Photovoltaic Cell

Last Updated : 04 Mar, 2024

Photovoltaic Cell is an electronic device that captures solar energy and transforms it into electrical energy. It is made up of a semiconductor layer that has been carefully processed to transform sun energy into electrical energy. The term "photovoltaic" originates from the combination of two words: "photo," which comes from the Greek word "phos," meaning light, and "voltaic," which is derived from the name of Alessandro Volta, an Italian physicist who invented the voltaic pile, a forerunner of the electric battery.

Get a deep insight into Photovoltaic cells in this article, by learning its basics such as definition, characteristics, construction, working, and applications.

Table of Content

What is a Photovoltaic Cell?

A photovoltaic cell is a specific type of PN junction diode that is intended to convert light energy into electrical power. These cells usually operate in a reverse bias environment. Photovoltaic cells and solar cells have different features, yet they work on similar principles.

Photovoltaic cells are essential for turning incident light into electrical energy that can be used, and their ability to function in a reverse bias situation emphasizes how specifically engineered they are to maximize solar power.

It is interesting to note that despite the fact that these names may pertain to distinct facets of the technology, their close proximity to the process of turning sunlight into electrical power makes them often used interchangeably.

Photovoltaic Cell Structure

A photovoltaic (PV) cell, commonly known as a solar cell, is a device that directly converts light energy into electrical energy through the photovoltaic effect. Here's an explanation of the typical structure of a silicon-based PV cell:

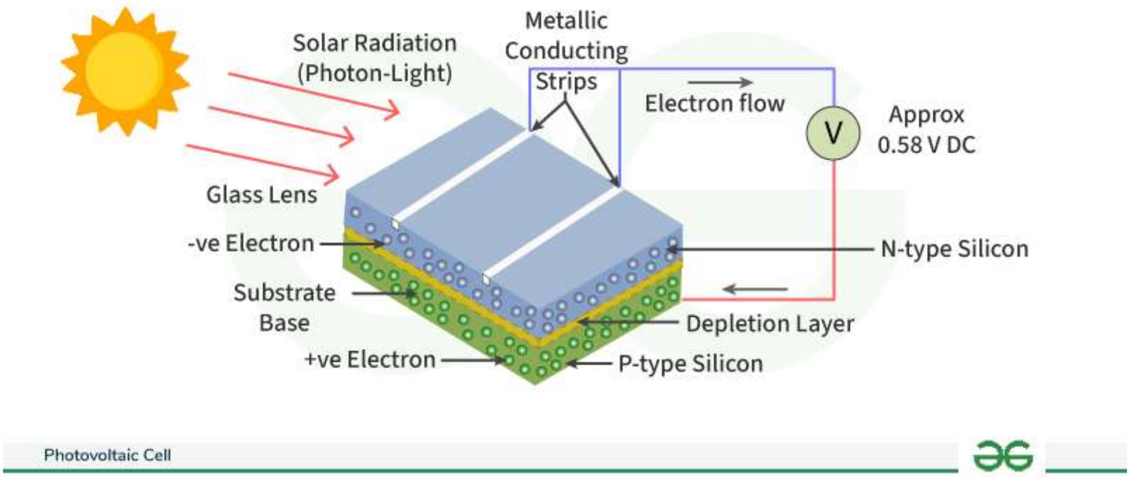
- **Top Contact:** This is the topmost layer of the PV cell, often made of a transparent conductive material like indium tin oxide (ITO) or doped tin oxide. Its transparency allows sunlight to pass through to the active layers beneath while also providing a path for the generated electrical current to flow out of the cell. The top contact is also called Transparent Conductive Layer.

- **Emitter Layer:** Beneath the top contact layer is the emitter layer, which is typically a thin layer of heavily doped (high concentration of impurities) n-type silicon. This layer facilitates the movement of electrons generated by absorbed sunlight.

- **Base Layer:** Below the emitter layer lies the base layer, which is usually a thicker layer of lightly doped (low concentration of impurities) p-type silicon. This layer helps in creating an electric field within the cell by providing positively charged "holes" for the electrons to move towards.

- **Back Surface Field (BSF) Layer:** In some PV cell designs, a back surface field layer is made of heavily doped p-type silicon. It is added to the rear surface of the cell to further enhance the collection of charge carriers (electrons and holes) and reduce recombination losses.

