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Solar Cells for Ecological Sustainable Development: A Review

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Abstract

Solar energy is considered an environmentally friendly and never-ending renewable source of energy. Solar cells are an essential component of ecological sustainability. This energy can be harnessed for generating electricity without any pollutants even in remote areas. This renewable source of energy has been used to eliminate fossil sources. Through the photovoltaic effect, solar energy is transformed into electrical energy in a solar cell. Engineers and scientists are constantly working to improve solar cell efficiency, lower their cost, and develop technologies that maximize the quantity of sunshine turned into electrical power. These efforts culminate into four generations of solar cells – first, second, third, and fourth generations. Various models have been utilized to conceptually analyze solar cells, which is also beneficial to improve the solar cell's performance. In this study, advancement in the generations of solar cells, their types, manufacturing processes, various models, and future aspects have been discussed.

Keywords: *Solar cell; ecology; Sustainable; silicone solar cell; dye sensitized solar cell; thin film solar cell, generations of solar cell.*

1. Introduction

The demand for electricity is rising day by day because of a rise in population, and industrial development. Continuous efforts are made by scientists and engineers to switch conventional methods of energy production to environment-friendly renewable energy. This is the necessity to sustain clean, widespread accessibility and eco-friendly sources for mankind [1–3]. Sun is the source of a vast quantity of heat energy emitted in form of radiation known as solar energy and this energy can be transformed to direct current using photovoltaic cells. A PV panel or solar panel is an assemblage of solar cells neatly organized and mounted in a frame [4–6]. Solar cells, well known as photovoltaic cells, are devices that directly generate electric power from sunlight. They are a popular form of renewable energy attributed to their low environmental impact and ability to generate electricity in remote or off-grid locations. Solar cells are a key component of ecological sustainability. These devices can be used to power homes, businesses, and vehicles. Solar energy doesn't emit any toxic substances and is a clean, sustainable energy source [7].

The best possible methods are developed by scientists and engineers to harness sunlight energy sufficiently. Solar cells can be accessible to everyone without the hurdle of laying electricity wires and powerhouses. The efficiency and cost of a photovoltaic cell and its efficiency highly depend on the methods and materials used to make it. The ideal material for solar cells should have a band gap between 1.1 eV to 1.7 eV, must have a direct band structure, be easily available, have no toxicity, and should have high photovoltaic conversion efficiency [8–10].

Compared to wind, hydro, and geothermal energy, solar cells offer a range of benefits and advantages. A primary advantage of solar cells is their versatility. Solar cells have the flexibility of being installed in various locations, from rooftops to deserts, and can be integrated into a variety of applications, such as buildings, vehicles, and portable electronics. This makes them a highly flexible source of renewable energy [11–14]. Another advantage of these cells is that they have a relatively low impact on the environment. Unlike wind turbines and hydroelectric dams, solar cells do not require large amounts of land or water to generate electricity. Solar cells do not produce any hazardous emissions or contaminants that can be detrimental to the environment. In addition, solar cells have a low maintenance requirement and a long lifespan, making them a cost-effective investment in the long run.

Furthermore, they are getting more and more affordable, with the cost of solar cells and panels dropping significantly in recent years [15–17]. However, solar cells do have some disadvantages compared to other renewable energy sources. For example, they are intermittent, meaning that these cells can generate electricity only when the sun is shining. This can be addressed by using energy storage technologies such as batteries and supercapacitors, but this adds to the cost of the system. In total, solar cells are an important and versatile source of renewable energy, and their advantages make them a popular choice for many applications. However, their suitability will depend on factors such as location, climate, and energy needs [18, 19].

Selenium was used to make the first solar cell by American inventor Charles Fritts in 1883 with an efficiency of 1 to 2% only. At Bell Labs, Gerald Pearson, Calvin Fuller, and Daryl Chapin created a silicon solar cell in 1954 that had a 6% efficiency [20–22]. It was considered the ancestor of modern-day silicon solar cells and served as a solar panel in space exploration applications. In the era of 1970-1980, silicon solar cells have been used to make Solar panels for space exploration satellites, solar panels for residences, solar-powered aircraft, etc. with enhanced efficiencies. In modern days, dye-sensitized, quantum dots, inorganic or organic, carbon nanotubes, and graphene-based solar cells are used with large efficiencies, low cost, and smaller sizes [23–28].

