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## Photovoltaic Energy Conversion Technique with Light Absorbing Material (A Review)

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**ABSTRACT:** Solar energy is most abundant energy source in the universe and solar is renewable recourse and does not emit any green house gases in energy generation process. Photovoltaic technology is one of the finest way to utilize the solar power. Photovoltaic conversion is the direct conversion of sunlight into electricity without any interface. This paper reviews photovoltaic technology, working of solar cell and different light absorbing materials.

**KEYWORD:** Photovoltaic cell, light absorbing materials.

### I. INTRODUCTION

Solar energy is the most readily available and free source of energy. Solar energy can be used directly for heating and lighting home and buildings, for generating electricity, cooking food, hot-water heating, solar cooling, drying materials, and a variety of commercial and industrial uses.

Solar energy can be converted into thermal energy with the help of solar collectors and receivers known as solar-thermal devices. PV-created direct current (DC) electricity that can be used as such is converted to alternating current (AC) or stored for later use. This type of solar electricity is more expensive than that produced by traditional sources. But over the past two decades, the cost gap has been closing. Solar photovoltaic technology has emerged as a useful power source of applications such as lighting, meeting the electricity needs of villages, hospitals, telecommunications, and houses. Gangopadhyay et al. [1].

Photovoltaic, also called solar cells, are electronic devices that convert sunlight directly into electricity. Photovoltaic power were first discovered by a French scientist Edmond Becquerel in 1839. The first working solar cell was successfully made by Charles fritt in 1882. It was made of thin sheets of selenium and coated with gold. The use of solar panels for generating electricity and heat seems relatively like new development, it has actually been widely used to generate power since early 1900's. In 1954 Bell laboratory mass produced the first crystal silicon solar cell. The bell PV converted 4% of the sun's energy into electricity a rate that was considered the cutting edge in energy technology. heir scientists Daryl M. Chapin et al made a silicon-based solar cell with an efficiency of about 6% reported in. Scientists continued to reinvent and enhanced on the design of the original solar cell and were able to produce a solar cell that was capable of putting 20% return electricity rate. In the late 1900's as awareness grew in the science community about the effects of global warming and the need for renewable energy sources, scientists continued to refine the silicon PV and by early 2000 they were able to make a solar cell with 24% electricity return. In just seven years scientists were again able to increase the electricity return of silicon solar cell using space age materials. By 2007, modern silicon PV Solar cells were operating with 28% electricity return. There are a wide range of PV cell technologies on the market today and more applications. Eldin et al. [2]

### II. PHOTOVOLTAIC TECHNOLOGY

Photovoltaic is the field of technology and research related to the devices which directly convert sun light in to electricity. The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is

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that their conductivity may easily be modified by introducing impurities into their crystal lattice. For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity. On one side of the cell, the impurities, which are phosphorus atoms with five valence electrons (n-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers. On the other side, atoms of boron with three valence electrons (p-donor) create a greater affinity than silicon to attract electrons. Because the p-type silicon is in intimate contact with the n-type silicon a p-n junction is established and a diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side). When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. However, the diffusion of carriers does not occur indefinitely, because the imbalance of charge immediately on either sides of the junction originates an electric field. This electric field forms a diode that promotes current to flow in only one direction. Ohmic metal-semiconductor contacts are made to both the n-type and p-type sides of the solar cell, and the electrodes are ready to be connected to an external load. When photons of light fall on the cell, they transfer their energy to the charge carriers. The electric field across the junction separates photo-generated positive charge carriers (holes) from their negative counterpart (electrons). In this way an electrical current is extracted once the circuit is closed on an external load. European Commission et al. [3]

