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REVIEW ARTICLE

Using of Nanotechnology for Photovoltaic Solar Energy Systems

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HIGHLIGHTS

> Nanomaterials used in photovoltaic cells are discussed.

> Increasing the efficiency of photovoltaic cells has a very important effect on reducing carbon emissions.

> The development and use of photovoltaic cells producing electrical energy from the sun and the effect of nanomaterials were investigated.

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ABSTRACT

It is very important to obtain energy from renewable energy sources at this time when energy consumption is increasing rapidly and environmental pollution has reached significant dimensions. Solar energy is one of these sources. Recently used photovoltaic systems are very important in the supply of electrical energy. The low efficiency of photovoltaic panels used to generate electricity is one of the most important disadvantages of these systems. The efficiency of photovoltaic cells is greatly affected by both the materials used to convert the incoming solar energy into electrical energy and the surface pollution. The use of nanomaterials has recently increased considerably to increase efficiency. Studies are carried out on self-cleaning materials in order to reduce the reflection of incoming rays and to ensure that the energy is selectively absorbed by the surface and prevent surface pollution. Nanotechnology makes very important contributions to the design and production of thin-film PV cells. PV cells developed using nanomaterials will continue to reduce the cost of commercial solar cells using cheaper raw materials. Nanomaterials have some desirable properties such as high catalytic activity, better stability in aqueous media, relatively easier preparation techniques, and material economy. In this study, information is given about nanomaterials used in photovoltaic cells and efficiency-enhancing studies in PV technology.

1. Introduction

The rapid increase in the world population and the rapid development of the industry are increasing the need for energy. Fossil fuels are generally used to meet the world's energy needs. Consumption of fossil fuels both causes the depletion of these limited resources and increases environmental pollution due to harmful gas emissions to the environment. Fossil fuels cause an increase in the temperature of the earth's atmosphere and climate change due to greenhouse gas emissions.

Due to the rapid increase in the world's atmospheric temperature, the Paris Agreement [1], which was accepted with the approval of 195 countries at the United Nations Framework Convention on Climate Change Conference of Parties in December 2015, is a historical turning point in terms of fighting against climate change on a global scale. The long-term temperature target of the Paris Agreement, to which our country is also a party, is to limit the global average temperature increase to 2 °C above pre-industrial levels and even to strive for 1.5 °C. It is assumed that limiting the temperature increase to 1.5 °C will significantly reduce the risks and impacts of climate change. To achieve this, it is aimed to reduce emissions as soon as possible and to balance greenhouse gases. This agreement guides the whole world in the transition to renewable energy on a global scale [2]. Fossil fuel consumption causes countries to be dependent on foreign sources. In addition, the rapid depletion of fossil fuels, the increase in harmful emissions in the atmosphere, the introduction of a low carbon economy by developed countries have started to cause all countries in the world to limit fossil fuel consumption. Renewable energy sources, whose investment costs are significantly reduced in order to limit fossil fuel consumption, are the most important alternative energy sources [3].

Our country has a high solar energy potential due to its geographical location. According to the Turkey Solar Energy Potential Atlas (GEPA) [4], the average annual total sunshine duration is 2741.07 hours, and the average annual total radiation value is 1527.46 kWh/m^2. As of the end of 2020, solar energy-based electricity installed power is 6,667 MW, and its share in total electricity generation is 3.66% [5]. Moreover, as of October 29, 2021, 34% of electricity production in Turkey is obtained from renewable energy. The share of solar energy in this rate is 8% [6].

Photovoltaic panels are the most used product in the conversion of solar energy into electricity. These panels work on a semiconductor basis. The structure of the materials that make up these panels affects the yields. Kalyon PV, one of the PV panel manufacturers in our country, predicts the efficiency rate of the panels, which are processed into advanced technology by processing the silicon mine, as 21.8% [7].

The low efficiency of photovoltaic panels used to generate electricity from the sun in our country and in the world, which has very important values in terms of sunshine duration, causes an increase in the unit cost of energy and a long recovery period for the investments made. For this reason, various studies are carried out in the world to increase the efficiency of PV panels. One of the most studied subjects for this purpose is nanomaterials. In order to understand the contribution of nanomaterials to PV cells, it is necessary to have knowledge about how photovoltaic cells work.