There are four generations of solar cells having unique characteristics and improvements over the previous generation. Typically, silicon is the material of choice for producing first-generation solar cells and have been in use since the 1950s [29–32]. Thin-film solar cells, which belong to the second generation of solar cells, are usually composed of materials including amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS) [33–35]. Third-generation solar cells are manufactured by utilizing materials, such as organic molecules, quantum dots, and perovskite materials [36–38]. Fourth-generation cells are fabricated using graphene, carbon nanotubes, metal nanowires, and metal grid structures [37–39].

There are various advantages of using solar cells as a source of renewable energy such as: It is an energy source that is clean, renewable, and emits no hazardous gases or pollutants that can damage the environment [40, 41]. Solar panels can be installed in remote locations to make it feasible to produce electricity in areas where there is no access to the power grid. It is a free resource, which means that once the solar panel is installed, there are no ongoing costs associated with generating electricity. Solar panels are low maintenance and have a long lifespan, making them a cost-effective investment in the long run. There are several benefits to using solar cells for ecological sustainability. Solar cells do not release any harmful emissions, such as greenhouse gases or air pollutants. These sources of energy can never run out. These cells are becoming increasingly affordable to make them a more accessible option for homes and industrially [42,43].

In this study, advancement in the generations of solar cells, their types, manufacturing processes, various models, and outlook have been discussed.

2. Milestones on development of Solar cells

There are some important milestones in the development of solar cells: -

In 1839, French physicist Antoine-César Becquerel discovered the photovoltaic effect, which is the process of converting light into electricity. William Grylls Adams and Richard Day developed the first working selenium solar cell in 1876 [21, 22, 44]. The first silicon solar cell was invented by Bell Labs scientists: Gerald Pearson, Calvin Fuller, and Daryl Chapin, with an efficiency of 6% in 1954 [20]. It is known as the first-generation solar cells. NASA began using solar cells to power spacecraft. In 1970, The first solar-powered satellite, Vanguard 1 was sent into Earth's orbit [45]. In 1980, solar panels were made for residential and commercial use due to improvements in the solar cell efficiencies, cost effectiveness and known as second-generation solar cells [46, 47]. In this generation, the use thin-film technology, which involves the deposition of a thin layer of semiconductor material onto a substrate. Thin-film solar cells are typically less efficient than first-generation cells, but they can be made at a lower cost. Solar panels grown in popularity for remote areas and off-grid power systems in 1990 [48–50]. In 2000-2010, Research into new solar cell materials, such as organic materials, dye-sensitized solar cells, and perovskites, started known as third-generation solar cells [51–53]. These cells are still in development and include a variety of materials and technologies that aim to improve efficiency and lower costs. 2010 onwards, Solar energy becomes the fastest-growing source of renewable energy on a global scale, with solar panels with high efficiencies and affordability. Fourth-generation solar cells include quantum dot solar cells, nanostructured solar cells, and hot carrier solar cells. are also in development and include a wide range of technologies that aim to improve efficiency and reduce costs. Fourth-generation solar cells may also incorporate new materials, such as graphene and other 2D materials [54–56].

3. Photovoltaic Technology

Photovoltaic technology harnesses the power of sunlight to produce electricity, without requiring a heat engine. The technology comprises of cells made of a semiconductor material, where each cell generates electricity when exposed to light, thanks to the electric field across various layers of the semiconductor [57, 58]. The amount of electricity produced by each cell is determined by the intensity of light falling on it. PV cells produce a direct current (DC) which can be converted to alternating current (AC) for future use [59]. The rating of PV systems is usually expressed in kilowatts peak (kWp). Mainly, these cells are fabricated using semiconductor materials like p-type and n-type silicon layers to form a p-n junction as shown in Fig.1.

