Unit-IV

Photodetectors
&
Solar Cells

Photodetectors:

- **Photodetectors** are semiconductor devices that can detect optical signals through electronic processes.
- It is device that converts incident optical energy or photon energy into electrical energy.
- Quantum photo electric effect is the principle of photoelectric detectors.

Types of Photodiode

Although there are numerous types of photodiode available in the market and they all work on the same basic principles, though some are improved by other effects.

The types of photodiodes can be classified based on their construction and functions as follows.

- PN Photodiode
- PIN Photodiode
- Avalanche Photodiode

Photodiode:

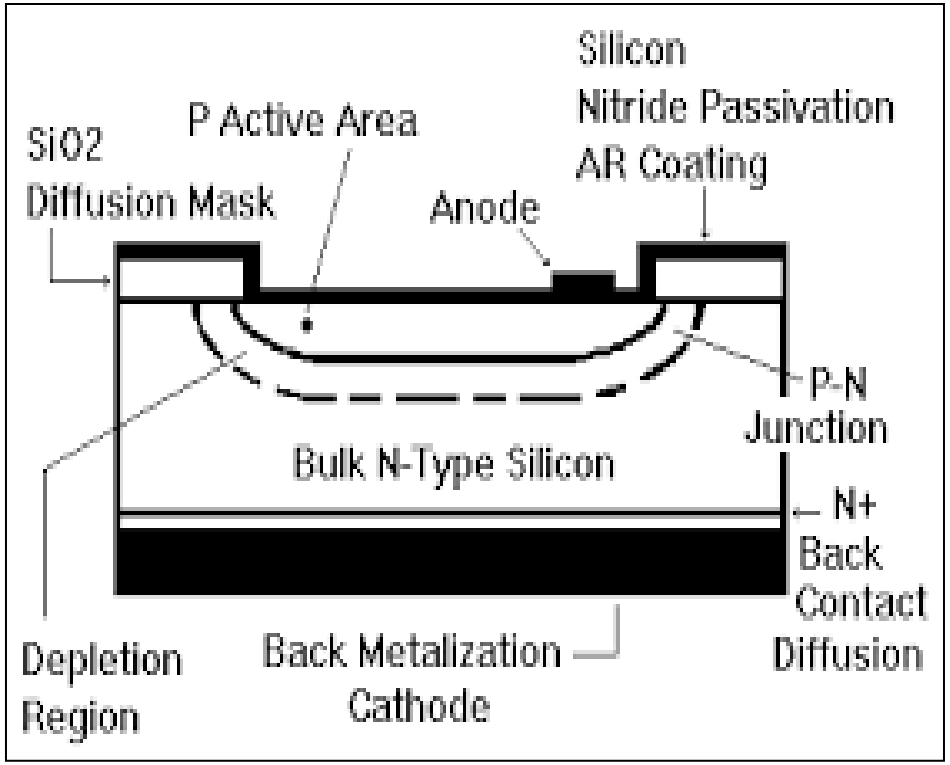
- A commonly used photo detector is the photodiode.
- A photodiode is basically a PN junction diode.
- It is essentially a reverse biased junction diode with light permitted to fall on one surface of the device across the junction.
- During the fabrication of the PN diode, a depletion layer forms at the junction region.
- The built in potential that developed across the junction stops flow of charge carriers across the junction.
- But still a small amount of current, called reverse saturation current, flows due to thermally generated minority carriers.

Construction

A cross section of a typical silicon photodiode is shown in the figure.
N type silicon is the starting material. A thin "p" layer is formed on the front surface of the device by thermal diffusion or ion implantation of the appropriate doping material (usually boron). The interface between the "p" layer and the "n" silicon is known as a pn junction.

Small metal contacts are applied to the front surface of the device and the entire back is coated with a contact metal.
The back contact is the cathode and the front contact is the anode.

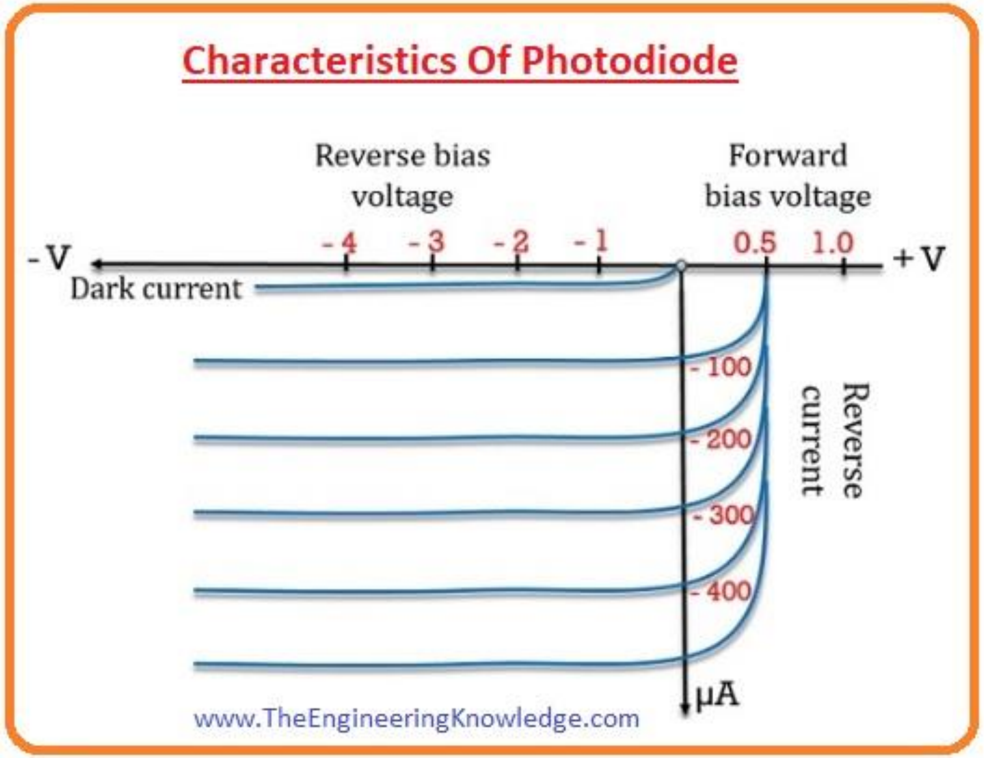
The active area is coated with an antireflection coating of material so that most of the light falling on the device can be trapped by it. The thickness of this coating is optimized for particular irradiation wavelengths.