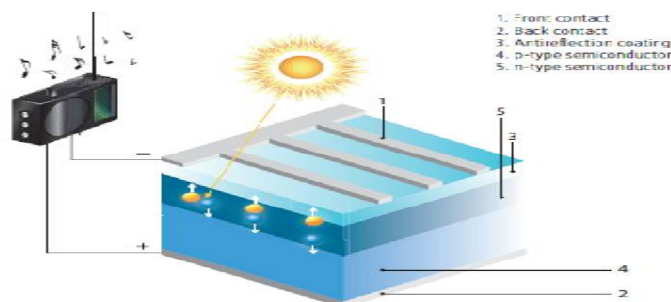


Fig 2.1: Solar Cell Structure

### III. THE WORKING PRINCIPLE OF A SOLAR CELL

The working principle of solar cells is based on the photovoltaic effect, i.e. the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation. The photovoltaic effect is closely related to the photoelectric effect, where electrons are emitted from a material that has absorbed light with a frequency above a material-dependent threshold frequency. In 1905, Albert Einstein understood that this effect can be explained by assuming that the light consists of well defined energy quanta, called photons. The energy of such a photon is given by-

$$E = h\nu \quad (1)$$

where  $h$  is Planck's constant and  $\nu$  is the frequency of the light. For his explanation of the photoelectric effect Einstein received the Nobel Prize in Physics in 1921.

The photovoltaic effect can be divided into three basic processes:

1. Generation of charge carriers due to the absorption of photons in the materials that form a junction.
2. Subsequent separation of the photo-generated charge carriers in the junction.
3. Collection of the photo-generated charge carriers at the terminals of the junction.

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## 1. Generation of charge carriers due to the absorption of photons in the materials that form a junction.

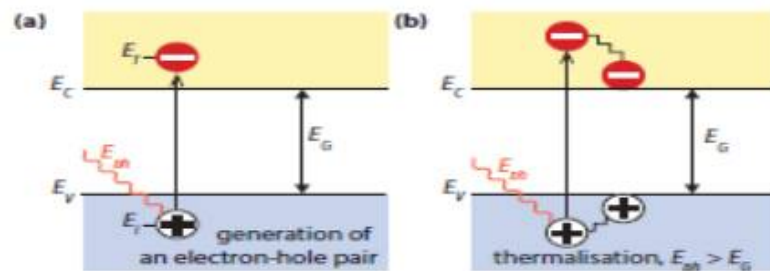


Fig 3.1(a) Illustrating the absorption of photon in a semiconductor with bandgap  $E_g$ . The portion with energy  $E_{ph}=h\nu$  excites an electron from  $E_i$  to  $E_f$ , at  $E_i$  a hole is created. (b) If  $E_{ph} > E_g$ , a part of the energy is thermalized.

Absorption of a photon in a material means that its energy is used to excite an electron from an initial energy level  $E_i$  to a higher energy level  $E_f$ , as shown in Fig.3.1 (a). Photons can only be absorbed if electron energy levels  $E_i$  and  $E_f$  are present so that their difference equals to the photon energy,  $h\nu = E_f - E_i$ . In an ideal semiconductor electrons can populate energy levels below the so-called valence band edge,  $E_v$ , and above the so called conduction band edge,  $E_c$ . Between those two bands no allowed energy states exist, which could be populated by electrons. Hence, this energy difference is called the bandgap,  $E_g = E_c - E_v$ . If a photon with an energy smaller than  $E_g$  reaches an ideal semiconductor, it will not be absorbed but will traverse the material without interaction.

In a real semiconductor, the valence and conduction bands are not flat, but vary depending on the so-called k-vector that describes the crystal momentum of the semiconductor. If the maximum of the valence band and the minimum of the conduction band occur at the same k-vector, an electron can be excited from the valence to the conduction band without a change in the crystal momentum. Such a semiconductor is called a direct bandgap material. If the electron cannot be excited without changing the crystal momentum, we speak of an indirect bandgap material. The absorption coefficient in a direct bandgap material is much higher than in an indirect bandgap material, thus the absorber can be much thinner.

If an electron is excited from  $E_i$  to  $E_f$ , a void is created at  $E_i$ . This void behaves like a particle with a positive elementary charge and is called a hole. The absorption of a photon therefore leads to the creation of an electron-hole pair, as illustrated in Fig. 3.2 (1). The radiative energy of the photon is converted to the chemical energy of the electron-hole pair. The maximal conversion efficiency from radiative energy to chemical energy is limited by thermodynamics. This thermodynamic limit lies in between 67% for non-concentrated sunlight and 86% for fully concentrated sunlight.