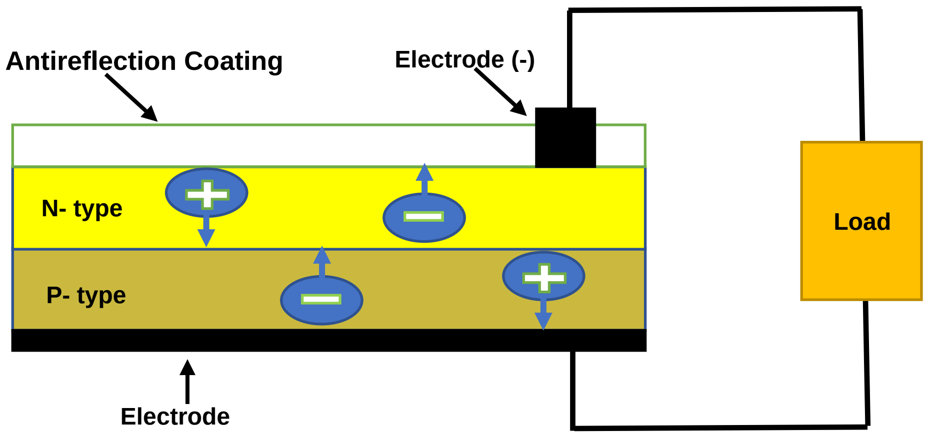

Figure.1 p-n junction solar cell

The p-type and n-type layers of solar cells are attaches to the external load by utilizing a metal-semiconductor. When photons from sunlight reach the cell, energy is transferred to the charge carriers in the cell. By closing the circuit with an external load, electricity can be drawn from the cell.

Models

Solar cell is a simple pn junction diode and is governed by the following Schottky diode equation [60]

$$I = I_{ph} - I_0 \left(e^{\frac{V}{n V_T}} - 1 \right) \quad (1)$$

where I_{ph} is the photogenerated current V_T (= kT/q) represents the thermal voltage, k is Boltzmann constant, T is temperature of solar cell, q is the charge, n is the ideality factor and I_o is the reverse saturation current.

However, there are a few other factors that reduce the current I and the above model was improved by including shunt resistance R_{sh} and series resistance R_s. This model is called one diode model and is given by the following equation [61]

$$I = I_{ph} - I_0 \left(e^{\frac{V+I\,R_S}{n\,V_T}} - 1 \right) - \frac{V+I\,R_S}{R_{Sh}} \tag{2}$$

The solar cell's electric equivalent circuit is depicted in Figure 2 that follows the one diode model. The one diode model is used for calculating the parameters (such as I_{ph}, I_o , n, R_s, and R_{sh}) of solar cells because it is easier to interpret the equation describing the model. However, few researchers also used two diode model to determine solar parameters [62-64].

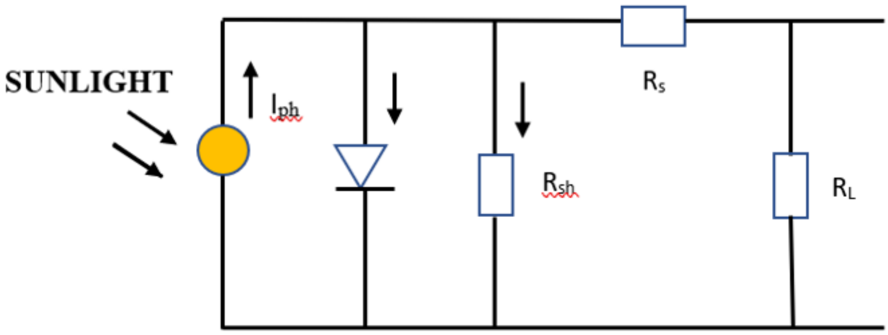

Figure 2. Electric equivalent circuit of the solar cell on the basis of one diode model.

If electronic conduction mechanisms (diffusion, generation-recombination, and thermionic) within the solar cell are studied individually, then modeling can be done by considering a diode in parallel for each mechanism. The mathematical equation can be modified by incorporating an exponential term for each mechanism. If diffusion and recombination mechanisms are considered, an expression for two diode model is

$$I = I_{ph} - I_0 \left(e^{\frac{V+I\,R_S}{n_d\,V_T}} - 1 \right) - I_{or}\left(e^{\frac{V+I\,R_S}{n_r V_T}} - 1\right) - \frac{V+I\,R_S}{R_{Sh}} \tag{3}$$

where subscripts d and r represent the diffusion and the generated- recombination mechanisms.

The literature has reported a variety of techniques to calculate the solar cell parameters on the basis of one diode model/two diode model [7, 65–67]. In addition, optics model to explain multi-junction solar cell and model for solar cell combinations were also developed. According to the experimental set up and data, suitable model and method can be selected to determine solar cell parameters which are useful for further investigations [66].