- When the radiation is incident, electron – hole pairs are created on both sides of junction.
- The photo induced electrons in the conduction band of P-type will move across the junction down the potential hill with thermally generated minority carriers.
- Similarly, holes produced in the valence band of N-type will flow across the junction to P-side.
- This process of diffusion and rapid crossing of charge carriers across the depletion region due to strong electric field is so rapid that there is a little possibility of recombination.

V-I Characteristics

- The typical voltage – current characteristic of PN photodiode is very much similar to the characteristics of reverse biased PN junction diode.
- With zero illumination, the current equals to the reverse saturation current or **dark current**.
- Curves with different illuminations are shown in fig. The curves do not pass through the origin.



Disadvantages:

- The depletion region is relatively small portion of the total volume of the diode. Therefore only few photons, which are absorbed in the depletion region, cause current in the circuit whereas many of the photons absorbed in the bulk of the diode do not result in current.
- To increase the width of the depletion region, the reverse bias applied across the junction has to be increased; which many not be possible beyond a certain value.
- The electrons and holes generated by the photons in the bulk of the diode recombine before they cause current in the circuit.

The disadvantage of the *pn* junction photodiode is that the depletion width is small and depends on the doping concentrations in the semiconductor. It is not possible to tailor the depletion region over a wide range.
This can be overcome by using the *pin* photodiode, which is a special case of the *pn* junction photodiode.

Responsivity :

Responsivity of a detector is given as the ratio of the generated photocurrent (I) to the amount of optical power (P_0) incident on the detector

$$\mathcal{R} = \frac{I}{P_0}$$

The unit of responsivity is amperes/watt.

Quantum Efficiency :
A detector is not capable of collecting all the photons and convert them to electron-hole pairs. The number of electrons produced per incident photon is defined as the **quantum efficiency** , which is usually expressed as a percentage

$$\eta = \frac{\text{No. of electrons produced}}{\text{No. of incident photons}}(\times 100\%)$$

$$\boxed{\eta = \frac{I/q}{P_0/h\nu}}$$

If $I =$ photocurrent in the external circuit and $P_0 =$ the incident optical power (dropping the percentage in the definition,)

Using this in the expression for the responsivity, we get

$$\mathcal{R} = \frac{I}{P_0} = \frac{q\eta}{h\nu} = \frac{q\eta}{hc}\lambda$$

The responsivity, therefore, depends on the wavelength λ. For an ideal photodetector, $\eta = 1$ and $\mathcal{R}$ is linear with λ.