## 2. Subsequent separation of the photo-generated charge carriers in the junction.

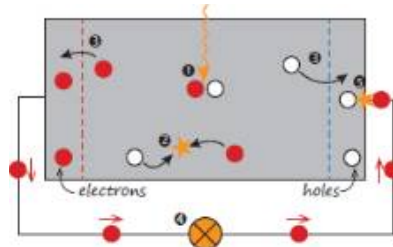


Fig 3.2 : A very simple solar cell model 1) Absorption of a photon leads to the generation of electrons –hole pair. 2) Usually, the electrons and holes will combine. 3) With semi-permeable membranes the electrons and holes can be separated. 4) The separated electrons can be used to drive an electric circuit. 5) After the electrons passed through the circuit, they will recombine with holes.

Usually, the electron-hole pair will recombine, i.e. the electron will fall back to the initial energy level  $E_i$ , as illustrated in Fig. 3.2 (2). The energy will then be released either as photon (radiative recombination) or transferred to other electrons or holes or lattice vibrations (nonradiative recombination). If one wants to use the energy stored in the electron-hole pair for performing work in an external circuit, semipermeable membranes must

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be present on both sides of the absorber, such that electrons only can flow out through one membrane and holes only can flow out through the other membrane, as illustrated in Fig. 3.2(3). In most solar cells, these membranes are formed by n- and p-type materials.

A solar cell has to be designed such that the electrons and holes can reach the membranes before they recombine, i.e. the time it requires the charge carriers to reach the membranes must be shorter than their lifetime. This requirement limits the thickness of the absorber.

### 3. Collection of the photo-generated charge carriers at the terminals of the junction.

Finally, the charge carriers are extracted from the solar cells with electrical contacts so that they can perform work in an external circuit Fig. 3.2 (4). The chemical energy of the electron-hole pairs is finally converted to electric energy. After the electrons passed through the circuit, they will recombine with holes at a metal absorber interface, as illustrated in Fig. 3.2.(5)

#### Loss mechanisms

The two most important loss mechanisms in single bandgap solar cells are the inability to convert photons with energies below the bandgap to electricity and thermalisation of photon energies exceeding the bandgap, as illustrated in Fig. 3.1 (b). These two mechanisms alone amount to the loss of about half the incident solar energy in the conversion process. Thus, the maximal energy conversion efficiency of a single junction solar cell is considerably below the thermodynamic limit. This single bandgap limit was first calculated by Shockley and Queisser in 1961. Jäger et al [4]

## IV. LIGHT ABSORBING MATERIALS

All solar cells require a light absorbing material which is present within the cell structure to absorb photons and generate free electrons via the photovoltaic effect. The photovoltaic (PV) effect is the basis of the conversion of light to electricity in photovoltaic, or solar cells. Sunlight, which is pure energy, on striking a PV cell, imparts enough energy to some electrons (negatively charged atomic particles) to raise their energy level and thus free them. A built-in-potential barrier in the cell acts on these electrons to produce a voltage, which in turn is used to drive a current through a circuit.

### A Silicon

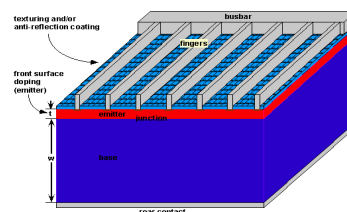


Fig 4.1: Silicon solar cell

Bruton asserted that silicon technology has been the dominant one for the supply of power modules into photovoltaic applications and the likely changes are an increasing proportion of multi-crystalline silicon and monocrystalline silicon being used for high-efficiency solar cells while thinner wafers and ribbon silicon technology continue to grow reviewed the recent advances in chemical and metallurgical routes for photovoltaic (PV) silicon production and found that production of (solar-grade silicon) SoGSi (expand the acronym) can be five times more energy efficient than the conventional Siemens process that uses more than 200 kWh/kg and Rabl presented current PV production cost ranges, both in terms of capacity installation and electricity generation, of single crystalline silicon, multi-crystalline silicon, amorphous silicon and other thinfilm technologies assessing possible cost reductions as expected according to the learning-curve methodology .

