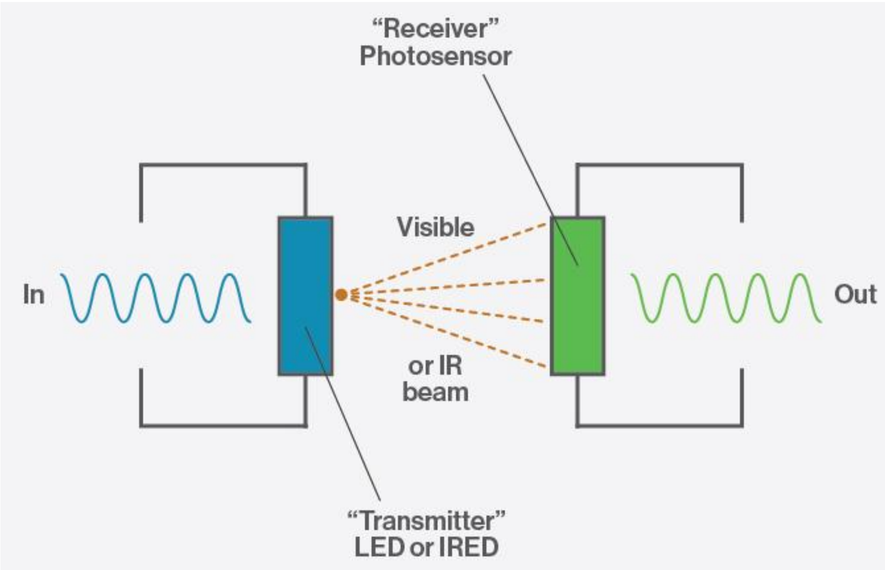
Areas of application for the Phototransistor include:

- Punch-card readers.
- Security systems
- Encoders – measure speed and direction
- IR detectors photo
- electric controls
- Computer logic circuitry.
- Relays
- Lighting control (highways etc)
- Level indication
- Counting systems

4. Optocouplers

An optocoupler, also called opto-isolator or optically coupled isolator, is a transmission and reception device that works as a switch activated by light emitted by a LED,which saturate an optoelectronic component, usually a phototransistor or phototriac.

In its simplest form, an optoisolator consists of a light-emitting diode (LED), IRED (infrared-emitting diode) or laser diode for signal transmission and a photosensor (or phototransistor) for signal reception. Using an optocoupler, when an electrical current is applied to the LED, infrared light is produced and passes through the material inside the optoisolator.



The beam travels across a transparent gap and is picked up by the receiver, which converts the modulated light or IR back into an electrical signal. In the absence of light, the input and output circuits are electrically isolated from each other.

4.1 Types of octocouplers

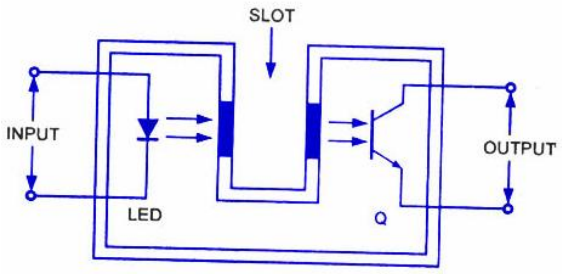
We can distinguish two different types of optocouplers depending on the connection between emitter and receptor, they are slotted optocouplers and reflective optocoupler:

- Slotted Optocoupler

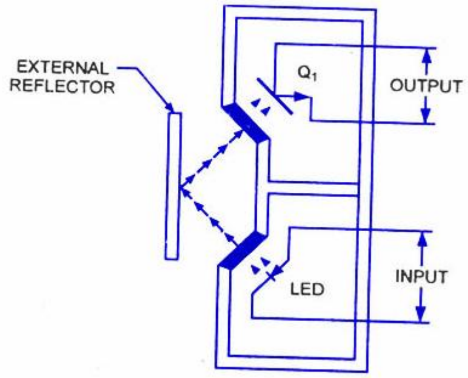
A slotted optocoupler has a slot moulded into the package between the LED light source and the phototransistor light sensor; the slot houses transparent windows, so that the LED light can normally freely reach the face of transistor, but can be interrupted or blocked via opaque object placed within the slot.

- Reflective Optocoupler

Here the LED and phototransistor are optically screened from each other within the package, and both face outwards (in same direction) from the package. The construction is such that an optocoupled link can be set up by a reflective object (such as metallic paint or tape, or even smoke particles) placed a short distance outside the package, in line with both the LED.



Slotted Optocoupler

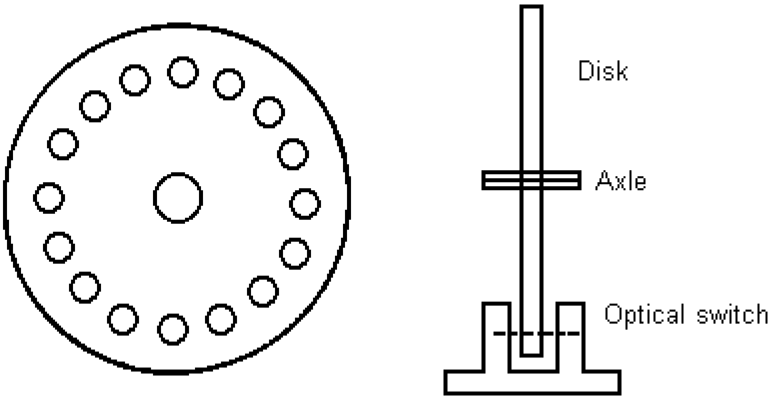


Reflective Optocoupler

4.2 Applications

The different types of optocouplers con be used for several applications:

- The slotted optocoupler can thus be employed in a variety of presence detecting applica-tions, including end-of-tape detection, limit switching, and liquid level detection.



Slotted optocoupler application

In this example when a thin plastic or metal disk with perforations or slots cut at its outside edge is rotated inside the slot of the optocoupler, the infrared light can be detected where an opening in the slot exists. As a result, current flows at the output of the coupler. When the infrared light is blocked by the opaque section of the disk, there is no output current (Figure 13.8).

As the infrared light beam is interrupted, pulses are generated at the output of the coupler and rotational speed of the disk can be measured, and motor speed control can be achieved. If the disk is rotated by the flow of a liquid, the rate of flow of the liquid can be determined. With a properly calibrated counting system, the exact number of gallons of gasoline being pumped at a gas station can be measured accurately with this device and its associated circuitry.

- The reflective coupler can thus be employed in applications such as tape-position detection, en-gine-shaft revolution counting or speed measurement, or smoke or fog detection etc.