Chapter

Nanotechnology in the Service of Solar Energy Systems

Farzaneh Ghasemzadeh and Mostafa Esmaeili Shayan

Abstract

Nanotechnology can help to address the existing efficiency hurdles and greatly increase the generation and storage of solar energy. A variety of physical processes have been established at the nanoscale that can improve the processing and transmission of solar energy. The application of nanotechnology in solar cells has opened the path to the development of a new generation of high-performance products. When competition for clean energy options is growing, a variety of potential approaches have been discussed in order to expand the prospects. New principles have been explored in the area of solar cell generation, multi-generation, spectrum modulation, thermo-photoelectric cells, hot carrier, the middle band, and many other techniques. Nanoparticles and nanostructures have been shown to enhance the absorption of light, increase the conversion of light to energy, and have improved thermal storage and transport.

Keywords: nanotechnology, thin-film, solar cells, renewable energy

1. Introduction

Nanotechnology is an interdisciplinary area of research, engineering and development that encompasses nanoscale materials from 1 to 100 nanometers. At these nanometer measurements, materials can exhibit new properties that are absent or low in their bulk. For this purpose, nanotechnology applications have been proved in a broad variety of areas, such as physics, chemistry, biological sciences, materials sciences, electronics and energy sciences. Owing to the dwindling fossil fuel supplies and the environmental consequences of their usage and the rising greenhouse gas emissions that have warmed the earth, discovering a new source of renewable, efficient and biocompatible energy is a problem confronting scientists and researchers today [1]. Attention to alternative energy sources such as solar energy, wind, hydro and tides, and biomass from fuel cells and hydrogen is of great interest in industrial and science communities today [2]. Solar energy, the world's biggest energy source, as a renewable energy source, inexpensive and free emissions, has a special role in energy supply. The sunlight that the Sun reflects on the planet every hour is greater than the entire resources that the people of the world eat in a year [3]. The production of this energy is therefore of considerable significance. Currently, owing to the need to harvest solar energy, numerous forms of solar power production systems have been developed in different countries with the correct capacity for solar radiation, so that their electricity is transmitted to the national grid [4]. Todays, about 178

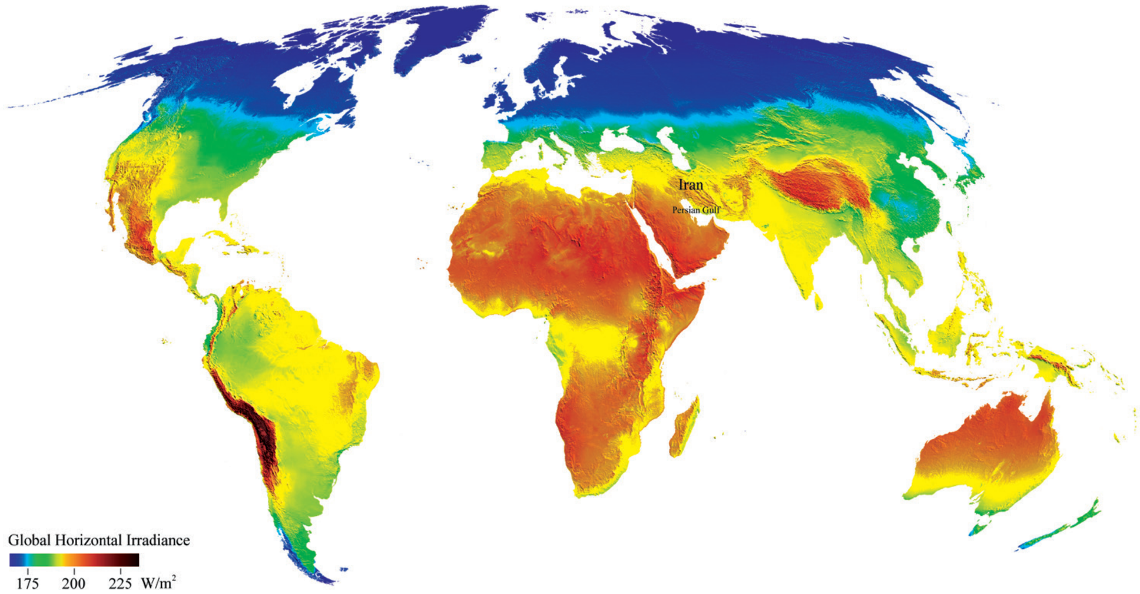

Figure 1.
Global horizontal irradiation.

GW of electricity supply has produced by solar energy [5]. This resource came to expected that, with the elimination of barriers, the solar power potential of built power plants would hit more than 500 GW by 2020 [6]. Since the underlying essence of green energies, like solar energy, is mostly local and distributed, so if it is not feasible to utilize the global grid, it is reasonable that the usage of such resources would be decentralized so spread, rather than centralized output, will be more justifiable. **Figure 1** shows the influence of solar energy in the World. Iran has a strong potential to get this energy supply close to the equator. In the meantime, Iran ranks seventh in mine resources.

It must be remembered that solar energy can be used in two ways [7]:

1. Using sunlight to produce energy directly

2. Usage of solar thermal energy in high-temperature power plants for the generation of electricity and in low-temperature power plants for the processing of hot water and the ventilation of houses, as well as for use of solar water desalination plants

Nanotechnology can be very successful in the extraction of solar energy in this field. Using this technique, the performance of the system can be improved in the two areas of power and heat production.