The majority of the solar cells on the market today are made of some type of silicon - by some estimates, 90% of all solar cells are made of silicon. However, silicon can take many different forms. Variations are most

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distinguished by the purity of the silicon; purity in this sense is the way in which the silicon modules are aligned. The greater the purity of the silicon molecules, the more efficient the solar cell is at converting sunlight into electricity. The majority of silicon based solar cells on the market - about 95% - are comprised of crystalline silicon, making this the most common type of solar cell. But there are two types of crystalline - monocrystalline and polycrystalline. Paridaa et al [5]

## B Amorphous silicon

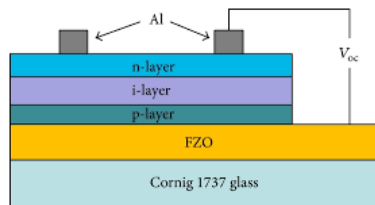
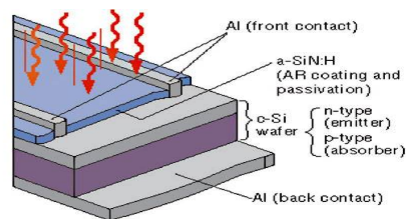


Fig 4.2: Amorphous Silicon solar cell

Amorphous (uncrystallized) silicon is the most popular thin film technology with cell efficiencies of 5–7% and double- and triple-junction designs raising it to 8–10%. But it is prone to degradation. Some of the varieties of amorphous silicon are amorphous silicon carbide (a-SiC), amorphous silicon germanium (a-SiGe), microcrystalline silicon (μc-Si), and amorphous silicon-nitride (a-SiN). The advances made in amorphous-Si PV technology that led to the achievement of an AM 1.5, 13% stable cell efficiency and set the foundation for the spectrum splitting triple-junction structure being manufactured by the roll-to-roll continuous deposition process. Paridaa et al [5]

## C Crystalline silicon



Crystalline Silicon (c-Si) Photovoltaic Cell Construction

Fig 4.3: Crystalline Silicon solar cell

Crystalline silicon has an improved efficiency as compared to amorphous silicon while still using only a small amount of material. The commercially available multi-crystalline silicon solar cells have an efficiency around 14–19%. Crystalline silicon on glass (CSG) solar cell technology combines the advantages of standard silicon wafer-based technology with that of thin-films, with the lowest likely manufacturing cost of these contenders and confirmed efficiency for small pilot line modules already in the 8–9% energy conversion efficiency range, on the path to 12–13%. The present status of high-throughput plasma enhanced chemical vapour deposition (PECVD) machines for the deposition of SiN onto c-Si wafers, and the fundamental properties of Si-SiN interfaces fabricated by PECVD. The intrinsic microcrystalline silicon deposited at temperatures as low as 200–250 °C by the VHF-GD (very high frequency glow discharge) method has been used successfully as photovoltaically active material within p-i-n and n-i-p type solar cells - an alternative approach to implementation of the impurity-photovoltaic (IPV) effect in crystalline silicon, referred to as electronically coupled up-conversion that avoids two of the major problems associated with the conventional IPV approach—namely, recombination of minority carriers generated in the base by a single photon, and parasitic absorption. Paridaa et al [5]

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## D Cadmium telluride (CdTe) and cadmium sulphide (CdS)

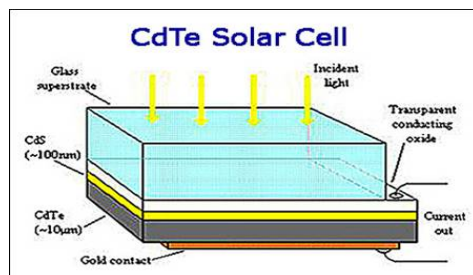


Fig 4.4: (CdTe) solar cell

Thin film solar cell with cadmium telluride (CdTe) has become a promising candidate for low cost solar cells with power conversion efficiency having 18.3% or higher [1]. Cadmium sulfide (CdS) is the most commonly used window layer in CdTe photovoltaic devices. CdTe/CdS solar cells have reached on laboratory efficiency values higher than 20% [6]. This kind of heterojunction solar cell is now considered as promising material for large scale production. Moreover the fabrication technology of CdTe is suitable for large scale production, since it uses the thin film deposition techniques like sputtering and close-spaced sublimation.