4. Types of Solar cell

Solar cells, which are also known as photovoltaic cells, have the ability to directly generate electricity from sunlight using one or more semiconducting layers, such as silicon, that absorb photons and release electrons, resulting in the generation of an electric current. There are various types of solar cells available, such as monocrystalline, polycrystalline, and thin-film solar cells. Single silicon crystals are used to make monocrystalline cells while polycrystalline cells are fabricated from multiple silicon crystals. Thin-film cells are created using the layers of different materials, such as cadmium telluride or copper indium gallium selenide. Solar cells have many applications, from powering small electronics like calculators to providing electricity to homes and businesses. They are a popular form of renewable energy due to their low environmental impact and ability to generate electricity in remote or off-grid locations. The solar cell's efficiencies has increased significantly over the years, and ongoing research is focused to develop new materials and manufacturing processes to improve their performance.

There are four generations of the types of solar cells based on manufacturing material.

First Generation Solar cell

Chaplin, Fuller, and Pearson demonstrated the first-generation solar cell at Bells Labs in 1954 earliest and most widely used types of solar cells [20]. They are mainly fabricated from silicon wafers and have been in use since the 1950s [46, 68]. The most common types of first-generation solar cells are monocrystalline and polycrystalline solar cells. Monocrystalline solar cells are made from a single crystal of silicon, while polycrystalline solar cells are created from multiple silicon crystals. The technology is founded on crystalline film, wherein semiconductors such as silicon and GaAs are utilized. GaAs, being the oldest material used for creating solar cells, is known for its high efficiency. Meanwhile, silicon (Si) is the most widely utilized semiconductor in the photovoltaic solar cell industry, accounting for more than 90% due to its commercial viability as it is found in the earth's crust in abundance and is non-toxic chemical [69]. The first-generation solar cells can be categorized as single crystal, polycrystalline and amorphous.

The Czochralski technique is used to produce monocrystalline solar cells. Si crystals are carved from large-sized ingots during this Czochralski technique. The big single crystal must be manufactured using precise processing, which raises the cost of "recrystallizing." Several crystals are combined to create a multi-crystalline silicon solar cell, this form of solar cell is processed more cheaply by cooling a mould that is filled with graphite. Although the efficiency of multi-crystalline silicon is lower than that of monocrystalline silicon, it is still utilized in commercial modules. This is due to the increasing production of solar photovoltaic voltage cells and the necessity to reduce their cost. However, in contrast, thin film cells that use a hydrogenated alloy of amorphous silicon have been established commercially as there is a high cost of manufacturing crystalline silicon [72].

The first-generation solar cells, also known as conventional or traditional solar cells, are the First-generation solar cells have an efficiency rate of around 15-20%, which means they can convert about 15-20% of the sunlight they receive into usable electricity [73]. They are widely used in residential and commercial applications, such as rooftops and solar parks. One of the major drawbacks of first-generation solar cells is their high cost of production due to the expensive materials used and the complex manufacturing process. Additionally, they are not as environmentally friendly as other types of solar cells, as they require a significant amount of energy to manufacture. However, ongoing research is focused on developing new materials and manufacturing processes to reduce the cost and environmental impact of first-generation solar cells, while also improving their efficiency and performance [74, 75].

Second Generation Solar cell

The majority of second-generation solar cells are built using thin films. In these cells, thin layers of materials are deposited on the substrate like metal and glass. These solar cells are more cost-effective as compared to first-generation solar cells. Thin-film solar cells have very thin light-absorbing layers (~ 1 µm) as compared to silicon-based solar cells whose thickness is about 300 µm. The main solar cells of this generation are Amorphous Silicon Thin Film (a-Si) solar cells, Cadmium Telluride (CdTe) Thin Film Solar Cells, Copper Indium Gallium Di-Selenide (CIGS) Solar Cells, etc [34, 76, 77].

Second-generation solar cells are a type of thin-film solar cell that use a variety of materials to convert sunlight into electricity. These materials include amorphous silicon, cadmium telluride, and copper indium gallium selenide. Second-generation solar cells have many advantages over first-generation solar cells, including higher efficiency, lower production costs, and the ability to be integrated into a variety of applications [74, 75]. They have high flexibility and lightweight, making them easier to install and transport. Additionally, second-generation solar cells can be produced using less material, making them more environmentally friendly than first-generation solar cells [78]. These cells are an exciting advancement in the field of renewable energy and have the potential to revolutionize the way we generate electricity.