- **Back Contact:** The bottom layer of the PV cell is the back contact or back electrode, which is typically made of a conductive material like aluminum or silver. Its primary function is to collect the generated electrons and provide an external path for the electrical current to flow out of the cell.



Photovoltaic Cell Characteristics

The characteristics of Photovoltaic(PV) cells can be understood in the terms of following terminologies:

- **Efficiency:** Determines the ability to convert sunlight into electricity, typically measured as a percentage.
- **Open-Circuit Voltage (Voc):** Maximum voltage produced when not connected to any external load.
- **Short-Circuit Current (Isc):** Maximum current produced when terminals are short-circuited.
- **Fill Factor (FF):** Ratio of maximum power output to the product of Voc and Isc, indicating conversion efficiency.
- **Temperature Coefficient:** Measures performance change with temperature variations, usually expressed as a percentage per degree Celsius.
- **Durability and Reliability:** Ability to withstand environmental factors over the operational lifetime.

These characteristics collectively determine the performance, suitability, and economic viability of PV cells for various applications.

Construction of Photovoltaic Cell

The construction of a photovoltaic cell involves several key components and materials. A detail of such components and method is discussed below:

- **Semiconductor Material:** Photovoltaic cells are typically made from silicon, a semiconductor material that has the ability to absorb photons of sunlight and release electrons. **Silicon** is chosen for its availability, stability, and efficiency in converting sunlight into electricity.

- **P-N Junction:** The basic structure of a PV cell involves a P-N (positive-negative) junction. This junction is created by doping the silicon with specific impurities. The P side is doped with a material that introduces positive charge carriers (holes), while the N side is doped with a material that introduces negative charge carriers (electrons).

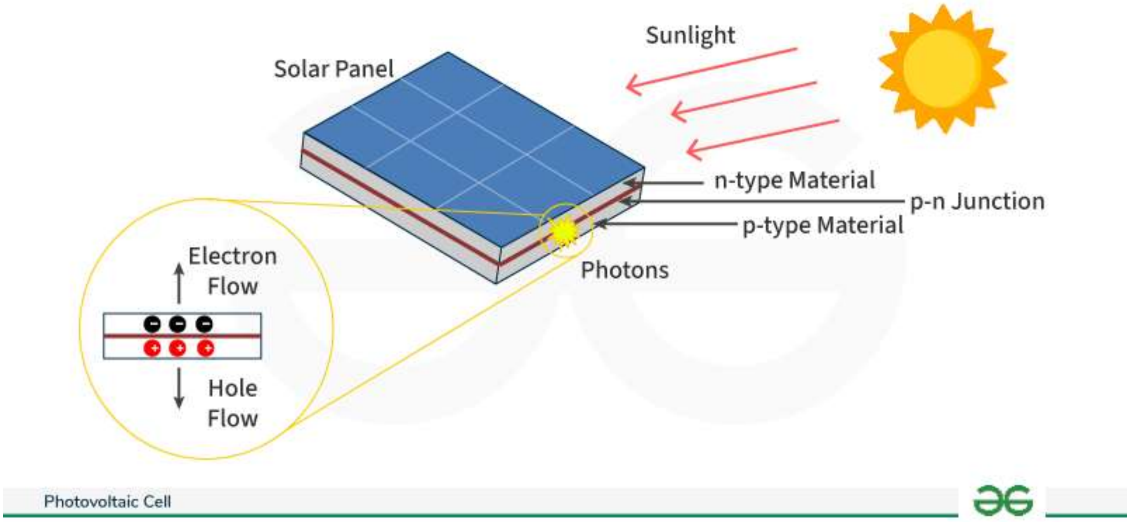
- **Absorption Layer:** Above the P-N junction, there is a thin layer known as the absorption layer. This layer is crucial for capturing photons from sunlight. When photons strike the absorption layer, they energize electrons, causing them to break free from their atomic bonds.

- **Metal Contacts:** Metal contacts are placed on the top and bottom surfaces of the PV cell to allow the flow of electrons. The metal contacts form an electrical circuit, capturing the freed electrons and providing a pathway for them to be utilized as electrical power.

- **Antireflection Coating:** To enhance the absorption of sunlight, an antireflection coating is often applied to the surface of the PV cell. This coating minimizes the reflection of sunlight, ensuring that more photons penetrate the cell and contribute to the generation of electricity.