It is now easier to learn more about the solar power production program and get acquainted with the specifications of this sector.

2. Solar power generation mechanism

Sunlight comprises of various hair lengths of light continuum (ultraviolet, yellow, and red) from energy packets called photons. The intensity of these photons differs based on their wavelength [8]. Sunlight after exposure to the surface of the solar Panels, solar cells absorb the Sun's energy and turn it into electricity (**Figure 2**).

A solar cell is a semiconductor electron that transforms sunlight energy directly to electricity through its photovoltaic influence. If the sunlight passes to the semiconductor, the electron moves from the capacitance band to the semiconductor conduction band and generates an electron–hole pair, each of which can engage in the semiconductor load transfer cycle and create possible variations such that, with the intervention of the user, the load can be guided to the external circuit (**Figure 3**).

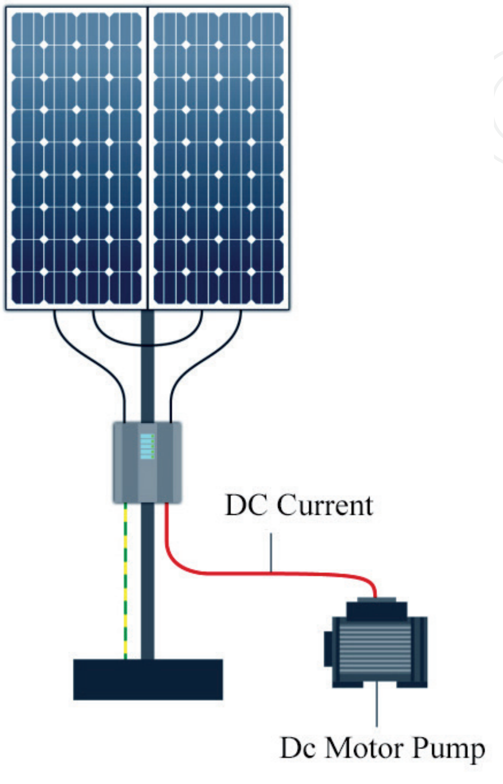

Figure 2.
A simple circuit of photovoltaic [7].

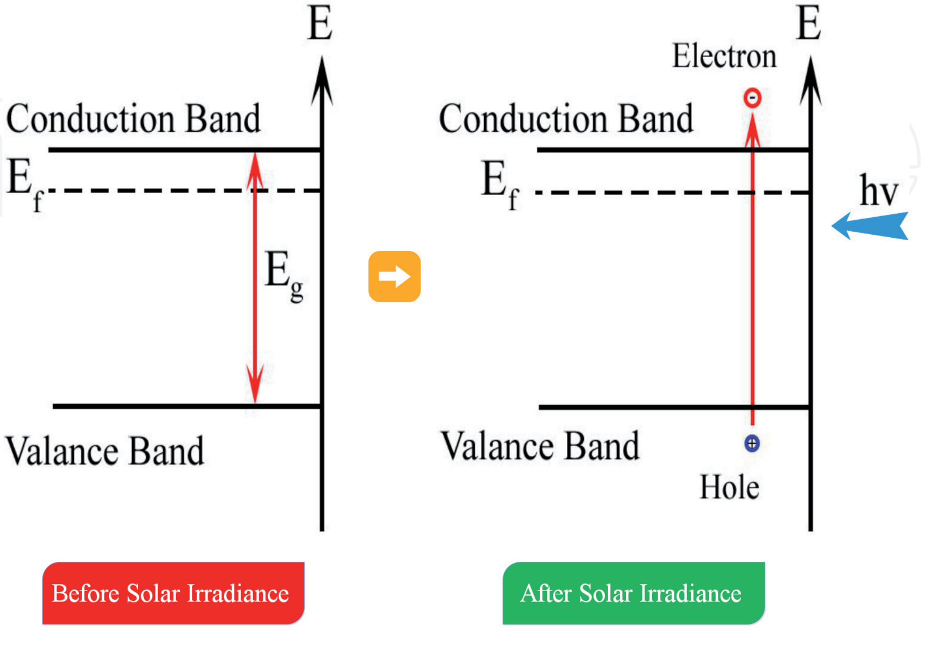

Figure 3.
Schematic of electron and hole in solar irradiation present and non-solar irradiation [9].

3. Types of solar cells

3.1 Silicon solar cells (First generation)

The technology of the first generation is based on silicon wafers with a thickness of between 300 and 400 microns with a single crystal or multi-crystal structure. The silicone materials used are polluted with different elements in order to locate a sufficient amount of electrons-holes. Such solar cells are made up of a combination of electron-contaminated and perforated silicone layers that emit electron-cavity light [7]. Therefore, an electrical current is created by moving the load to the external circuit. These solar cells have been commercialized because of their high performance, but the major drawbacks of this group are the high cost of processing silicon raw materials and the high energy usage [10] (**Figure 4**).

3.2 Thin film of solar cells (Second generation)

As the name suggests, the operating concepts of these cells are focused on thin layers of semiconductors deposited on the surface, such as glass, metal or polymer substrates. In such solar cells, each coating is responsible for consuming part of the Sun's wavelength [11]. As a consequence, the absorption rate in this form of solar cells decreases and their energy transfer improves.