2. Material and method

2.1. Photovoltaic Cells

Photovoltaic cells are structures that convert incoming sunlight into electrical energy, and the development of these cells from the first production to the present can be classified into 3 categories.

First-generation PV cells are divided into three categories as monocrystalline, polycrystalline silicon and Gallium Arsenic cells.

Second-generation PV cells focused on thin- film technologies to reduce the high costs associated with the first generation. Amorphous silicon contains cadmium telluride/cadmium sulfide cells [8].

Third-generation PV cells are dye-sensitive solar cells. By changing the size of nanoparticles in PV cells, the energy band gap of various layers can be made to the desired value. Integrating a high-quality film of silicon nanoparticles into a silicon solar cell increases the conversion efficiency by 50-60% in the ultraviolet range of the spectrum. This results in less material usage and lowers costs. The essential components of a pigmented solar cell are a photoelectrode consisting of a pigment-sensitive film of titanium dioxide (TiO_2). In these cells, when photons come to Dye Sensitive Solar Cells, they are absorbed by the pigment and produce electrons and holes [9]. Electrons in the dye are passed to nanoparticles of TiO_2. Here, TiO_2 nanoparticles serve as carriers. Examples of 3rd generation photovoltaic cells are given in Table 1.

Table 1. Third-generation PV cells are paint-sensitive solar cells.

Technology	Efficiency	Benefits	Limitations
DSSC (Dye-sensitized solar cell)	5-20%	Low cost. Operate in low light and wider angle, work at lower internal temperature condition, robustness and long life	Temperature stability issues, toxic and volatile compound
QDS (quantum dot cell)	11-17%	Low production cost, low power consumption	Highly toxic in nature. Degradation
OPSC (Organic and polymeric solar cell)	9-11%	Low processing cost, light weight, flexible, thermally stable	Low efficiency
PVSC (Perovskite cell)	21%	Cheap and simple construction, light weight, flexible, high efficiency, low production cost	Unstable
MJ (Multi junction cell)	36%	High efficiency	Complex, costly

Last generation PV cells are flexible and cost-effective. These cells consist of organic-based nanomaterials such as carbon nanotubes, graphene, and derivatives of metallic nanoparticles and new inorganic nanostructures such as metal oxides. The carbon used here, its nanoparticles, and allotrope forms such as fullerenes, carbon nanotubes, and graphene have been used as energy materials in many different fields due to their extraordinary mechanical, chemical, electrical and thermal properties. In addition, its light-weight, flexibility, printable inks, low temperature, and ambient pressure manufacturing facilities provide a significant reduction in production costs. Organic solar cell devices based on carbon nanostructures and electrochemical capacitors, also called super capacitors, may enable the production of devices that may be more efficient and cheaper than conventional batteries in the near future [10–12].

2.2. Nanotechnology used in PV cells

Nanoparticles are a modern engineering material consisting of solid particles with sizes typically ranging from 1 to 100 nm. These materials have advanced thermo-physical properties such as viscosity, thermal conductivity, convective heat transfer coefficients, and optical properties. Nanofluids, on the other hand, are the process of obtaining a new heat transfer fluid by adding nanoparticles to heat transfer fluids. Nanofluids are widely used in various applications as a coolant with their improved thermal properties. Each nanoparticle type has unique thermo-physical properties represented by thermal conductivity and thermal diffusivity in addition to viscosity. The thermal values of the most commonly used nanofluids are shown in Table 2 [13]. In Figure 1, the types of nanoparticles are seen [14].