- **Encapsulation:** Photovoltaic cells are often encapsulated to protect them from environmental factors such as moisture and mechanical stress. Encapsulation materials can include glass or transparent plastics that allow sunlight to reach the cell while providing a protective barrier.

- **Back Surface Field:** Some advanced PV cells may incorporate a back surface field to enhance the collection of electrons and improve overall efficiency.



Working of Photovoltaic Cell

The working principle of a photovoltaic (PV) cell involves the conversion of sunlight into electricity through the photovoltaic effect. Here's how it works:

- **Absorption of Sunlight:** When sunlight (which consists of photons) strikes the surface of the PV cell, it penetrates into the semiconductor material (usually silicon) of the cell.

- **Generation of Electron-Hole Pairs:** The energy from the absorbed photons is transferred to electrons in the semiconductor material, allowing them to break free from their atomic bonds and create electron-hole pairs. Electrons are negatively charged and move freely, while the holes are positively charged.

- **Separation of Charges:** Due to the built-in electric field within the PV cell (created by the junction between different semiconductor layers), the newly generated electron-hole pairs are separated. Electrons are pushed towards the n-type (negative) side of the cell, while holes are pushed towards the p-type (positive) side.

- **Flow of Electrons:** The separated electrons are collected by metal contacts on the surface of the cell, forming an electric current. This current can be harnessed for external use.

- **External Load:** When an external electrical load (such as a light bulb or a battery) is connected to the PV cell, the flow of electrons through the load generates electrical power, which can be used to power various devices or stored in batteries for later use.

As long as sunlight is available, the photovoltaic cell continues to generate electricity through this process, providing a sustainable and renewable source of energy.

Photovoltaic Cell Working Principle

Working principle of Photovoltaic Cell is similar to that of a diode. In PV cell, when light whose energy(hv) is greater than the band gap of the semiconductor used, the light get trapped and used to produce current.

In the absorption layer of the cell, photons from sunlight provide electrons energy, which causes the electrons to break free from their atomic connections and form electron-hole pairs. These charge carriers separate more easily at the P-N junction due to the electric field there, which pushes holes toward the P-type region and electrons toward the N-type region.

When an external circuit is linked, the space separation between the two sides generates a voltage potential that causes electrons and holes to flow, producing an electric current.

Types of Photovoltaic Cell

There are several types of photovoltaic cells, each employing different materials and technologies to convert sunlight into electricity. The main types of photovoltaic cells include:

Silicon Photovoltaic Cell

Silicon photovoltaic cell, also referred to as a solar cell, is a device that transforms sunlight into electrical energy. It is made of semiconductor materials, mostly silicon, which in turn releases electrons to create an electric current when photons from sunshine are absorbed.

Monocrystalline Silicon Solar Cells

Monocrystalline cells are made from a single crystal structure, resulting in a high efficiency of solar energy conversion. These cells are known for their sleek appearance and high power output per square foot.

Polycrystalline Silicon Solar Cells

Polycrystalline cells are made from multiple crystal structures. While they are less efficient than monocrystalline cells, they are more cost-effective to produce. Polycrystalline solar panels often have a blue tint.

Thin-Film Solar Cells

Thin-film solar cells use layers of semiconductor materials that are only a few micrometers thick. Common materials include amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS). Thin-film cells are lightweight, flexible, and cost-effective but generally have lower efficiency.

Multijunction Solar Cells

Multijunction solar cells consist of multiple layers of semiconductor materials stacked on top of each other. Each layer is designed to absorb a specific range of wavelengths of sunlight, increasing the overall efficiency. These cells are often used in concentrated photovoltaic systems.

Organic Photovoltaic Cells (OPVs)

Organic photovoltaic cells use organic (carbon-based) materials as the semiconductor. They are lightweight, flexible, and have the potential for low-cost manufacturing. However, their efficiency is currently lower compared to traditional solar cells.

Perovskite Solar Cells

Perovskite solar cells use a class of materials called perovskites, which have shown great promise due to their high efficiency and relatively simple fabrication process. Research in perovskite solar cells is ongoing to address issues such as stability and scalability.

Tandem Solar Cells

Tandem solar cells combine multiple solar cell technologies in a stacked configuration to enhance efficiency. For example, a tandem cell might combine silicon and perovskite layers to capture a broader range of the solar spectrum.