3.3 Dye-sensitized solar cell (Third generation)

The essential components of a pigmented solar cell are a photo-electrode composed of a pigment-sensitive titanium dioxide film (TiO_2). In this cells as Showed in **Figure 5**, when photons are incoming into the Dye-Sensitized Solar Cells, absorbed by the pigment and produced electrons and holes [12]. The electrons in the dye are passed to the nanoparticle of TiO_2. The nanoparticles of TiO_2 serve as carriers of

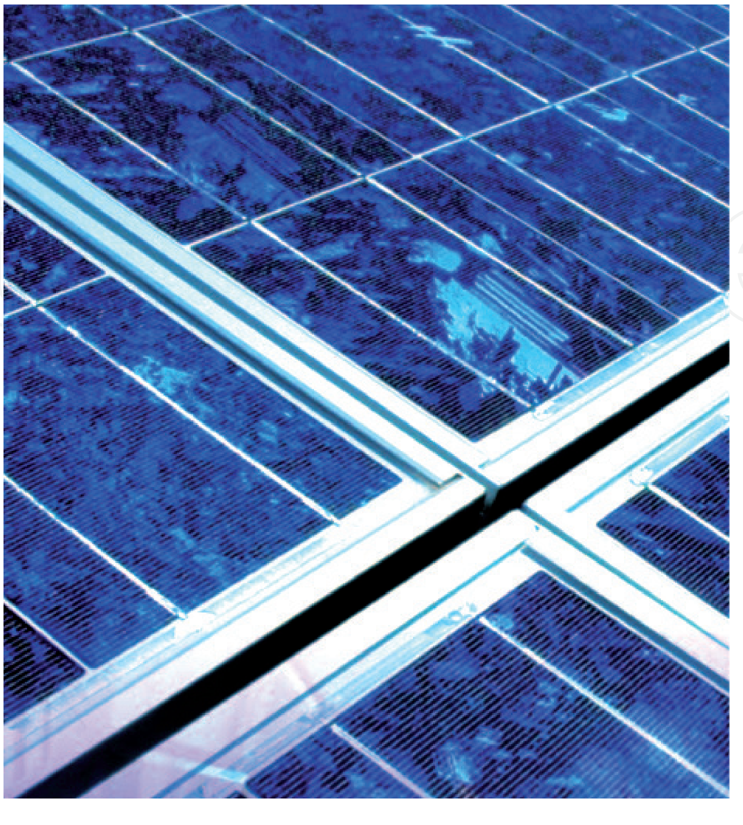

Figure 4.
Silicon solar panels [7].

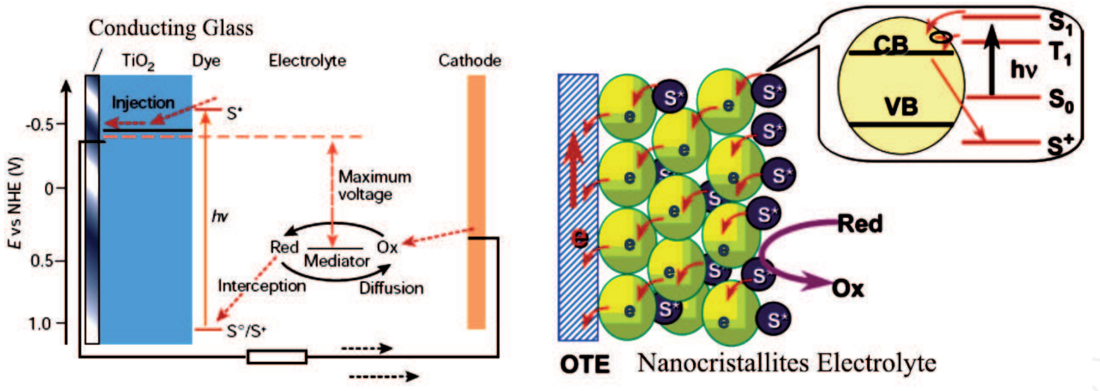

Figure 5.
Schematic of dye-sensitized solar cells [13].

this electron, and finally the electron enters the electrode. The electron that enters the electrode is passed by wire to the opposite electrode (reducing electrode) and is used in the electrolyte recovery cycle. The pigment cavity, on the other side, is regenerated by a solvent and able to absorb the next photon. In this way, the current is also formed on the external circuit.

4. The application of nanotechnology in solar cells industry

Generally, nanotechnology has a beneficial impact on the efficiency of solar cells in a variety of respects [14]. Such functional consequences shall include:

1. Boost absorption and retention of sunlight
2. Providing modern nanotechnology designs for solar cells
3. Using nanowires to boost solar cell efficiency
4. Application of nanotechnology dependent photo-catalysts in solar cells
5. Application of nanocoatings
6. Application of nanotechnology in power storage systems

The list is only several of the features of nanotechnology in the field of solar energy and nanotechnology in other fields of solar energy, such as solar thermal systems, has already demonstrated major applications.

