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The Application of Nanomaterials to Increase Solar Cell Efficiency: A Review

Ameen Alwan Mohaimeed

Directorate of Education Babylon, Ministry of Education, Iraq

Ameenalwan87@gmail.com

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Plasma method;
(CVD);
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Abstract

The findings demonstrated that nanoparticles have significant potential for use in improving photovoltaic cell performance, particularly in the area of thin film PV systems. Compared to conventional wafer-based or thin-film systems, nanomaterials of solar cells may offer advantages in terms of cost, innovative charge separation methods, strain relaxation effects, and optical, electrical, and mechanical properties. All findings point to the possibility of successfully enhancing solar cell performance through the use of ultrawide band gap oxide semiconductor nanomaterials. At the TiO2/hole conductor contact, gold and silver nanoparticles (NPs) produce sustained plasmonic photocurrents as well.

Introduction

Nanotechnology is one of the hottest areas of research and development right now, and this is true across the board in the technical sphere [1]. Nanotechnology can be utilised to generate new materials, allowing for the design and construction of new buildings and assets with improved functionality, higher performance, lower maintenance costs, and novel optoelectronic/magnetic material properties [2]. A nanometer measures down to the billionth of a metre (nm). For a material to be considered nanoscale, its smallest component must be between one and one thousand nanometers in size. Nanomaterials study takes a materials science perspective on nanotechnology. These materials often have distinctive qualities because of their size, shape, and chemical composition [3].

Methods like chemical vapour deposition and laser ablation are two (CVD) [4], these nanostructures are produced by using various techniques. The increased surface area of nanoparticles and the

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associated quantum effects set them apart from more traditional materials. Nanomaterials are filled into the nanopores of the templates and, by etching the template, nanowires or nanotubes with similar diameter and length as the template nanopores are obtained. Because the size and shape of the nanomaterial that depends on the nanoholes of the template, fabricating a template with uniform pore diameters is very important.[5]. Solar cells, commonly known as photovoltaic cells, are electronic devices that convert solar radiation directly into usable electricity. The photovoltaic effect can be either natural or manufactured [6]. ZnO NPs and other oxide semiconductors were used to construct the porous electrode, however porous anatase TiO2 nanoparticles (NPs) sheets in a solar cell yield the highest efficiency. In thin films it has been reported that the anatase structure has higher mobility for charge carriers versus the rutile structure. For photocatalytic processes, anatase is the preferred structure, although all three forms have shown to be photocatalytic. The electronic structure of brookite is similar to anatase, based on minor differences in the local crystal environment [7]. ZnO NPs, with a band gap of 3.37 eV and electrical properties similar to TiO2, can be used as an electrode material in solar cells [8].

Solar cells

The use of photovoltaic cells to generate electricity is a hotly debated topic in the context of renewable energy. After O'Regan and Graetze discovered the solar cell, they developed nanocrystalline TiO2 solar cells. High conversion efficiency, low part costs, simple production, and plentiful availability are only a few of solar cells' many benefits. [10]. The solar cell has four main components: a counter electrode, an electrode formed of nanomaterials (like TiO2, SnO2, or ZnO), a transparent conducting oxide substrate (like FTO or ITO), and an electrolyte that acts as a redox mediator [11]. Research was conducted by Kei Muraoshi and others to test the impact of TiO2 nanoparticles on solar cell efficiency, pyrrole was photoelectrochemically polymerized on a porous nanocrystalline TiO2 electrode that had been sensitised by the Gratzel dye [12]. Research comparing ZnO nanoparticle layers produced by two different technical techniques was proposed by Znajdek et al. They looked at how a thin film of zinc oxide (ZnO) nanoparticles may perform in a solar cell. The findings indicated that ZnO nanoparticles could be employed to improve solar cell efficiency, particularly in thin film PV systems, thanks to their promising potential as down converting layers, especially in thin-film PV systems that can be used to improve the efficiency of solar cells [13].

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Working methods

1. Some of the chemical methods

a. Thermal decomposition

Thermolysis, also known as thermal breakdown, is the chemical breakdown brought on by heat. Since this technique is endothermic, energy must be supplied in the form of heat in order to break the chemical bonds in the target substance. If the heat released during decomposition is high enough, the system may enter a runaway thermal state due to a positive feedback loop. In order to create TiO_2 nanoparticles, Chin et al. utilised a tubular electric boiler and TTIP, breaking down the TTIP thermally at different synthesis temperatures (700-1300 °C). The photocatalytic activity of the manufactured TiO2 nanoparticles was determined by measuring the rate at which methylene blue is decomposed in the presence of high temperatures (80-110 °C). The material was characterised with X-ray diffraction (XRD), Brunauer-Emmett-Teller (BET) studies, and transmission electron microscopy (TEM) [14]. Several experimental results suggest that as catalysts, nanometals far outperform their nanosized metal oxide counterparts. When oxygen-containing species are produced during metal breakdown, they can mix with the metal. In comparison to nanoparticles of metal oxide, the catalytic activity of metals is enhanced due to the high temperatures required for their generation [15].

b. Electrochemical synthesis

An electrochemical cell can be used for a process known as electrochemical synthesis. The capacity to carefully regulate the selected voltage and the rejection of potentially wasteful alternative half-reactions are the key advantages of electrochemical synthesis over conventional chemical techniques. Recently, there has been a lot of interest in the electrochemical method of creating nanoparticles. This electrochemical process involved dissolving a metallic anode in an aprotic solution [16]. Electrochemical synthesis allows for the rapid production of nanostructured energy materials with benefits including cheap cost, high purity, simplicity, and environmental friendliness. One may easily produce many different types of nanostructures, such as nanorods, nanowires, nanotubes, nanosheets, dendritic nanostructures, and composite nanostructures [17].