The crucial parameters for short circuit current, open circuit voltage, efficiency and fill factor of any solar cell are the absorber layer (CdTe) thickness, carrier lifetime, carrier concentrations etc [9]. The goal of this paper is to study and analyze the effect of the parameters of the material (CdTe) especially thickness and carrier life time over the efficiency of CdTe/CdS heterojunction solar cell and to recommend their best possible combination for improving the efficiency of the solar cell. Banerjee et al [6]

## E Organic and polymer cells

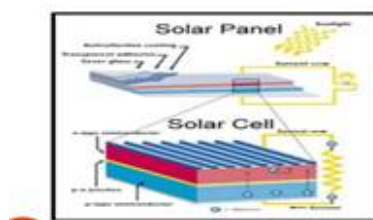


Fig 4.5: Organic and Polymer solar cell

Conjugated polymers are excellent material for use in low-cost electronics and photovoltaic (PV). Polymer-based solar cells have reached power conversion efficiencies of 5% in recent reports. Deposition of organics by screen printing, doctor blading, inkjet printing, and spray deposition is possible because these materials can be made soluble. These techniques are required for the high-throughput roll-to-roll processing that will drive the cost of polymer-based PV down to a point where it can compete with current grid electricity. Additionally, these deposition techniques all take place at low temperature, which allows devices to be fabricated on plastic substrates for flexible devices. In addition to the inherent economics of high-throughput manufacturing, light weight and flexibility are qualities claimed to offer a reduction in the price of PV panels by reducing installation costs. Flexible PV also opens up niche markets like portable power generation and aesthetic PV in building design. Mayer et al [7]

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## F Hybrid photovoltaic cell

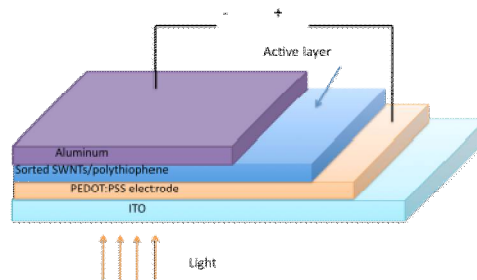


Fig 4.6: Hybrid solar cell

Photovoltaic solar panels suffer from high production costs and low energy conversion efficiency. Whereas thin-film modules are quite cheap but only achieve 10-13% efficiency, crystalline modules which are more expensive achieve 14-19%. Yet theoretical limits for solar panel efficiency are as high as 40%. One promising prospect for the future is the organic solar cell and the Grätzel cell. But with efficiencies well below the standard of 10%, they need further research work before they reach the commercial market. Most an organic photovoltaic currently have high production costs relative to the level of energy conversion efficiency achievable and the energy cannot be produced or released at night without a storage system. Furthermore as much as 80 to 90% of the solar input energy is lost as heat. The efficiency of the photovoltaic energy conversion is inversely proportional to the temperature. This has led to the development of hybrid PV Solar panels in which a top photovoltaic layer catches the sun rays and produces electricity whilst tubes extending around the back of the layer are heated for hot water generation. Cold water is passed through these tubes cooling the photovoltaic system, thereby enabling the system to work at a more efficient temperature. The heated water is then available for use in a domestic heating system for example. Morris et al. [8]