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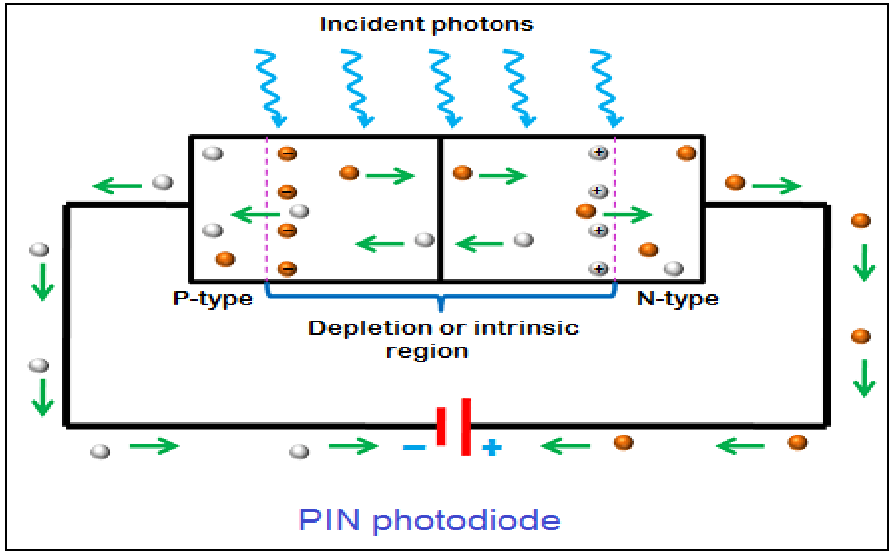
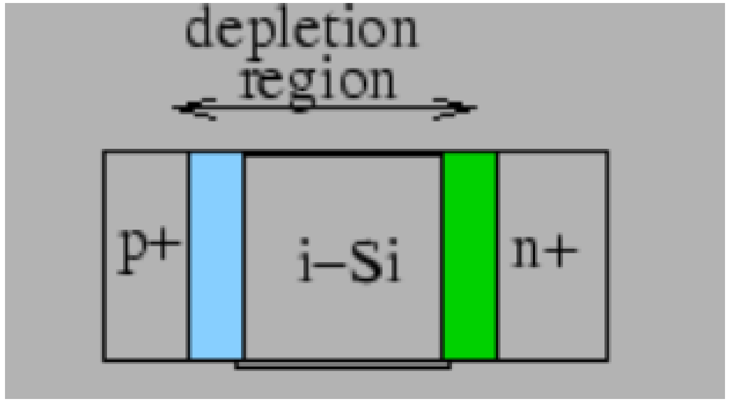
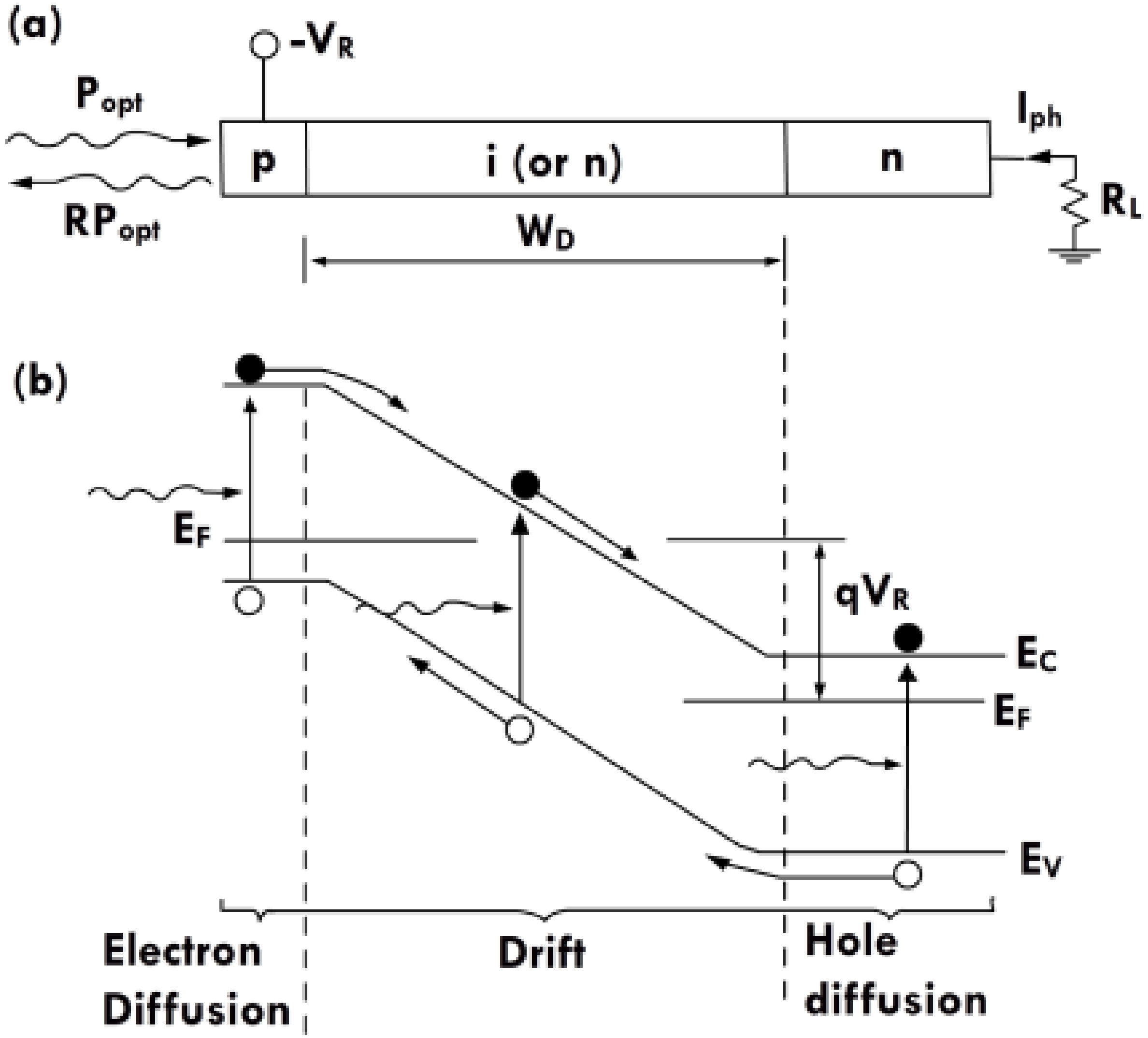
PIN diode

- The width of the depletion layer may be increased artificially, by adding an intermediate intrinsic region.
- As the intrinsic region has high resistance, a small reverse bias is good enough to increase the width of the depletion region so that it extends into the n-layer.
- A p-i-n photodiode consists of an intrinsic region sandwiched between heavily doped p+ and n+ regions. The depletion layer is almost completely defined by the intrinsic region.

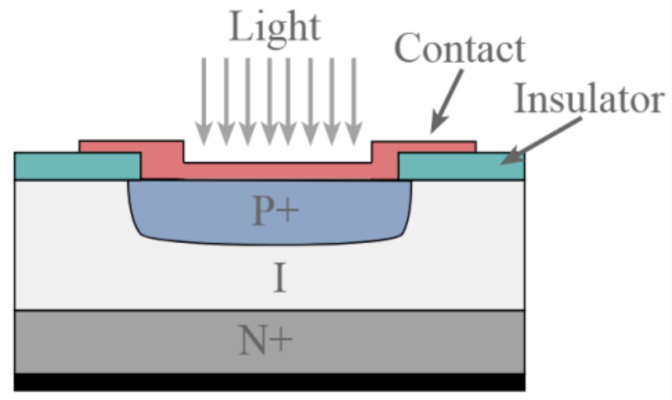





(a)
$-V_R$
P_{opt}
RP_{opt}
p
i (or n)
n
I_{ph}
R_L
W_D
(b)
E_F
qV_R
E_C
E_F
E_V
Electron Diffusion
Drift
Hole diffusion

The thickness of the depletion region or intrinsic layer can be tailored to optimize the quantum efficiency and frequency response. Figure shows the simplest PIN structure, with light being introduced through the upper p^+ layer.

The depletion region extends well into the intrinsic region as it is lightly doped. Under sufficiently large reverse bias the entire intrinsic region could be made free of charge carriers. Its resistance is high and most of the bias voltage drops across it.



When the PIN diode is illuminated by a photon energy, free EHP are created in the intrinsic region. Since the depletion region is under high field, the photo generated charge carriers are quickly separated and collected at electrodes to constitute photo current in the external circuit. As the intrinsic layer is wide enough, most of the photons are absorbed and larger photocurrent is produced, Therefore, PIN photodiode is more sensitive than PN photodiode.

Advantages:

- Due to the presence of intrinsic region, the reverse bias need not be varied to widen the depletion region.
- Low reverse bias is enough
- Capturing area is large this improves the efficiency
- Dark current in the device is small
- Due to high electric field at junction the response speed is high.