Dye-Sensitized Solar Cells (DSSCs)

Dye-sensitized solar cells use a layer of organic dye to absorb sunlight. The dye transfers its energy to semiconductor particles, generating electric current. DSSCs are known for their simplicity and potential for low-cost manufacturing.

Equivalent Circuit of a Photovoltaic Cell

The equivalent circuit of a photovoltaic (PV) cell represents the electrical behavior of the cell in terms of passive circuit elements such as resistors, diodes, and current sources. This simplified model helps in analyzing the performance of the PV cell under different operating conditions.

The equivalent circuit of a PV cell typically consists of the following components:

Photovoltaic Current Source (Iph): This represents the current generated by the PV cell when exposed to light. It is proportional to the intensity of incident light and the efficiency of the cell.

Diode: The diode represents the behavior of the p-n junction within the PV cell. It accounts for the voltage drop across the junction and the recombination losses within the cell. The diode equation is often used to model this behavior.

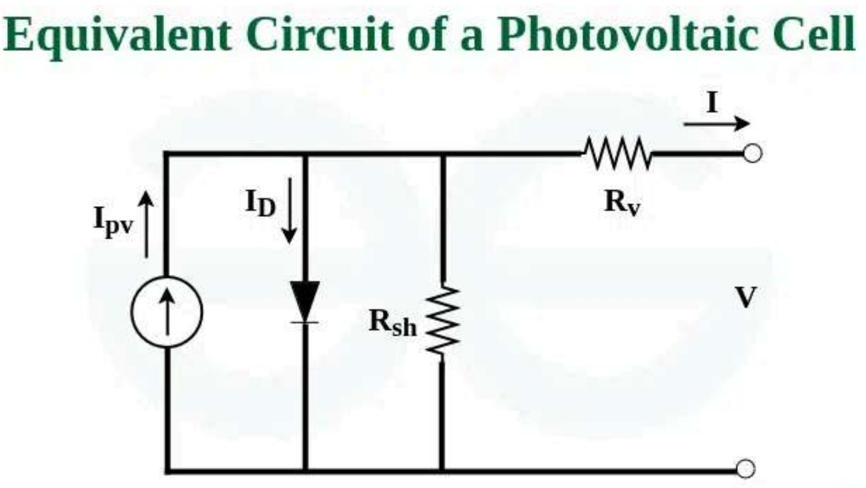
Series Resistance (Rs): This represents the internal resistance of the PV cell, including the resistance of the semiconductor material and the metal contacts. It causes a voltage drop across the cell when current flows through it.

Shunt Resistance (Rsh): This represents any parallel paths for current flow within the cell, such as surface leakage or defects in the semiconductor material. It affects the overall current-voltage characteristics of the cell.

Load Resistance (R_L): This represents the external load connected to the PV cell, such as a battery or an electrical device. It affects the operating point of the cell and determines the maximum power output.

Photovoltaic Cell Circuit Diagram

The equivalent circuit of photovoltaic cell is given below:



Photovoltaic Cell

Generations of Photovoltaic Cell

Photovoltaic cells have evolved over several generations, each characterized by advancements in materials, design, and efficiency. Currently, there are three generations of Photovoltaic Cell or solar cells which are discussed below:

- First Generation Photovoltaic Cell
- Second Generation Photovoltaic Cell
- Third Generation Photovoltaic Cell

First Generation Photovoltaic Cell

First generation of photovoltaic (PV) cells emerged in the 1950s It primarily utilized crystalline silicon as the semiconductor material. These cells are often referred to as single-crystal silicon or monocrystalline silicon cells. They were the earliest commercialized PV technology and laid the foundation for modern solar energy systems.

Second Generation Photovoltaic Cell

Second generation of photovoltaic (PV) cells emerged in the 1980s and introduced new semiconductor materials and thin-film technologies as alternatives to traditional crystalline silicon cells. This generation of PV cells is often referred to as thin-film solar cells and includes cadmium telluride (CdTe), and copper indium gallium selenide (CIGS).

Third Generation Photovoltaic Cell

The third generation of photovoltaic (PV) cells, which began to emerge in the early 2000s, focuses on advanced materials and novel device architectures to improve efficiency, reduce costs, and enable new applications. Some key examples of third-generation PV technologies include:

Efficiency of Solar Cell

Efficiency of a solar cell refers to its ability to convert sunlight into usable electrical energy. It is a key performance that indicates how effectively the solar cell can convert sunlight into electricity.