5. The improve of absorption and capture of sunlight

5.1 Light emitting nanoparticles; a reasonable way to improve the performance of a solar cell

Nanomaterials have been developed and manufactured in numerous ways for diverse uses since the advent of nanotechnology in the last decades. Meanwhile, the light emitting nanoparticles got a lot of coverage owing to their very fascinating properties in the area of light absorption and reflection [5]. Light emitting nanoparticles, such as quantum dots, gold or silver nanoparticles and fluorescent nanofibers, are commonly used to improve the performance of solar cells. The basic denominator of such nanoparticles is their special optical properties. Simply stated, the key characteristic of such nanoparticles is the fact that they are fluorescent. Such nanoparticles, based on their shape and scale, may absorb various wavelengths and become agitated, and then release absorbed energy in the form of radiation from another wavelength or original wavelength. Quantum dots will be used as a replacement for pigments owing to their outstanding optoelectronic properties in solar cells [15]. This leads to the likelihood of increasing the voltage or output current of the responsive solar cell to the quantum level. Another drawback of such materials is that they will extend the spectrum of absorption of sunlight outside visible light due to their photoelectric properties (conversion of solar energy into electricity).

Although they also receive infrared rays, quantum-based cell theory simulation has projected an improvement in cell performance of about 64 percent, which is quite important. The light emitting in some of the quantum dots materials are shows in **Figure 6**.

One of the newest products to improve the response of solar cells to light and improve their absorption is the quantum dots of silver sulfide (Ag_2S). Such quantum dots are immune to wavelengths between 400 and 1000 nm in the solar spectrum; thus, in addition to visible light (400–700 nm), they often reflect the intensity of infrared radiation. The genus of this category is silver selenide (Ag_2Se) quantum dots, which span the entire solar spectrum and have a susceptibility range

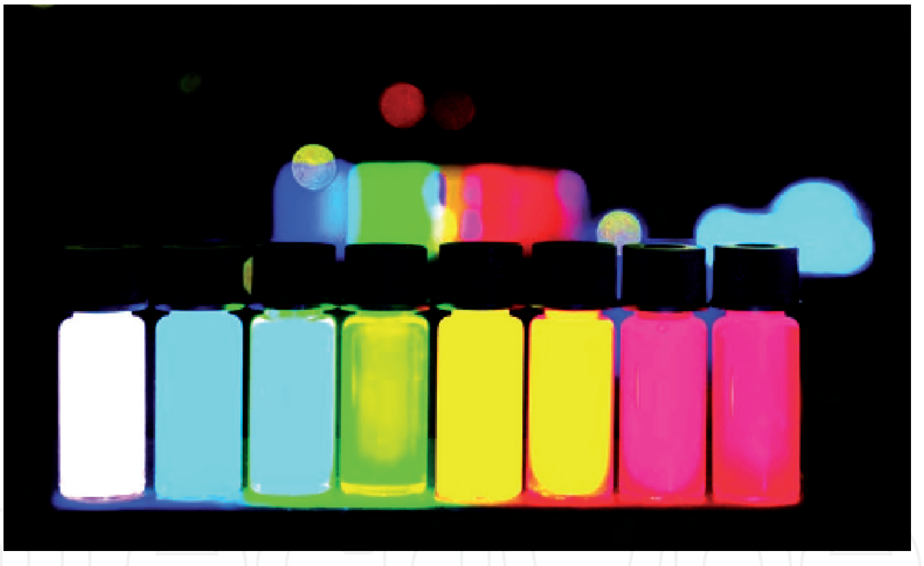

Figure 6.
The light emitting of quantum dots [16].

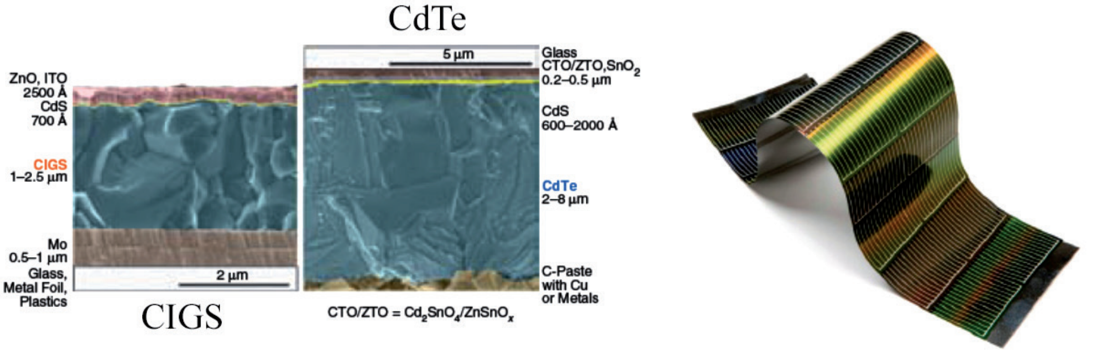

Figure 7.
CIGS and CdTe flexible solar technology [16].

7–14 times that of standard quantum dots [7]. The electrical current production of these cells is 4 times that of regular pigment-sensitive cells. It can also be noted that such quantum dots are very strong choices for increasing the performance of solar cells and, as a result, investing in further work in this area in order to enter the commercial process is completely important and imminent (**Figure 7**).