SOLAR CELL

What is Solar cell??

- **A structure that converts solar energy directly into dc electrical energy.**
- **It is like a battery because it supplies dc power.**
- **It is different from a battery in the sense that voltage supplied by the cell changes with changes in the resistance of the load.**

What is the Need??

- **Increase in population has increased energy demand**
- **More dependence on technology**
- **Concern for the environment (need environmental resources)**
- **Need of the hour**
- **Coal deposits will get depleted in 100 to 200 years.**
- **Petroleum deposits will get depleted in next few decades.**
- **Other non – renewable sources also get depleted shortly.**

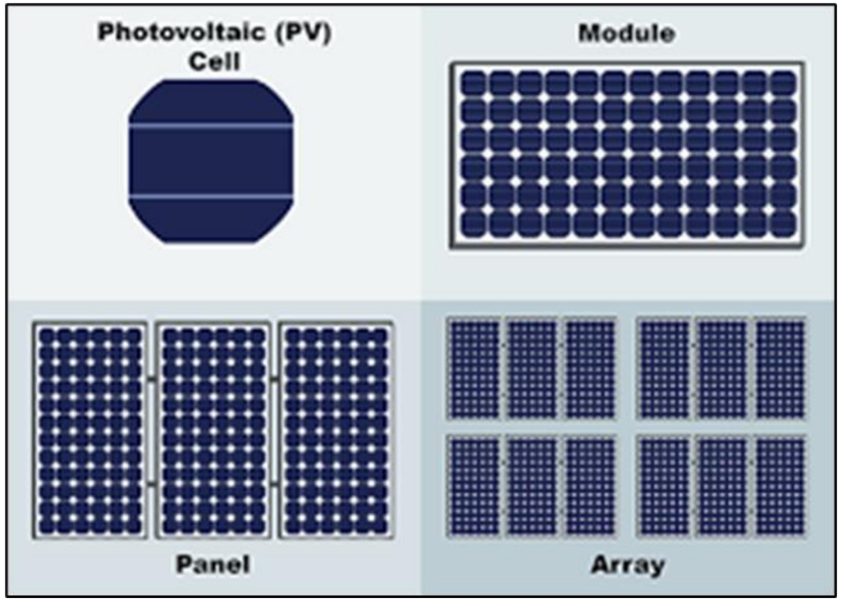
Hence, need to find an alternative.

Solar cell, Module, Array

A **Solar panel/ array** is interconnection of a number of Solar modules to get efficient power.

A **Solar module** consists of number of interconnected solar cells.

These interconnected cells are embedded between two glass plates to pretect them from bad weather.



Introduction

- Solar cells and photodetectors are devices that convert an optical input into current.
- A solar cell is an example of a ***photovoltaic device***, i.e, a device *that generates voltage when exposed to light*.
- The photovoltaic effect was discovered by Alexander-Edmond Becquerel in 1839, in a junction formed between an electrode (platinum) and an electrolyte (silver chloride).
- The first solid state photovoltaic device was built, using a Si *pn* junction, by Russell Ohl in 1939.
- The functioning of a solar cell is similar to the photodiode (photodetector). It is a photodiode that is unbiased and connected to a load.

There are three qualitative differences between a solar cell and photodetector

1. A photodiode works on a narrow range of wavelength while solar cells
   need to work over a broad spectral range (solar spectrum).

2. Solar cells are typically wide area devices to maximize exposure.

3. In photodiodes the metric is quantum efficiency, which defines the signal to noise ratio, while for solar cells, it is the power conversion efficiency, which is the power delivered per incident solar energy. Usually, solar cells and the external load they are connected to are designed to maximize the delivered power.

Photo cell	Solar cell
Photo Cell is operated under applied reverse biased in photo conductive mode	Solar cell is operated in unbiased condition with no external applied voltage in photovoltaic mode
Photo Cell need to work on narrow band of wavelengths	Solar cell need to work over broad band of wavelengths
Photo cell is not a large area device	Solar cell should be large area to get maximum exposure to sunlight
The metric for photo cell is quantum efficiency	The metric of solar cell is conversion efficiency
Wavelength range is not fixed – depend on material	Wavelength range is fixed – depends on solar spectrum.

Different types of solar cells

- Homo junction solar cell:
- Hetro junction solar cell:
- Tandem solar cells:
- Thin film solar cells:

Solar Cell:

- It is a PN junction device with no voltage directly applied across the junction. It converts photon power into electrical power and delivers this power to a load. It is the example of photovoltaic device. Effort is made to ensure that the surface area perpendicular to sun is more.

The basic steps in the operation of solar cell:

1. The generation of EHP's
2. Collection of light generated carriers to generate a current
3. Generation of large voltage across solar cell
4. Dissipation of power to load and external circuit.