## G Thin film technology

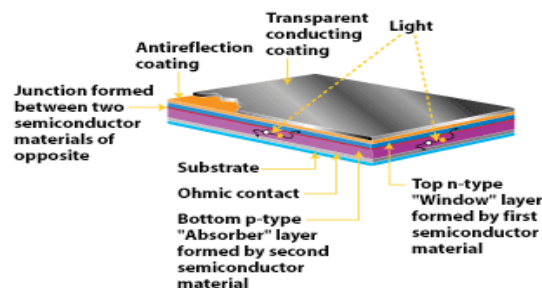


Fig 4.7: Thin film solar cell

The problem of high cost of Si was recognized right from the beginning. And it has also been recognized that cheaper solar cells can be produced only if cheaper and more sparingly used materials and lower cost technologies are utilized. The first thin/thick-film Cu<sub>2</sub>S/CdS cell<sup>6</sup> was based on rather simple and cheap technology known as the 'Clevite process' in which several mm-thick CdS film was deposited on to a metal or metallized plastic substrate, then an acid etch of the CdS film followed by immersion in hot cuprous chlorides solution for few seconds to topotaxially convert the CdS surface to Cu<sub>2</sub>S. Small-area cell efficiencies as high as 10% were reported and produced commercially by several companies in USA and France. Chopra et al [9]. Thin-film solar cells are basically thin layers of semiconductor materials applied to a solid backing material. Thin films greatly reduce the amount of semiconductor material required for each cell when compared to silicon wafers and hence lowers the cost of production of photovoltaic cells. Paridaa et al [5]

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However, the rapidly rising stabilized efficiency of cells based on the better-understood Si technology, compared with lower and questionable stability of Cu<sub>2</sub>S/CdS cell, led to premature death of the latter. Nevertheless, extensive basic research on the Cu<sub>2</sub>S/CdS PV devices has proved very useful for later developments in thin-film solar cells (TFSC). The chance discovery of the possibility of doping amorphous hydrogenated Si (a-Si:H) films created a lot of excitement in the PV industry.<sup>9</sup> As a result of an enormous amount of basic and applied research by a very large number of scientists and engineers worldwide, a major PV industry on megawatt scale, based on a-Si:H thin films, grew rapidly in several countries. However, after several years of significant development and production activities, a-Si:H has failed to challenge the supremacy of crystalline silicon, largely because of little cost advantage, lower efficiency and relatively poor stability compared with crystalline Si cells. The number of possible and viable thin/thick-film materials for solar cells is quite large. Some of the most attractive candidates, based on a-Si:H, CdTe and CuInSe<sub>2</sub> materials have been the subject of intense R&D and exploration of manufacturing technologies for the last three decades. Despite all these efforts, which cell material and which production technology will ultimately succeed in the commercially competitive field is still anybody's guess. Chopra et al [9]

## H Nano solar cell

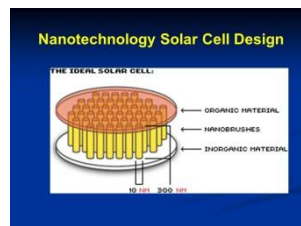


Fig 4.8: Nano solar cell

Conventional solar cells are called photovoltaic cells. These cells are made out of semiconducting material, usually silicon. When light hits the cells, they absorb energy through photons. This absorbed energy knocks out electrons in the silicon, allowing them to flow. By adding different impurities to the silicon such as phosphorous or boron, an electric field can be established. This electric field acts as a diode, because it only allows electrons to flow in one direction. Consequently, the end result is a current of electrons, better known to us as electricity. Conventional solar cells have two main draw backs: they can only achieve efficiencies around ten percent and they are expensive to manufacture. The first drawback, inefficiency, is almost unavoidable with silicon cells. This is because the incoming photons, or, light, must have the right energy, called the band gap energy, to knock out an electron. If the photon has less energy than the band gap energy then it will pass through the device. Plastic and solid state DSSCs incorporating single walled nano tubes and imidazolium iodide derivative has been fabricated. The introductions of carbon nano tubes improve performance through reduction of the series resistance. TiO<sub>2</sub> coated CNTs were recently used in DSSCs. Compared with a conventional TiO<sub>2</sub> cell, a TiO<sub>2</sub>- coated CNT cell gives an increase in short circuit current density, resulting in 50% increase in conversion efficiency. Ameer et al [10]

## V. CONCLUSION

A new power system scenario renewable sources are very important part of energy generation. Utilization of solar power has day by day goes on increasing. one of the way to increase the use of photovoltaic technology is by reducing the cost of solar cell and increasing the efficiency of solar cell, the research is still going on in this topic. A review of photovoltaic technology, working principle of solar cell, different material used for making the solar cell. This may be helpful for the researchers.



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