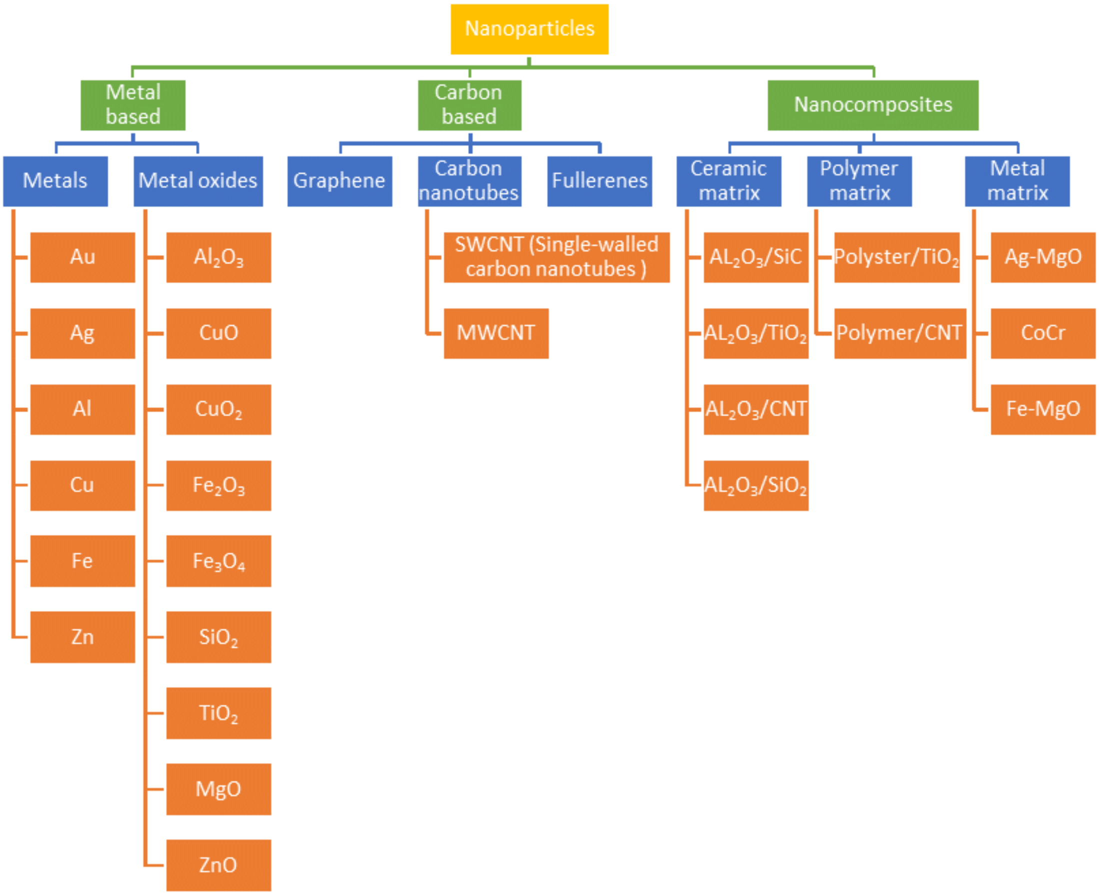

Figure 1. Types of nanoparticles

The use of nanotechnology in PV cells is very diverse. Firstly, nanoparticles are added to solar cells as a superficial layer and used to increase their efficiency and to convert incoming sunlight into electrical energy without being reflected back. Secondly, PV cells are the process of cooling these cells as a solution to the decrease in their efficiency with the increase in air temperature. Many studies are carried out to cool PV cells using nano liquids. The third is the coatings made to prevent the accumulation of dust on the solar panels by using nanoparticles, which causes a significant decrease in inefficiency.

Table 2. Thermal values of commonly used nanoparticles

Solids	$k_{c(p)}$(W/mK)	Liquids	$k_{c(f)}$(W/mK)
Silver	427	Water	0.613
Copper	395	Ethylene glycol	0.253
Aluminum	237	Engine oil	0.145
Carbon nanotubes	3200-3500	Alcohol	0.115
Brass	120	Glycerol	0.285
Nickel	91		
Alumina	39		

2.3. Use of Nanoparticles in PV Cells

Conventional solar cells have two main disadvantages. First, low efficiency is almost inevitable in silicon cells. This is because incoming photons of light must have the right energy, called band-gap energy, to hit an electron. If the photon has less energy than the band-gap energy, then it will pass. If it has more energy than the band-gap, that extra energy will be wasted as heat. These two effects alone constitute the loss of approximately 70% of the radiation energy incident in the cell. The second is the high production cost.

Because nanoparticles are so small, most of the nanoparticle atoms are usually on the surface. This means that the surface interactions nanoparticle property dominates the material behavior and therefore they often have different properties and properties from larger pieces of the same material. Nanostructured layers in thin-film solar cells have three important advantages. First, due to multiple reflections, the effective optical path for absorption is much larger than the actual film thickness. Second, the electrons and holes produced by the light have to travel a much shorter path, thereby greatly reducing recombination losses. As a result, the absorber layer thickness in nanostructured solar cells can be as thin as 150 nm instead of a few micrometers in conventional thin-film solar cells. Third, by varying the size of the nanoparticles, the energy band-gap of the various layers can be made to the desired design value. Being able to use thin films requires much less material and reduces costs. Most such cells use amorphous silicon, which does not have a crystalline structure and consequently has a much lower efficiency (8%), but is much cheaper to manufacture [15].