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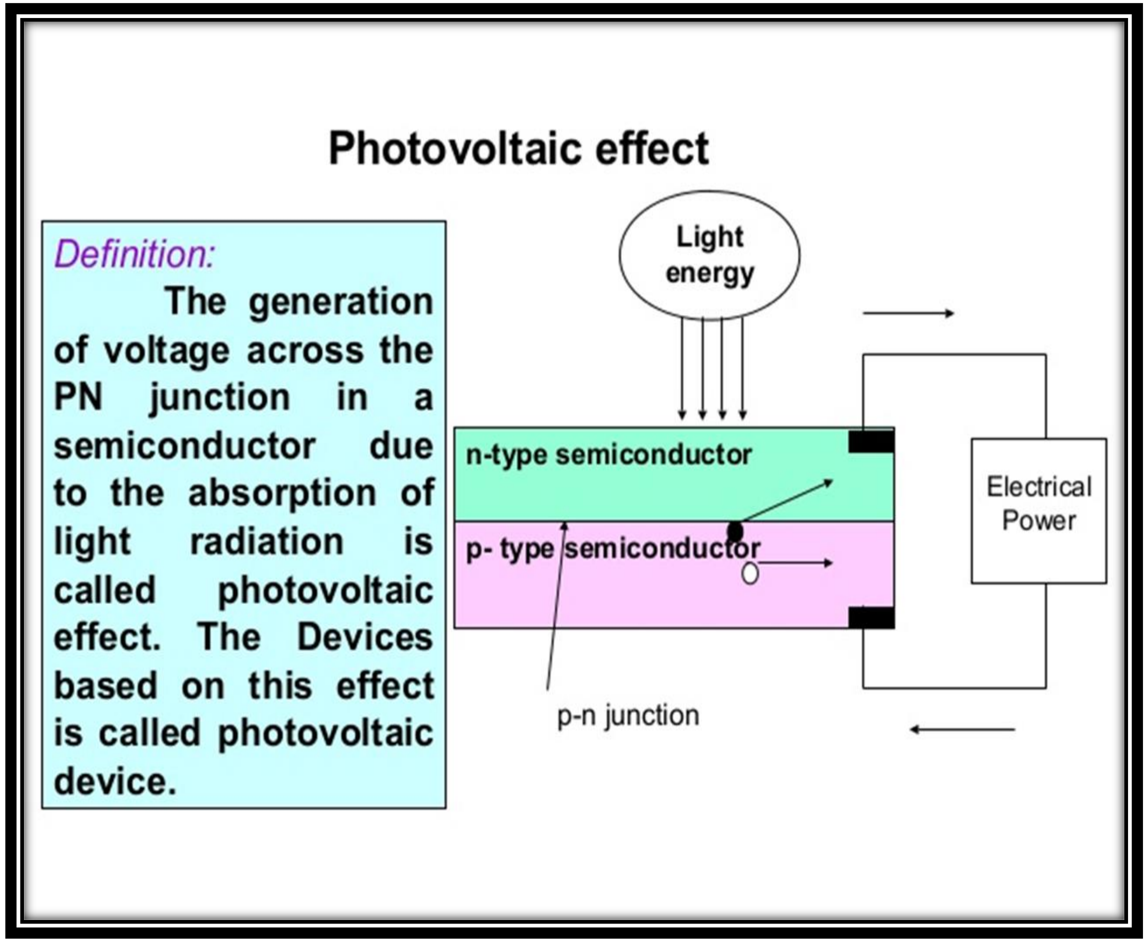
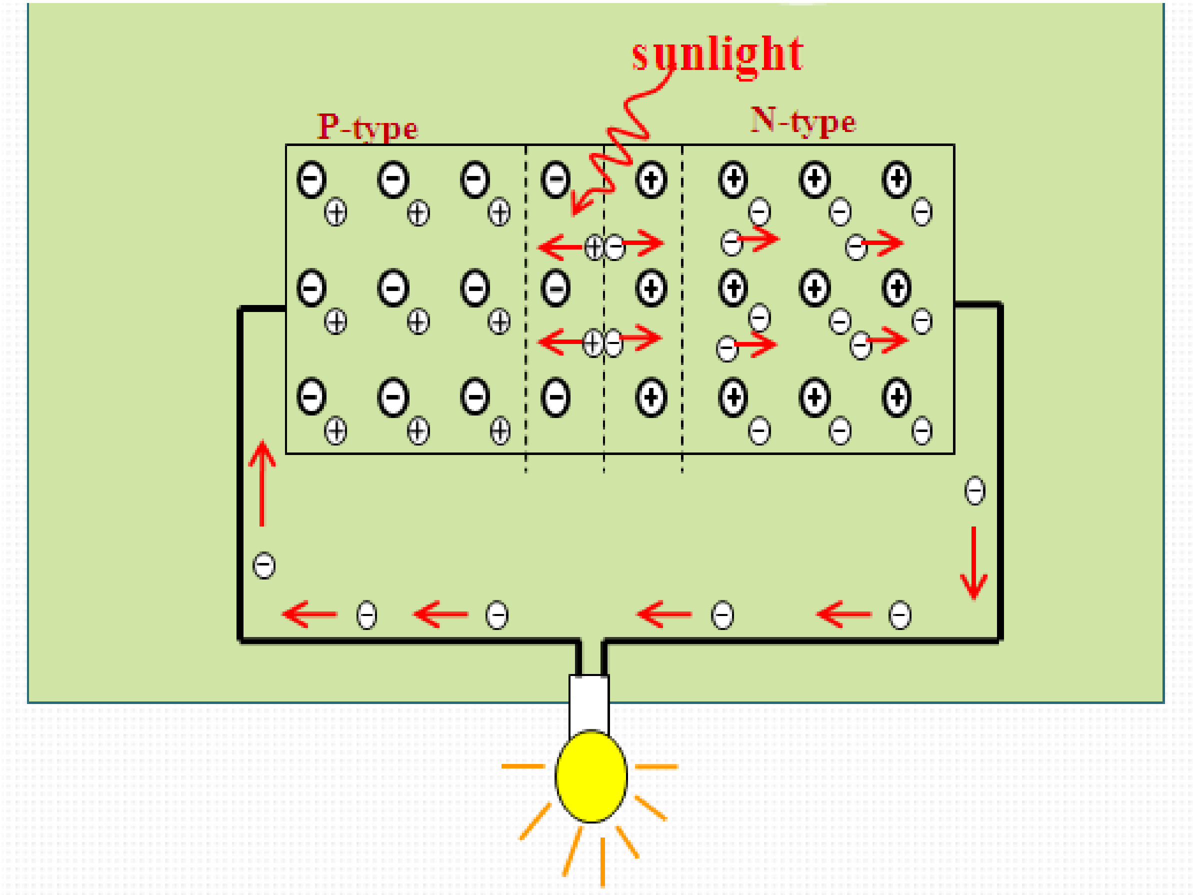
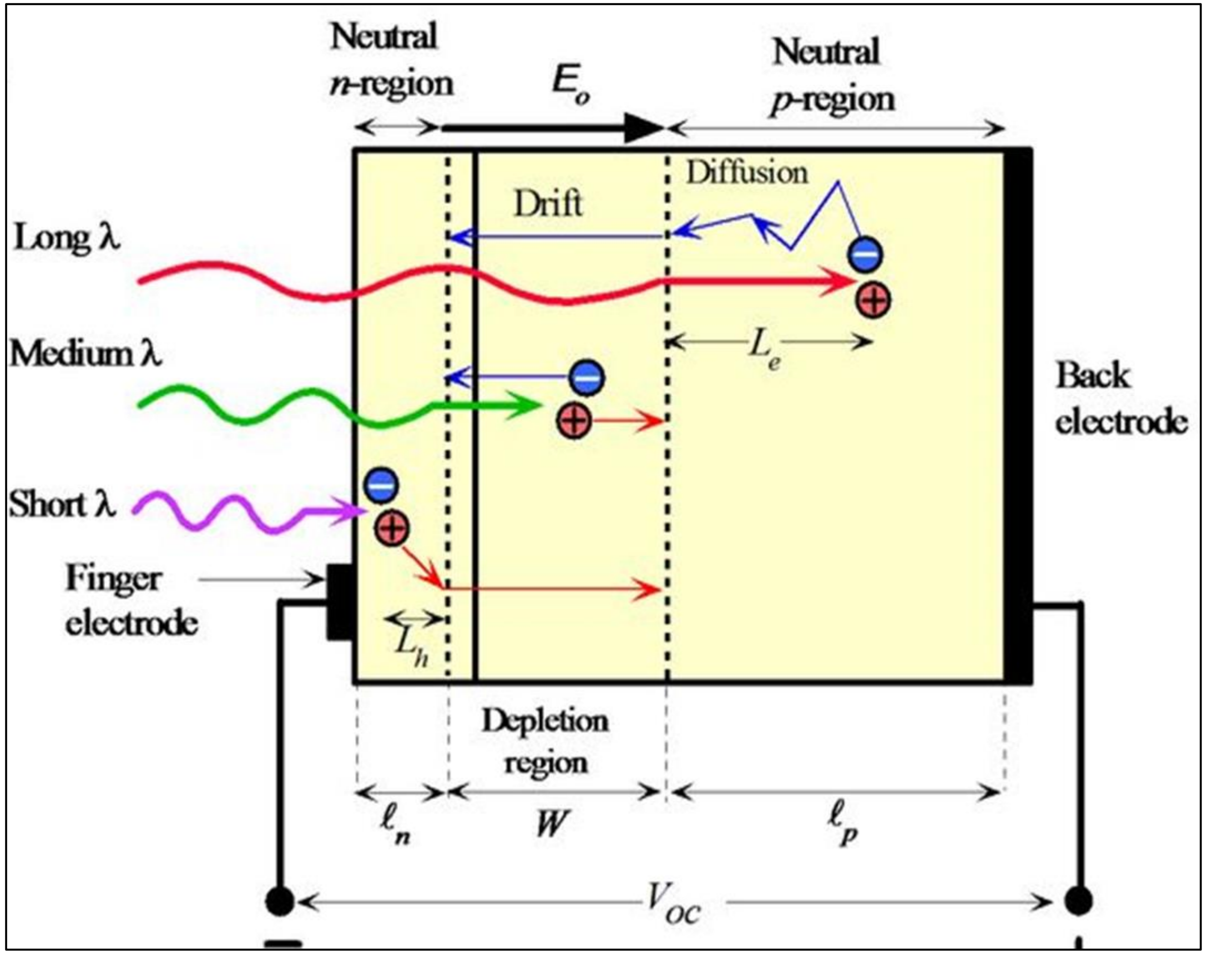
Working Principle: Photovoltaic effect