Amorphous Si (a-Si) PV modules are the first solar cells that can be used industrially. These cells are fabricated using a coating of doped silicon on the substrate or glass plate. a-Si cells have very unstable efficiency lies in the range of 4% - 8%. Cadmium telluride (CdTe) solar cells have exceptional direct band gap material and cheaper PV devices which could make easy absorption of light and thus have improved efficiency. It is fabricated using cadmium sulfide layers to form a p-n junction diode on a glass substrate as shown in Fig.3. These cells have efficiencies lies between 9% - 11% and a band gap of around 1.5 eV and are cost-effective. However, cadmium is hazardous and environmentally harmful which is the main issue with these cells. Copper Indium Gallium Di-Selenide (CIGS) Solar Cells are constructed using sputtering, evaporation, electrochemical coating technique, printing, and electron beam deposition.

These cells use Copper, Indium, Gallium, and Selenium. These cells have higher efficiencies (~10% - 12%) as compared to amorphous Silicon Thin Film (a-Si) and Cadmium Telluride (CdTe) Thin Film Solar Cells. In these cells, glass plates, aluminium, polymers, steel, etc. are used as a substrate. These cells have a long life without substantial degradation [80].

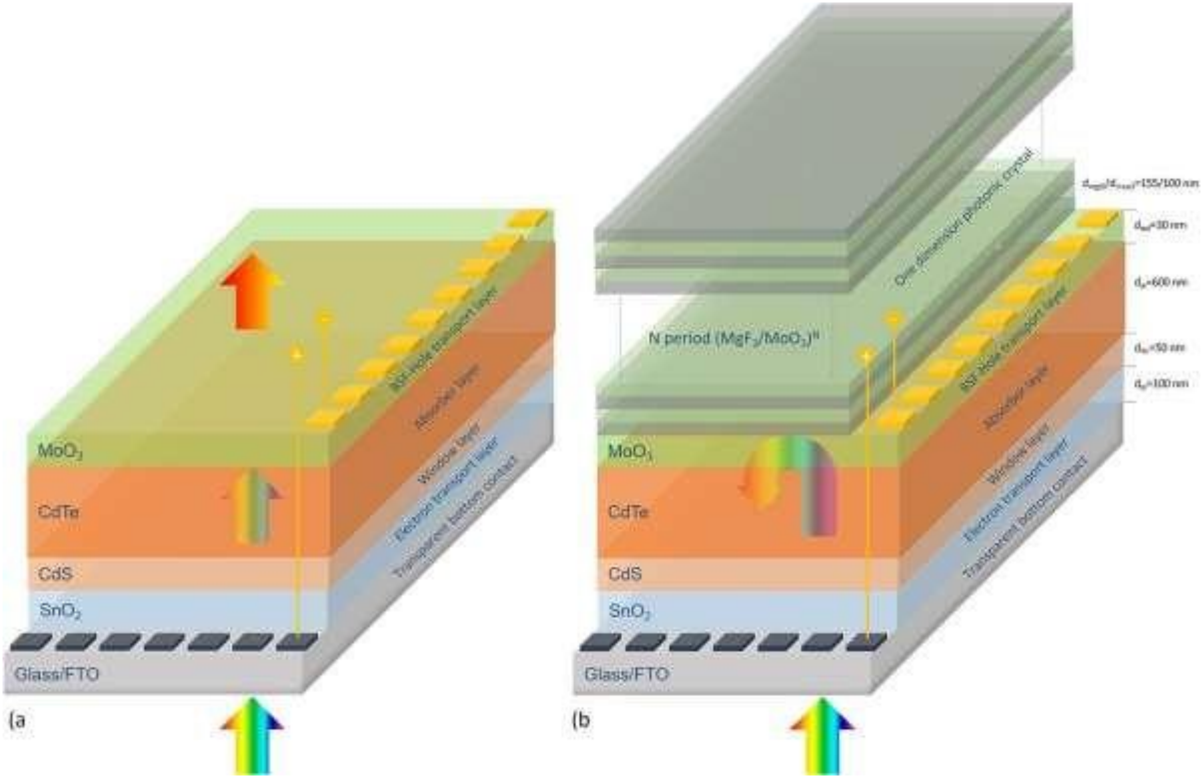

Figure.3. Structure of the CdTe solar cell. Reproduced from ref. [79] under a Creative Commons Attribution 4.0.

Third Generation Solar Cell

Third generation solar cells include multijunction organic heterojunction, dye-sensitized solar cells, Perovskite solar cells and Quantum Dot solar cells [51–53].