6. Provide new architectures for solar cells focused on nanotechnology

6.1 Transparent solar cells: A change in the solar industry

With the emergence of nanotechnology in the area of solar cell manufacturing and the development of modern architectures, new opportunities for different forms of solar cell applications have been opened to the world of business and technology. All of these new designs is to render solar cells fully translucent. The ultimate composition of transparent solar cells is a mixture of translucent substrate (made of glass or plastic) and Nanolayers of materials of specific optical properties and thicknesses, which are responsible for absorption beyond the spectrum of visible light. Transparent cells emit visible light and then consume ultraviolet light and infrared-producing electricity. This innovative aspect of translucent solar cells enables a broad variety of applications in buildings and cars. The volume of visible light in various forms of cells ranges from 50% to 80%. Researchers expect that, with the aid of nanotechnology, it would not be difficult to reach 12% performance without compromising the properties of cell movement [17]. The thickest layer of this system is the sheet of glass or plastic to which the sheet of grating and coating is added. Some coatings are added to the ground in nanoscale. At the middle of the layers are two active cells, which absorb stimulated light and emit electrons. One of these two compounds is chloroaluminium phthalocyanine, which serves as an organic electron donor, and the other is carbon 60 (C_{60}) electron receptor [18]. The thickness of phthalocyanine chloroalumine is 15 and C-60 is 30 nm. The electrodes are mounted on all sides of these walls. The electrodes are constructed of ITO/MoO_3. The width of such electrodes is less than 20 nm [19]. As the electrodes may be translucent (and not constructed of ordinary metal), a coating at the end of

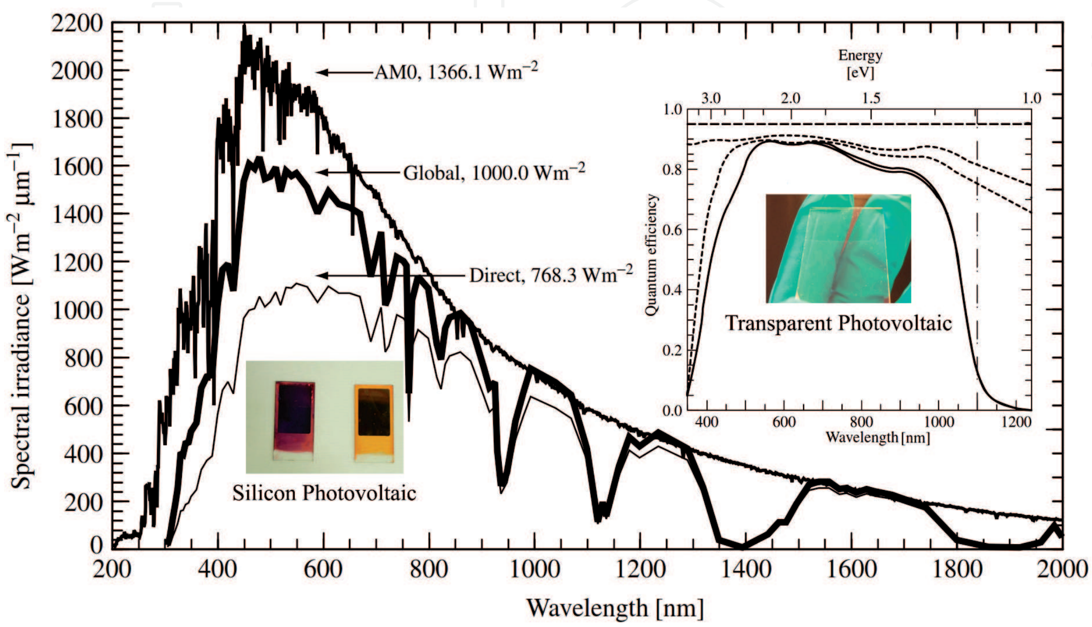

Figure 8.
Effect of spectral and wavelength on transparency photovoltaic and silicon based photovoltaic [20].

the cell can be inserted to replicate the length of the thin from other positions in the sunlight and return it to the cell atmosphere in such a way that the cycle of absorption and conversion is replicated, as shown in **Figure 8**. It is found that, during this special feature, much of the visible light moves across and out. The short and long line extensions in the spectrum in sunlight are consumed and converted.

7. Nanofluid is a reasonable way to move power and rising the output of solar systems

A stable nanocrystal line is a metal or non-metallic nanoparticle which is embedded in a base solution. Suspended nanometer particles such as silicone oxide, titanium oxide, copper oxide, or nickel metal nanoparticles, or carbon nanotubes and graphene, change fluid displacement and heat transfer properties that are extremely capable of increasing heat transfer. Nanofluid is mostly used in manufacturing because of its high coefficient of heat transfer in engines or heat exchangers to increase both performance and economy. Recently, several academic organizations and businesses have been utilizing nanofluid in solar heaters or batteries. Since the emission of light over long wavelengths on the surface of solar cells allows it to heat up, and this rise in temperature decreases performance, the cooling of solar cells is especially significant [17, 19]. At present, this cooling is achieved by going through a sea of liquid, which has no impact on temperature reduction. The usage of nanofluid moves more power from the solar cells to the outside which improves the performance which lifespan of the solar cells. At the other side, this heat may be used to preheat the water tanks and to heat the interior of the house. Nanofluid is also used in solar thermal systems. Such solar thermal devices, such as flat collectors and solar panels, solar water heaters or desalination plants, operate by collecting solar thermal energy and transmitting absorbed heat to power exchangers by another stream. The heat may be used to power water tanks or houses. To this respect, nanofluid is stronger and more efficient than regular fluids to moving heat from structures to heat exchangers. Through utilizing nanofluid, the measurements of solar thermal systems can be minimized and rendered more effective, thereby raising the initial costs of constructing and sustaining such systems.