If a load is connected across the cell, electric current is formed and the energy is transmitted to the load.

Working

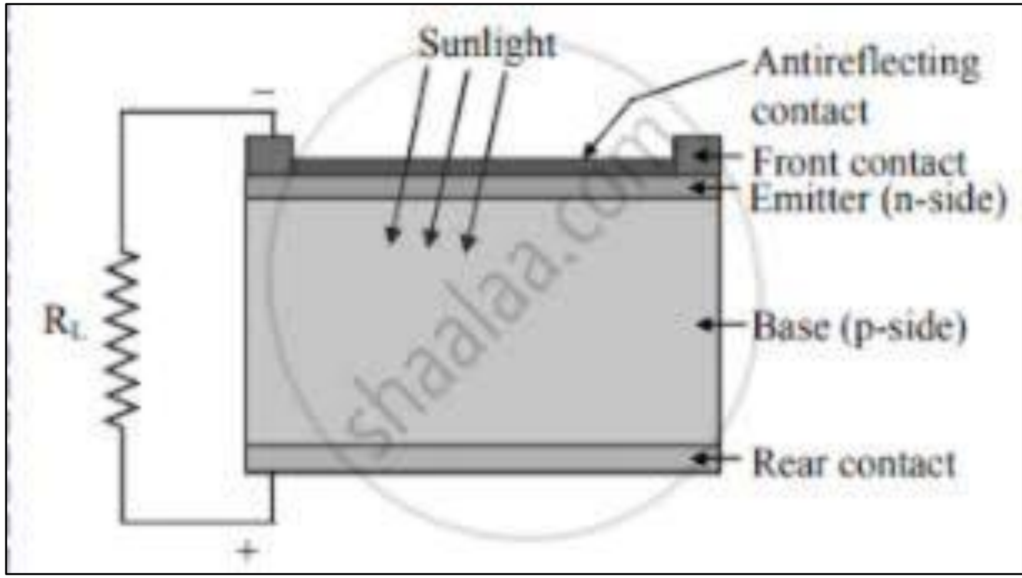
•A conventional solar cell, typically a pn junction, formed between heavily doped n^+ region and lightly doped p region. As p region is lightly doped the depletion region extends more in to the p region.