Third-generation solar cells are a new class of solar cells that use advanced materials and technologies to improve the efficiency and performance of solar panels. These cells include a variety of designs, such as dye-sensitized solar cells, organic solar cells, and quantum dot solar cells. One of the key advantages of third-generation solar cells is their ability to capture a broader spectrum of sunlight, including both visible and non-visible light. This allows them to generate electricity even in low light conditions, such as on cloudy days. Another advantage of third-generation solar cells is their potential for higher efficiency compared to previous generations. Some third-generation solar cells have achieved efficiencies of over 40%, which is significantly higher than the average efficiency of first and second-generation solar cells. Overall, third-generation solar cells are still in the experimental phase, and more research is needed to improve their efficiency and scalability. However, these cells could significantly improve the performance and cost-effectiveness of solar energy systems, making them a promising technology for the future of renewable energy.

All the photons in the incident sunlight must be absorbed by the solar cell in order to maximise efficiency. This problem cannot be solved by a single junction solar cell. Therefore, the multi-junction solar cell is viewed as a potential solution to this issue. Under irradiation of the sun spectrum AM1.5g, the National Renewable Energy Laboratory (NREL) produced a double junction solar cell efficiency world record of 32.6%. Theoretically, the maximum efficiency of a multijunction solar cell is 86%. Multi-junction (MJ, Tandem) III-V compound solar cells are have an efficiency of up to 50% and have potential applications in space and terrestrial fields [81, 82].

Dye-sensitized solar cells (DSSR) function under less intense light, such as dawn, dusk, or overcast conditions. In contrast to expensive Si solar cells, this method uses less expensive components or even natural dyes, and the fabrication procedure for DSSC is simpler. These benefits of DSSCs have led to a significant amount of ongoing experimentation in this field. DSSC offer a reliable substitute for pricey crystalline Si technology. Low-cost fabrication methods, including as inkjet/screen printing and the roll-to-roll method, can be used to create DSSC devices [83, 84]. These methods enable the fabrication of huge area devices on flexible substrates. In these DSSCs, dye molecules effectively absorb sun spectrum light. A DSSC is made up of five different parts: a counter electrode, a suitable sensitizer, a suitable electrolyte that will serve as a redox couple, and a conductive fixed mechanical support. Various methods have been used to increase efficiency of DSSR like co-sensitization technique, mixing two or more sensitizing dye agents having absorption over a wide range of solar spectrum. Polyvinylalcohol/ titanium dioxide dye-sensitized solar cell has shown good electron lifetime and charge collection efficiency as shown in Fig. 4 [85].

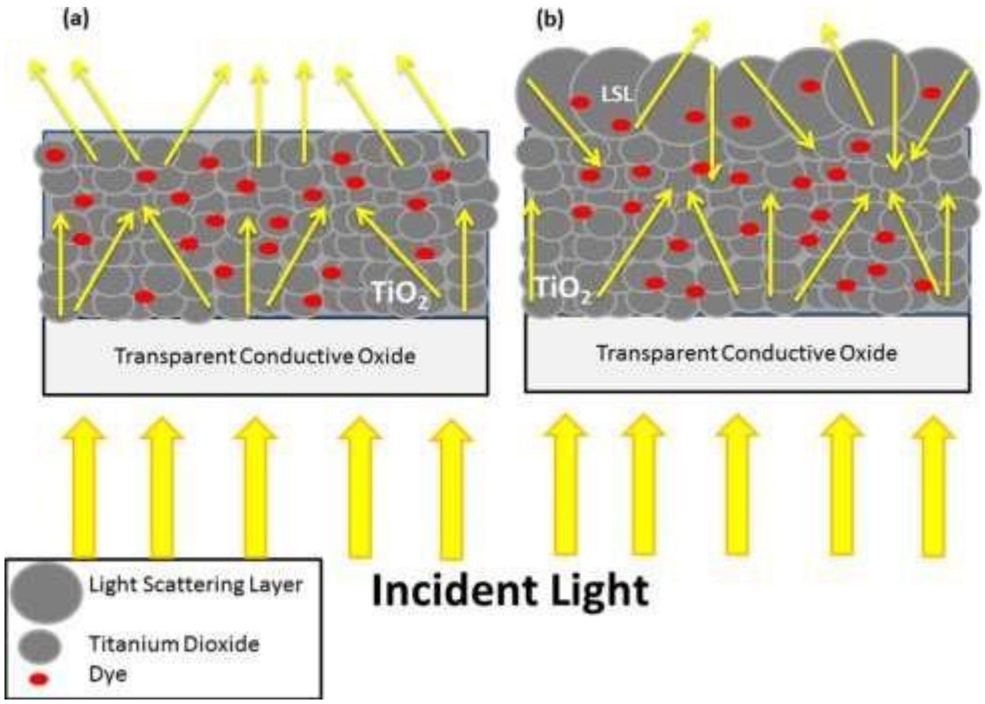

Figure.4 Polyvinylalcohol/ titanium dioxide dye-sensitized solar cell; Reproduced from ref. [85] under a Creative Commons Attribution 4.0.