Solar cell efficiency is typically expressed as a percentage and is calculated by dividing the electrical power output of the solar cell by the total solar power input. The electrical power output is determined by multiplying the voltage and current generated by the solar cell, while the solar power input is determined by the intensity of sunlight falling on the cell.

Solar Cell Efficiency Formula

The formula for calculating solar cell efficiency is given as

$$\eta = P_{out}/P_{in} = \{P_{max}/(\text{Area} \times \text{Incident Radiation Flux})\} \times 100\ \%$$

Where,

- η *is efficiency of solar cell*
- P_{out} *is output power of solar cell*
- P_{in} *is input power of solar cell*

Photovoltaic Cell and Solar Cell

Photovoltaic Cell and Solar Cell are used alternatively for each other in general context. However, to be very specific photovoltaic cells can accept any form of photon while solar cells accepts light incident from sun. Let's have detailed comparison between the two.

Feature	Photovoltaic Cell	Solar Cell
Definition	A device that converts light energy into electrical energy using the photovoltaic effect.	A device that converts sunlight into electricity through the photovoltaic effect.
Terminology	Often used interchangeably with solar cell.	Commonly used as a synonym for photovoltaic cell.
Purpose	Converts light energy from any source into electricity.	Specifically designed to convert sunlight into electricity.
Types	Various types, including organic, thin-film, and crystalline silicon cells.	Types include monocrystalline, polycrystalline, thin-film, and other emerging technologies.
Efficiency	Efficiency varies depending on the type and technology. Generally ranges from 15% to 25%.	Efficiency varies but can reach up to 25% for high-end technologies like monocrystalline.
Applications	Used in a wide range of applications, including calculators, watches, and small electronic devices.	Mainly used in solar panels for residential, commercial, and industrial power generation.

Feature	Photovoltaic Cell	Solar Cell
Materials	Can be made from various materials, including polymers, amorphous silicon, and crystalline silicon.	Materials include silicon, often in monocrystalline or polycrystalline form, as well as thin-film materials like cadmium telluride or copper indium gallium selenide.
Environmental Impact	Generally considered environmentally friendly, but manufacturing processes may involve some toxic materials.	Production and disposal can have environmental impacts, but solar energy is considered clean and sustainable.
Cost	Cost varies depending on the type and technology. Generally, costs have been decreasing over time.	Costs have decreased over the years, making solar energy more economically viable.
Lifespan	Typically has a lifespan of 20-30 years or more, depending on the type and usage.	Lifespan can vary but is often around 25-30 years for standard solar panels.

Application of Photovoltaic Cells

Photovoltaic cells can be used in numerous applications which are mentioned below:

- **Residential Solar Power**: Photovoltaic cells are commonly used in residential buildings to generate electricity from sunlight. Solar panels installed on rooftops or in backyard arrays capture sunlight used to power household appliances and lighting.

- **Solar Power Plants**: Photovoltaic cells are used in utility-scale solar power plants to generate large amounts of electricity for distribution to the grid. These solar farms consist of thousands of solar panels arranged over vast areas of land, providing clean and renewable energy to communities and cities.

- **Solar Water Pumping**: Photovoltaic cells power solar water pumping systems used for irrigation, livestock watering, and drinking water supply in rural and off-grid locations.

- **Solar-Powered Transportation**: Photovoltaic cells are utilized in solar-powered vehicles, including solar cars, bicycles, boats, and aircraft. Solar panels mounted on the vehicle's surface capture sunlight and convert it into electricity to supplement or replace traditional fuel sources.

- **Space Applications**: Photovoltaic cells are extensively used in space exploration and satellite missions to generate electrical power for spacecraft and space stations.

- **Portable Electronics and Charging Stations**: Photovoltaic cells are integrated into portable electronic devices such as solar-powered chargers, backpacks, and lanterns.

Advantages and Disadvantages of Photovoltaic cell

Advantages of solar cells are mentioned below:

- They are environmentally sustainable and produce clean energy.
- They have minimal upkeep expenses.
- It is a readily accessible and renewable energy source.
- They can be utilized for longer periods of time and are less likely to lose efficiency.
- They don't create noise pollution.
- As long as a certain region receives enough sunshine, they can produce power anyplace.
- They can end the energy problem of our planet.

Disadvantages of Solar Cells are mentioned below:

- The widespread infrastructure for photovoltaic cells is not readily available.