•Even with zero bias applied to the junction, an electric field exists in the space charge region (Electric field pointing towards p from n^+ region).

•Incident photon illumination can create EHPs in the space charge region.

•Electron hole pairs (EHPs) are mainly created in the depletion region and due to the built-in potential and electric field, electrons move to the *n* region and the holes to the *p* region, producing the photocurrent I_L.

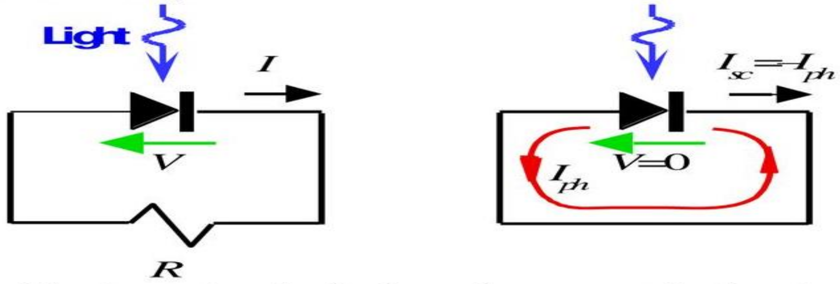
•Electrons and holes are also generated with the *p* and *n* regions.



The penetration depends on the wavelength and the ***absorption coefficient increases as the wavelength decreases.***
The shorter wavelengths (higher absorption coefficient) are absorbed in the *n* region and the longer wavelengths are absorbed in the bulk of the *p* region. Some of the EHPs generated in these regions can also contribute to the current.

•The photocurrent I_L produces a voltage drop across the resistive load which forward biases the pn junction.
•When load is removed and **short circuited**, then
$I_L = I_{SC}$.
Where I_L is photo current
I_{SC} is short circuit current
When the terminals of the illuminated solar cell are opened, then a voltage called *open circuited voltage* V_{OC} is developed across the terminals.
The net current in diode is now equal to $I_{net} = I_d - I_L$

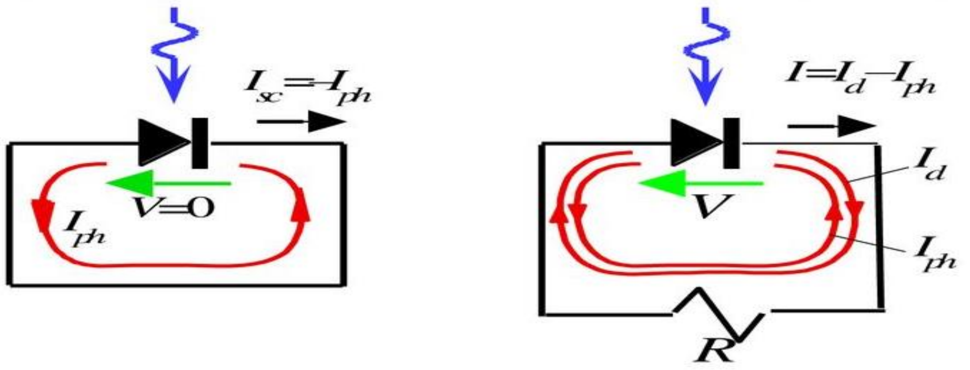
Solar cell I-V characteristics



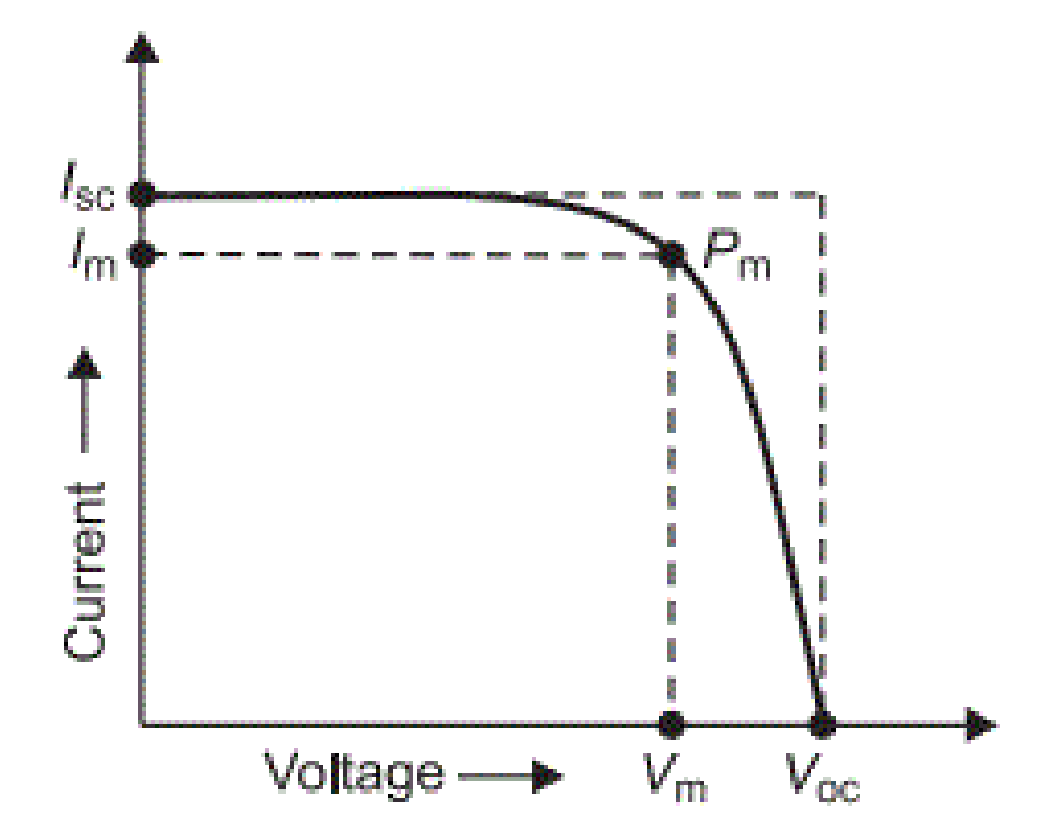
If the load is short circuit → the only current in the circuit is due to photogenerated (photocurrent),I_{ph}.