8. The application of nanotechnology-based photocatalysts in solar cells

8.1 Nanocatalysts are a new window into improving efficiency

Photocatalysts are typically stable semiconductor oxides creating an electron-hole pair by collecting photons. Such electron holes will interfere with the molecules on the surface of the particles. Photocatalysts are used in solar panels, water purifiers, air pollution, self-cleaning lenses, decomposition of organic compounds, and so on. The strong absorption potential of photocatalysts and their susceptibility to visible and ultraviolet light have increased their spectrum of use. A number of nanophotocatalyst have been used in this respect, such as titanium dioxide, zinc oxide, cadmium sulfide, etc. The biggest issue for photocatalysts is the accumulation of small wavelengths of sunlight [21]. As a consequence, their productivity and usefulness will decline and economic costs will rise. To address the issue and consume longer wavelengths (in the spectrum of visible light wavelengths) by photocatalysts, mix them with one another or use two forms of catalysts concurrently. For example, the application of silver nanoparticles to titanium oxide is the role of the titanium oxide photocatalyst in the absorption of wavelengths.

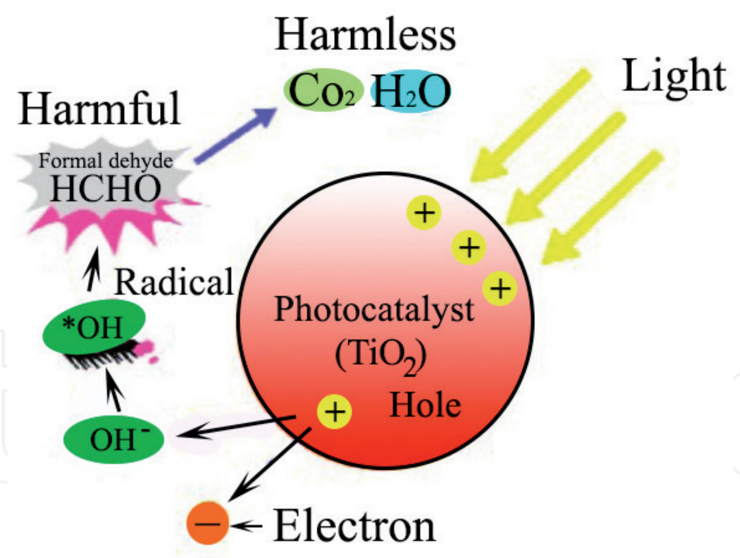

Figure 9.
Self-cleaning process in nanophotocatalysts [22].

This has greatly expanded the size from 400 to 450 nm. Considering the fact that photocatalysts absorb specific light spectra, their usage in solar cells improves the absorption of light within the cell and therefore enhances the performance of the solar cell. Often, most nanophotocatalysts have self-cleaning, anti-steam and anti-dust properties as showed in **Figure 9**, and utilizing them outside and in the body of solar cells provides an atmosphere free of air pollutants and obstacles to light in the cell and improves the absorption of sunlight and cell performance. Another function of nanophotocatalysts in solar cells, in addition to raising the spectrum of absorption and guiding it to visible light, is to enhance and increase the transition of electrons to the electrodes, thereby growing the resistance inside the cells [23]. In this situation, the recombination of the electrons with the cavities decreases and the electrical current produced rises and the energy transfer capacity improves.

9. Self-cleaning and anti-reflective nanocoatings, protect and increase efficiency

Environmental factors such as the absorption of light from the cell-solar surface, rainy weather and the barriers produced by the movement of light, such as sedimentary deposits on the surface of solar cells, are one of the factors that limit the performance of solar cells [24]. Advances in technology and the creation of nanometer layers with fascinating self-cleaning and anti-reflective properties improve the generation of solar power to address this issue. Titanium oxide nanoparticles, which can trap organic compounds, such as hydrocarbons, through blocking the ultraviolet wavelength of sunlight, may hold solar cell surfaces clear through reducing fossil fuel emissions and keeping them from being dirty (**Figure 10**).

In this way, the sunlight enters the cell surface and the reaction will be more effective and the development of electrons and cavities will begin to be more productive. In fact, utilizing nanotechnology, the hydrophilic and hydrophobic characteristics of the glass surface may be modified in such a manner that the water does not appear to damp the surface and that the sedimentary effects of the salts in the water stay on the glass surface [5]. As the amount of electron-hole output in the semiconductor cells is proportional to the strength of the sunlight, the elimination of the reflecting part of the sunlight by the protective glass of the solar cell surface and its transition to the semiconductor surface is one of the ways to increase