The perovskite solar cell utilizes a perovskite material to capture solar energy and behaves as a charge carrier conductor. Perovskite materials typically have the chemical formula AMX_3 (where X is oxygen or a halogen), with cation A occupying a cubo-octahedral site and cation B occupying an octahedral site. A and B are typically divalent and tetravalent when X is O_2, but monovalent and divalent cations are typically found in the A and B sites when X is a halogen anion. If the charge neutrality criteria is satisfied, it is practical to integrate a variety of elements with various valances at the various sites of this compound, which is one of the main reasons why perovskite is a well-researched optoelectronic material for the production of solar cells. The mesoscopic and planar structures of a perovskite solar cell are the two most popular designs. In order to effectively improve the surface morphology of Hybrid Perovskite Solar Cells, a variety of additives, including inorganic salts, organic halide salts, inorganic acids, fullerene, polymers, and even water, have been doped into the perovskite layers. High optical absorptivity in hybrid perovskites enables the use of substantially thinner solar films for efficient solar radiation harvesting [16, 86].

Quantum dots are nanocrystal semiconductors of materials from periodic groups of II-VI, III-V, or IV-VI. The size of quantum dot of few nanometers. Quantum dot solar cells (QD) are devices with tunable bandgaps that are fitted in the spectrum of the sun. This lowers the cost per watt of solar energy. The benefits of QDs include their ability to be moulded into a variety of shapes, including two-dimensional (sheets) and three-dimensional arrays; One of their notable characteristics is their capacity to be processed into junctions on cost-effective substrates such as plastic, glass, or metal sheets and their simplicity in combining with organic polymers and dyes. Quantum dots are produced using various processes, including chemical abrasion, electrochemical carbonization, laser abrasion, microwave irradiation, and hydrothermal / solvothermal treatment. QDs such as CdS, CdSe, PbS, and InAs are used as photosensitizers instead of organic dyes because of their versatile optical and electrical properties in Quantum dot sensitized solar cells (QDSCs) [87–88]. Some of the notable characteristics of quantum dots (QDs) are their ability to have a band gap that can be adjusted depending on their size, a higher extinction coefficient, increased stability against water and oxygen, and the capability to produce multiple excitons with just one photon absorption [89–91].

Fourth-generation photovoltaic solar cells

The fourth-generation solar cell is known as the 4G solar cell technology or nano photovoltaics. In this technology, a combination of inorganic and organic materials is used to enhance efficiency and make low-cost solar cells. These solar cells are flexible and stable and thereby known as hybrid inorganic cells [81, 92]. In 4G solar cells, mainly transparent tin-doped indium oxide is used as substrate. These cells are fabricated using graphene, carbon nanotubes, metal nanowires, and metal grid structures.

Fourth-generation solar cells are a new class of solar cells that are still in the research and development phase. These cells use advanced materials and technologies to enhance the efficiency and performance of solar panels beyond what is possible with current technologies. One of the main goals of fourth-generation solar cells is to improve their efficiency and make them cost-effective. These cells use advanced materials such as perovskites, graphene, and nanowires to improve the efficiency of solar panels. They also use new manufacturing techniques such as 3D printing and roll-to-roll printing to reduce the cost of production. Another goal of fourth-generation solar cells is to make them more flexible and lightweight. This will make it possible to integrate solar panels into a wider range of applications, such as clothing, buildings, and vehicles. Overall, fourth-generation solar cells are still in the early stages of development, and it may be several years before they become commercially available. However, they have the potential to significantly improve the efficiency, cost-effectiveness, and versatility of solar energy systems, making them a promising technology for the future of renewable energy.