When load is removed and **short circuited**, then $I_L = I_{SC}$.
Where I_L is photo current & I_{SC} is short circuit current

If R is not short circuit → the positive voltage V appears across the pn junction as a result of the current passing through.



Under open circuited condition $V = V_{OC}$ and $I = 0$



- **Open Circuit Voltage (V_{OC})** The open circuit voltage of the solar cell is the maximum voltage that the solar cell will supply; that is the voltage when an infinite load is applied.

- **Short Circuit Current (I_{SC})** The short circuit current of a solar cell is the maximum current of the solar cell under conditions of a zero resistance load; a free flow or zero volt potential drop across the cell.

- **Maximum power output (P_{MPP})** The maximum power point is the maximum product of voltage and current along the IV curve.

- **Fill factor (FF)** The fill factor is the ratio between the maximum power produced by the solar cell and the product of V_{OC} and I_{SC}.

- **Power conversion efficiency (η or PCE)** The power conversion efficiency is the ratio of output power to input power.

Fill Factor (FF):

- It measures the sharpness of the curve and is defined as the ratio of maximum obtainable out put power P_m to ideal power V_{OC} I_{SC}.

$$\boxed{Fill\ factor = \frac{V_m I_m}{V_{OC} I_{SC}}}$$

- It is a key parameter in evaluating the performance of a solar cell.
- The value of Fill factor ranges from 0.7 to 0.8.

The fill factor is used as a quality parameter for solar cells and has a value around 80% for a normal silicon PV cell.

Conversion Efficiency:

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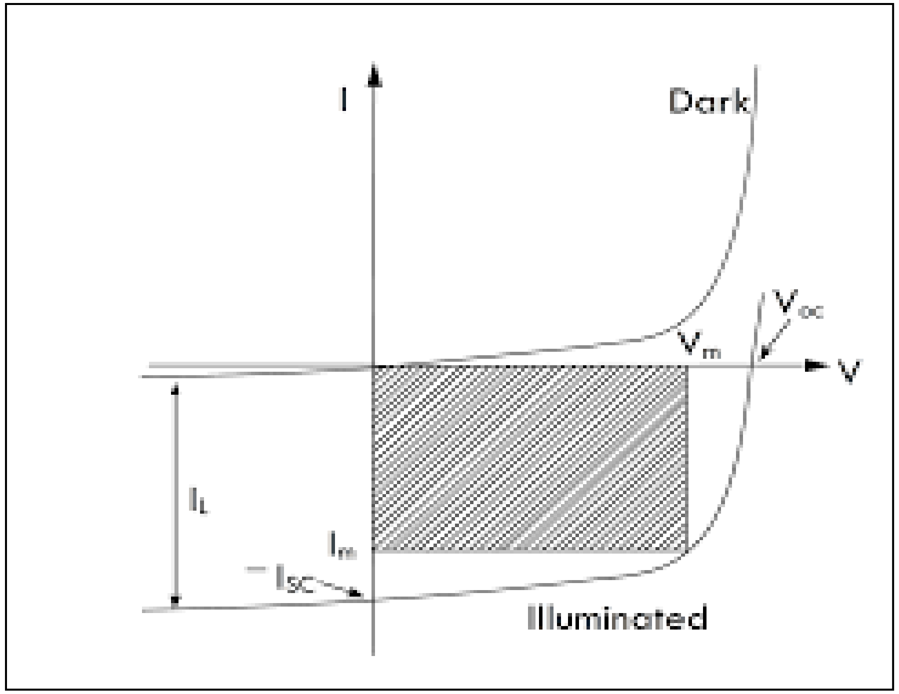
- It is defined as the ratio of maximum output power P_m to the incident power P_{in}.

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_m I_m}{E \text{ x } A} X\ 100\%$$

$$\eta = \frac{FF\ (V_{oc}\, I_{sc})}{P_{in}}$$



where
E is incident radiation flux (W/m²)
A is area of collector (m²)
P_m is Maximum power output (W)

Generation of solar cells

- **First Generation** – made of Si and GaAs

-High cost

– low efficiency

– **deployed in space applications**

- **Second Generation** (aim was to reduce cost)

– thin film solar cell and and amorphous solar cells

–individual efficiency is high - 10% - 22%

- **Third generation (**a decade ago**)** (aim was to reduce cost further)

– Dye sensitized cell – organic cell

– low efficiency (8% – 10%) - reduced cost

No pn junction was required for their fabrication

- **Fourth generation** – Hybrid cell

– combination of organic and inorganic solar cells.

Advantages:

- **Renewable energy:** The energy can be used both to generate electricity and heat.
- **Environmentally friendly:** With solar cells no pollution - Virtually non-polluting

- **Infinite energy:** Source of energy that will never be exhausted.
- **Long term energy:** Solar cells have a long life and a good durability - Nearly permanent natural power source
- **Low operating cost** – Virtually no maintenance for long time.
- Reduce dependence on fossil fuels.
- Excess power can be sold out or stored.
- Can be installed anywhere; in a field or on a building.

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Applications of Solar cell

- **Space:** Solar cells are very useful in powering space vehicles such as satellites and telescopes.
- **Solar powered vehicles:** Solar powered cars are cars which are powered by an array of photovoltaic cells.
- **Rooftop Solar Panels:** Many commercial and residential buildings have solar panels that produce electricity.
- **Off-Grid Power:** solar cells see wide use as an off-grid energy source. For example, many traffic, emergency and construction road signs use solar cells for power, reducing the need for gasoline-powered generators for remote and mobile uses.

Apart from previous mentioned applications,
powering consumer electronics has become a common solar power use in today's world: Cell Phones, wearable's, music speakers, solar watches, solar calculators, tablets, solar cookers, etc.,

Solar power and solar heating: Street lights, outdoor and indoor lighting.

Thank You!!!!!!!!