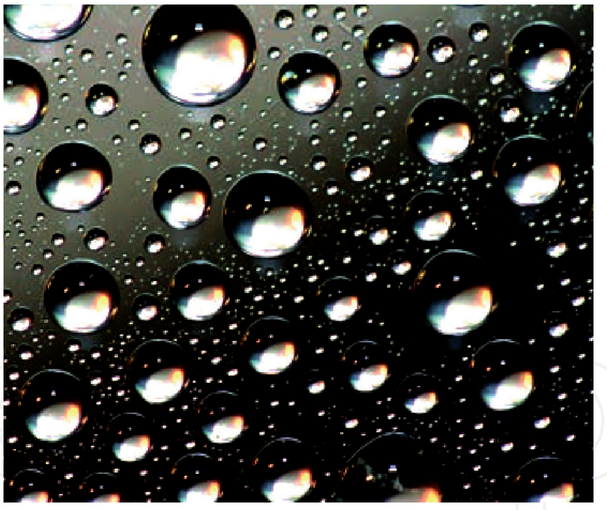

Figure 10.
Self-cleaning and anti-reflective nanocoatings [7].

capacity. Throughout this respect, anti-reflective nanocoatings composed of nanostructures such as nanocraft made of Polydimethylsiloxane (PDMS) or silica nanometer pores made of titanium oxide nanoparticles have been mentioned. Given that all of these nanocoatings are only in the laboratory phases of growth, increasing the performance of solar cells would render them desirable for commercialization.

10. Application of nanotechnology in power storage systems

Some of the issues with solar power generation systems are volatility and intermittent development. Power production in such systems relies on environmental factors such as atmospheric patterns, temperature, sunshine hours, so on. For this reason, continuous and consistent output in such processes is not feasible [25]. The existence of a storage unit, such as a pump, is also required in order to adjust the power supply at the moment.

Disable the intake. Ordinary batteries have a heavy weight, capacity and poor performance, so they can be expensive for the user to fix so remove. Lithium batteries are of concern in the latest wave of batteries [24]. Nanotechnology is also commonly used in this field. The most significant distinction between traditional cells and lithium batteries is the usage of organic solvents as an electrolyte solution instead of gas. In the case of lithium batteries, the lithium-ion battery creates an electrical connection between the two electrodes which, in the case of the two electrodes, transfers electrons through charging which unloading. The electrolytes used in LiPF6-based lithium batteries are primarily lithium alkyl carbonate, lithium alkoxide and other salt elements such as lithium fluoride. Some of the key issues of liquid electrolytes are the strong electrical resistance owing to the use of organic solvents. Nanomaterials are used to boost the efficiency of the electrolyte. Adding powders, particularly in the form of nanoparticles, from compounds such as aluminum oxide, silicone oxide and zirconium oxide to non-aqueous electrolytes, can increase conductivity by up to 6-fold. Extensive work has contributed to the production of solid polymer electrolytes rather than liquid first generation lithium batteries. Reducing the possibility of electrolyte contamination, growing fire tolerance and thus growing protection are properties of polymer electrolytes [26]. **Figure 11** indicates charge and discharge of a model lithium battery when connected to Photovoltaic Systems.

A great deal of concern is given to strong polymer with a polyethylene oxide foundation in the conductors of lithium ion conductors. Low price, strong chemical consistency and high protection are the hallmarks of these polymers, but the conduction of these polymers to lithium happens only at temperatures above 70° and the process of conduction in these polymers is primarily attributed to the movement of anions and the small volume of lithium transported by these polymers, which reduces the strength of the lithium-ion batteries [27]. Adding ceramic filler nanoparticles such as titanium oxide, aluminum oxide and silicone oxide to the polymer matrix polymer matrix dramatically removes this issue. Furthermore, the presence of nanoparticles inhibits the crystallization of recycled polymer chains at 70°C, which stabilizes the amorphous process at lower temperatures and improves the ion conductivity. A great deal of research has recently been conducted on crystalline oxide polymer polymers with SbLiX (where x = As, P) suggesting that such polymers contribute to lithium ions. In such polymers, the polyethylene oxide tube, in the shape of a pipe, enables the movement of lithium ions. **Figure 11** shows the formation of nanometer channels in the polymer structure which shape the lithium-ion transmission pathway (**Figure 12**).

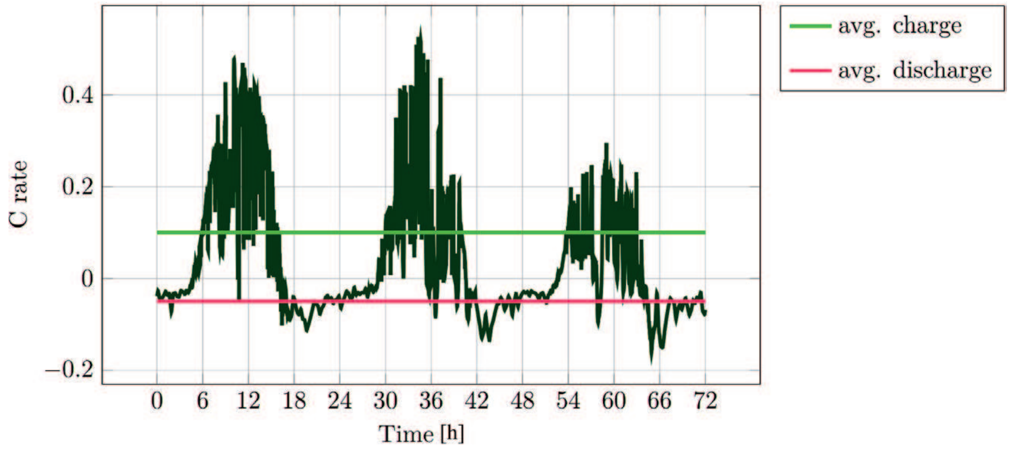

Figure 11.
One day charge and discharge of lithium batteries [26].