Graphene-Based Photovoltaic Cells are considered a promising future for solar cells due to the extraordinary properties of graphene such as high conductivity, high mobility, and 2-D lattice packing. The graphene- based silicon heterojunction solar cell is shown in Fig.5 [93]

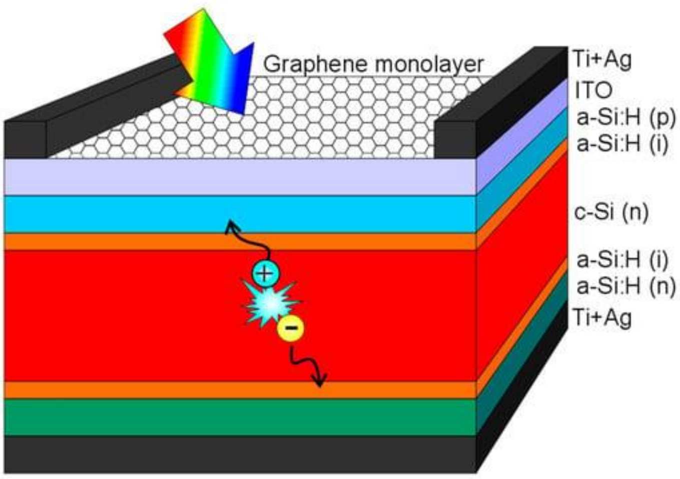

Figure 5. Schematic diagram of graphene- based silicon heterojunction solar cell fabrication; Reproduced from ref .[93] under a Creative Commons Attribution 4.0.

The application of graphene in solar cells highly depends on the synthesis and thereby structure and properties of graphene [93–94].

Highly conductive graphene is used in flexible photovoltaic devices due to its suitability with metal oxides, conductive polymers, and, metallic compounds. The graphene-based perovskite and organic bulk heterojunction (BHJ) solar cells have efficiencies of more than 20% and 10% respectively. Carbon nanotubes (CNTs) are used to fabricate organic solar cells (OSCs) due to their extraordinary physicochemical properties, cost-effectiveness, environmentally friendly, etc. [54]. These low resistance and high optical transmittance CNTs could be alternatives to toxic and expensive indium tin oxide (ITO). CNTs enable OSCs to enhance the moisture and thermal stability of OSCs, thus extending the lifetime of the cells. These cells have efficiencies of more than 14 % [95].

5. Future Prospect

Clean and regenerative solar energy should be exploited by utilizing all the available models, mechanisms, materials, and gadgets, The commercialization of this technology, however, faces several challenges, including stability against moisture and oxygen, heating under applied voltage, photo-instability, and mechanical fragility. To harness a significant amount of the solar energy that hits the Earth's surface, it is necessary to have solar panels that are of considerable size. Large solar panel installation and maintenance could be labour-intensive and chaotic. Large areas of the landscape are also lost when these solar panels are built. Land scarcity would result from the construction of big solar panels. Sophisticated solar panels can be designed to surpass this problem. This problem could be solved using nano-sized solar cells. However, a lot of research is carried out in this field. May be in the future, we would be able to harness maximum amount of sunlight using new techniques.

The future of solar cells is very promising, as they've already shown to be an important source of renewable energy. As technology continues to advance, solar cells are expected to become even more efficient, cheaper, and versatile, making them an increasingly popular choice for generating electricity. One of the key areas of research in the future of solar cells is the development of new materials and technologies that can significantly improve their efficiency. This includes the use of advanced materials such as perovskites, quantum dots, and nanowires, as well as the development of new manufacturing techniques such as 3D printing. Another area of focus is the integration of solar cells into a wider range of applications, such as buildings, vehicles, and portable electronics. This will require the development of more flexible and lightweight solar cells, as well as the ability to integrate them into a wider range of materials. Finally, the future of solar cells will also depend on the continued development of energy storage technologies, such as batteries and supercapacitors. This will help to address the issue of intermittency and ensure that solar energy can be stored and used when needed. Overall, the future of solar cells looks very bright, and they are expected to play an ever-more significant part in meeting the world's energy needs in the coming years.

6. Conclusion

Drawing conclusions from the studies undertaken that solar cell made a significant progress since their inception. The first generation of solar cells, which were made of silicon, laid the foundation for further advancements in the field. The second generation of solar cells, which included thin-film solar cells, increased efficiency and decreased the cost of production. However, they still faced challenges such as toxicity and limited efficiency The third and fourth generations of solar cells, which are still under development, have the objective of surpassing the limitations of the previous generations by using new materials and technologies such as organic and perovskite solar cells, using graphene, carbon nanotubes, metal nanowires to make solar cells. Overall, Solar cell technology has the capability to transform the energy sector by offering a renewable and sustainable energy source, thereby revolutionizing the industry for the future. However, further research and development are needed to make solar energy more efficient, cost-effective, and accessible to everyone.

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