- While maintenance costs are low, the initial installation of photovoltaic systems is considerably expensive.
- Photovoltaic cells are not currently capable of producing electricity at a commercial level; they are primarily suitable for devices with lower electricity and power requirements.
- Transmitting electricity over long distances poses difficulties for photovoltaic systems.
- Photovoltaic cells are fragile and susceptible to damage, making their durability a concern.

Also, Check

- VI Characteristics of a P-N Junction Diode
- Reverse Bias
- Difference Between PN Junction Diode and Zener Diode

Photovoltaic Cell FAQs

What is the meaning of Photovoltaic?

The meaning of "photovoltaic" is conversion of light (photons) is converted directly into electricity

What are the different types of Photovoltaic Cells?

The different types of Photovoltaic cells are: Monocrystalline Silicon Cells, Polycrystalline Silicon Cells, Thin-Film Solar Cells, Multi-junction (Tandem) Solar Cells, Organic Photovoltaic Cells (OPV) and Perovskite Solar Cells

What is the Efficiency of Photovoltaic Cells?

Efficiency of a solar cell refers to its ability to convert sunlight into usable electrical energy. The efficiency of current used photovoltaic cells is approximately 20%

Can Photovoltaic Cells work on cloudy days?

Yes, photovoltaic cells can generate electricity even on cloudy days, although their efficiency may be reduced compared to sunny days.

What are Monocrystalline Solar Cell?

Monocrystalline solar cells are made from a single crystal of silicon. The silicon used in monocrystalline cells is grown in a controlled environment, resulting in a highly pure and uniform crystal structure.

What are Polycrystalline Solar cell?

Polycrystalline solar cells are made from silicon material that consists of multiple small crystals or grains.

Are Photovoltaic Cells AC or DC?

Photovoltaic cells produce direct current (DC) electricity.

What materials are used to manufacture Solar Cells?

*Various materials used to manufacture solar cells are **Crystalline Silicon, Thin-Film Materials, Amorphous Silicon (a-Si), cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS)***

Photovoltaic Cell works in Reverse Bias or Forward Bias?

Photovoltaic Cell works in reverse bias when exposed to sunlight and in forward bias when in dark

Next Article

Cell Potential

Similar Reads

Photovoltaic Cell

Photovoltaic Cell is an electronic device that captures solar energy and transforms it into electrical energy. It is made up of a semiconductor layer that has been carefully processed to transform sun energy into...

15+ min read

Cell Potential

Cell Potential is the difference in electrical potential between an electrochemical cell's two electrodes. An electrochemical cell is a device that uses an electrochemical reaction to transform chemical energy into...

8 min read

Electric Cell

An electric cell is an electrical power supply that generates electrical energy from chemical reactions, it is simply a device that is used to maintain the electric current. The electric cell was invented by Alessandro...

13 min read

Galvanic Cell

Galvanic Cell also called Voltaic Cell is an electrochemical device that converts spontaneous chemical energy generated in a redox reaction into electrical energy. Table of Content What is Galvanic Cell?Cell...

12 min read

Solar Cell

A Solar Cell is a device that converts light energy into electrical energy using the photovoltaic effect. A solar cell is also known as a photovoltaic cell(PV cell). A solar cell is made up of two types of...

8 min read

Photoelectric Effect

Photoelectric effect refers to the phenomenon in which electrons are emitted from a material when it is exposed to light (electromagnetic radiation) of sufficient energy. Photoelectric effect provided evidence fo...

10 min read

Cyclic Photophosphorylation

Cyclic Photophosphorylation is a process to generate Adenosine triphosphate (ATP) without producing NADPH. This process generally takes place in the thylakoid membrane of chloroplasts. In the context of...

7 min read

Leclanche Cell

Leclanche Cell is a zinc-carbon battery known as a dry cell and is widely used in devices such as flashlights and portable zinc-manganese dioxide systems. It was initially used in telegraphy, signaling, an...

6 min read

Optoelectronic Devices

Optoelectronics is the research, design, and production of a hardware device that transforms electrical energy into light and light into energy using semiconductors. It is the connection between optics and...

5 min read

Photoelectric Sensor

A photoelectric sensor is a type of sensor used to detect the presence or absence of objects, as well as to measure distance, based on the principle of light reflection or interruption. It typically consists of a light...

11 min read