Figure 12.
The bank of batteries [5].

11. Conclusion

In sum, it can be seen that while the usage of nanotechnology in the construction and enhancement of solar cell efficiency is currently in the research process, it can be assumed that the transition period to the commercial arena for this field

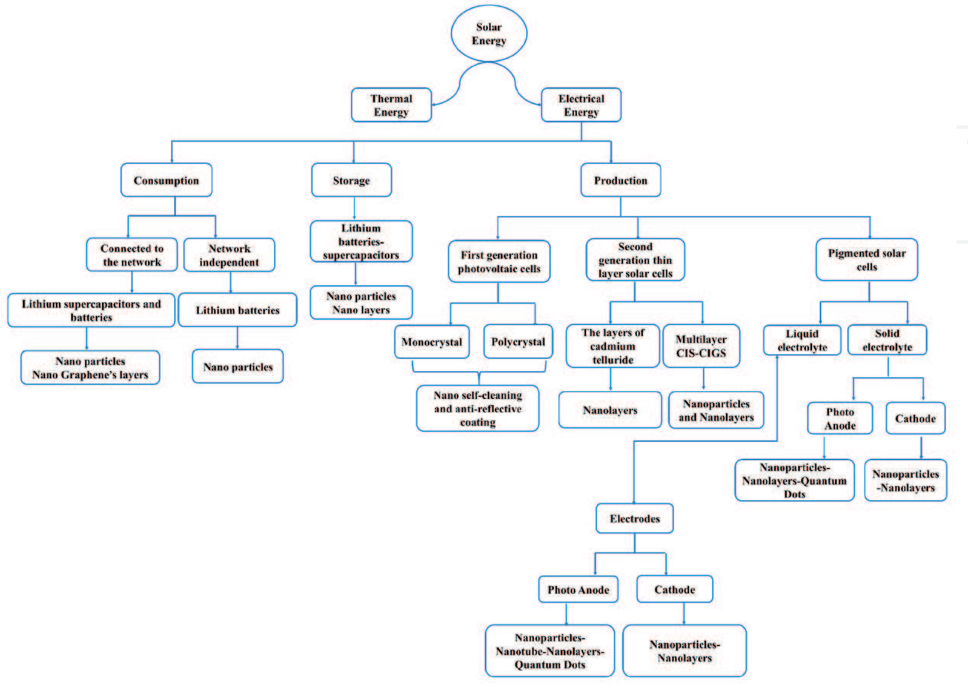

Figure 13.
The applications of nanotechnology in solar energy systems [7].

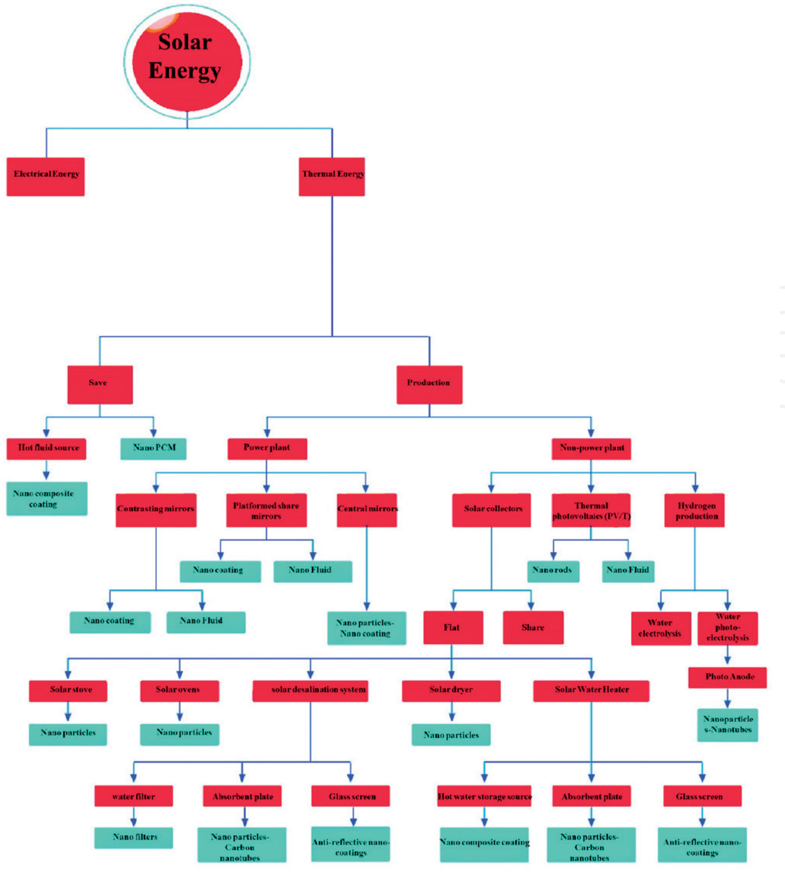

Figure 14.
Nanotechnology and solar energy tree guidance [7].

would be very near and inevitable. Seeing the tremendous promise that this sector has demonstrated in enhancing the efficiency of solar cells, the commercialization of this technology can be viewed as a major turning point in the solar cell industry. **Figures 13** and **14** show the summery of application of nanotechnology in solar technology.

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