In conventional solar cells, ultraviolet light is filtered or absorbed by silicon and converted into heat, not electricity. Integrating silicon nanoparticles in 1-nanometer size directly into silicon solar cells increased power performance by 60% in the ultraviolet range of the spectrum. Another potential feature of solar cells is that the nanorods can be 'tuned' to absorb various wavelengths of light. This can significantly improve the efficiency of the solar cell, as more of the incident light can be used on a film made of titanium dioxide nanoparticles, and double-walled carbon nanotubes can be used, doubling the efficiency of converting ultraviolet light into electrons compared to the performance of nanoparticles alone.

Another starting point for increasing the conversion efficiency of solar cells is the use of semiconductor quantum dots (QD). Thanks to the quantum dots, the band gaps can be tuned specifically to convert the longer wave light and thus increase the efficiency of the solar cells. These cells, called quantum dot solar cells, are used in combinations of other materials such as Si/Ge or Si/Be Te/Se.

2.4. Nanofluid Applications in PV Cells

Conventional cooling systems are not sufficient to increase the efficiency of the PV system. Various studies have been carried out with different nanofluids in order to increase the efficiency more and to increase the amount of electrical energy to be obtained. The good heat transfer properties of nanofluids and the use of hybrid systems used for this purpose have become quite common. In the hybrid system, both electricity is produced and the heat obtained is used according to the need for hot water. These hybrid systems not only generate a significant amount of electrical energy but also provide thermal energy. The thermal energy produced by these systems can meet the needs of the building and limit the fuel consumption in the heating system. Thus, nanofluid-based PV thermal systems can significantly reduce emissions of various greenhouse gases such as CO_2, SO_2, CO, NO_x kg/m^2 and particulate matter. For example, the photovoltaic/thermal nanofluid-based collector system is shown in Figure 2 [16].

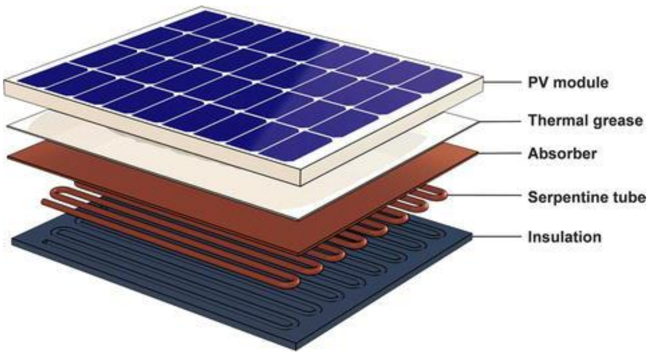

Figure 2. Photovoltaic/Thermal Nanofluid-Based Collector Systems

Many different designs are made in the hybrid system. In general, it is to increase efficiency thanks to the cooling process made with pipes placed under the PV panels. Various studies are carried out by changing the shape, diameter, material, type, and amount of nanofluid passing through the cooling pipes. Different design shapes and purposes are shown in Figure 3. In some studies, studies have been carried out to allow more sunlight to pass through the nanofluid cell to the PV cell.

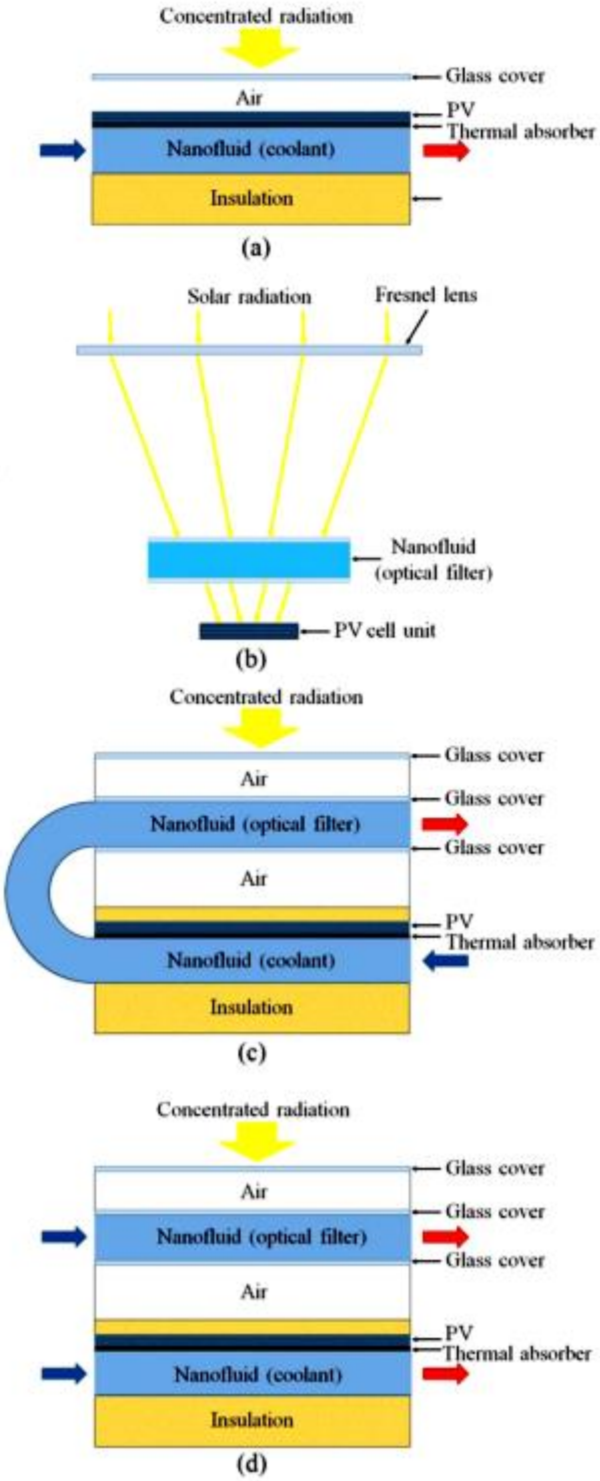

Figure 3. Schematic diagram [17], a) cooling the PV cell with nanofluid [18], b) using nanofluid as an optical filter [19], c) using nanofluid as both optical filter and coolant [20], d) using nanofluid as both optical filter and coolant with separate channels [21].

2.5. Self-cleaning and anti-reflective nano-coatings

One of the most important factors affecting the efficiency of PV cells is rainy weather and sedimentary deposits on the surface of solar cells [22]. Advances in technology and the creation of nanometer layers with self-cleaning and anti-reflective properties are crucial. Titanium oxide nanoparticles, which can trap organic compounds such as hydrocarbons by blocking the ultraviolet wavelengths of sunlight, can keep solar cell surfaces clean by reducing fossil fuel emissions and preventing contamination. In this way, sunlight enters the cell surface, the reaction becomes more effective, and the efficiency increases. Using nanotechnology, the hydrophilic and hydrophobic properties of the glass surface can be altered so that the water does not appear to moisten the surface and the sedimentary effects of the salts in the water remain on the glass surface [23]. Since the amount of electron-hole output in semiconductor cells is proportional to the strength of sunlight, the elimination of the reflective part of sunlight by the protective glass of the solar cell surface and its transition to the semiconductor surface is one of the ways to increase. In this direction, anti-reflective nano-coatings consisting of nanostructures made of silica nanometer pores made of Polydimethylsiloxane (PDMS) or titanium oxide nanoparticles are important.

3. Results and Discussion

The low efficiency of the photovoltaic panels used to generate electricity from the sun in our country and in the world, which has very important values in terms of sunshine duration, causes the energy unit cost to increase and the recovery period of the investments made to belong.

Investigations of PV/T systems with nanofluids are predominantly experimental. Most investigations have used empirical models of thermal conductivity and viscosity that only agree with their own experimental data. Future investigations should extend the developed models to greater data sets and/or develop theoretical models that explain the observed enhancements.

4. Conclusion

Studies have shown that nanomaterials will both increase material efficiency and decrease production costs. For this reason, studies should be continued and increased in order to produce different environmentally friendly, inexpensive, and commercially usable materials and systems.

Compliance with Ethical Standards

There is no conflict of interest to disclose.

Conflict of Interest

The author(s) declares no known competing financial interests or personal relationships.

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