2. Physical techniques

a. Plasma

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Nanoparticles are fabricated using a plasma process. To generate plasma, electric current is passed through radio frequency (RF) heating coils. The first metal is sealed in a pestle inside of an airtight container. High voltage RF coils are wrapped around the hoover chamber, heating the metal until it evaporates. The gas employed in the process, enters into the system and produces a hot plasma in the area around the coils. When metal vapour rises to a cold collecting rod, metal atoms form on the helium gas atoms, and the vapour is collected and passivated by oxygen gas to create nanoparticles [18]. The generation of nanoparticles in ionic liquids by using unrestrained electrodes of constant glow discharge plasmas was studied by Höfft et al. Many different aspects of plasma electrochemistry, including the basics, are covered. One area of research examines how collisions between plasma and ionic liquid affect the development of particles. It has been suggested that plasma, formed from ionic liquids, could provide an explanation for nanoparticle [19].

b. Deposition of chemical vapor

The process of chemical vapour deposition involves a chemical reaction (CVD). Thin films of a wide variety of materials are often created using the CVD method when semiconductors are being produced. An ideal deposit is produced when a volatile precursor or precursors are applied to a substrate and then decay. Precursors are vaporised and then introduced to a deposition of chemical vapour receptacle, where they react with a heated substance at a high temperature. Chemical processes take place or molecules breakdown to create crystals after being adsorbed. The CVD process consists of these three steps:

3. Above the forming surface, reactants are carried by a border layer.
4. A growing thing's surface is the site of many chemical interactions.
5. Phase gas reaction byproducts must be innocuous on the surface.

Heterogeneous nucleation occurs on the substrate, while regular nucleation occurs in the gas phase. By taking use of a chemical reaction that takes place in the gaseous phase, the CVD technique has the potential to create ultrafine particles with a size of less than 1 m. When the process is under control, nanoparticles between 10 and 100 nm in size can be created [20]. To create a durable silica membrane with a good H2/N2 permeance ratio, Nomura et al. used TMOS and O2 as reactants in a counter diffusion chemical vapour deposition method at 873 K (above 1000). By introducing TMOS and O2 into the substrates' opposing geometries, a silica layer was formed within the substrate pores. As the deposition temperatures rise, the apparent activation energies across the silica membranes rise too. The

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activation energy for H2 to pass through the membrane was around 20 kJ mol-1. Pa1 H2 permeance measurements at 873 K were 1.5 107 mol m2 s1. Under normal methane steam-reforming circumstances, the H2/N2 permeance ratio was stable for 21 hours [21].

3. Benefits of nanomaterial in solar cell

The last decade has seen a rise in the number of scientists and engineers interested in studying solar cells and nanomaterials. Solar cells made from nanmaterials may provide several benefits over traditional wafer-based or thin-film systems, including lower production costs, novel charge separation methods, strain relaxation effects, and improved optical, electrical, and mechanical characteristics. Nonetheless, there are situations in which planar solar cells do better than their axially connected or randomly arranged counterparts [22]. Dong and his associates looked into the interfacial charge dynamics controlled by producing a Ga2O3/SnO2 electron-transporting bilayer, with Ga2O3 inserted between fluorine-doped tin oxide and SnO2 NPs. This research suggests that the ultrawide band gap oxide semiconductor Ga2O3 might be used as a nanomaterial to boost solar cell efficiency [23]. Recent research has shown that the plasmonic properties of metallic nanoparticles can considerably boost the performance of solar cells because plasmonic nanoparticles can only be applied to a fraction of the surface area of solar systems (typically less than 30%). Increasing the Jsc of textured screen-printed solar cells by more than 2.5% through the use of plasmonic light-trapping is challenging. To go above and beyond the Jsc enhancement limit, a novel approach is needed to account for the parasitic absorption by the nanostructure [24]. Research was carried out by Reineck et al. to show that gold and silver nanoparticles (NPs) create persistent plasmonic photocurrents at the TiO2/hole conductor interface. The spectral photocurrent response closely follows the bands of surface plasmon absorption by the metal particles. Here, we present a straightforward method of using nanoparticle self-assembly in solar cell production [25].

4. Nanomaterials

Substances having dimensions of 100 nm or less, at least one unique attribute that distinguishes them from bulk materials, and the potential to be used in a wide variety of applications, including nanoelectronics, are considered nanomaterials. Form, composition, and X, Y, and Z dimensions are only some of the ways according which nanomaterials may be sorted [26]. At least one of a material's dimensions must be on the nanoscale for it to be considered a nanomaterial. Quantum dots (or 0D), 1D and 2D (nanotube, nanowire, and nanorod), 2D (nanofilm), and 3D (such as bulk materials composited

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with nanoparticles) are the most common dimensions used to categorise nanomaterials [27]. Single-wall nanotube (SWNT) or two-or-more termed multi-wall tubes multi-wall nanotube (MWNT) are the most common types of nanotubes, with one end open and the other closed in the shape of a hemisphere due to the possibility of individual atoms composing the tube's wall (MWNT). The tubes that make up the nanowire range in size from less than one nanometer to 100 nanometers in diameter and up to 100 micrometres in length, making them 50,000 times thinner than the width of a human hair. Nanotubes may be found in many different configurations, such as the straight, spiral, zigzag, bamboo, and conical tube. These tubes exhibit exceptional properties, like as strength, hardness, and electrical conductivity [28].

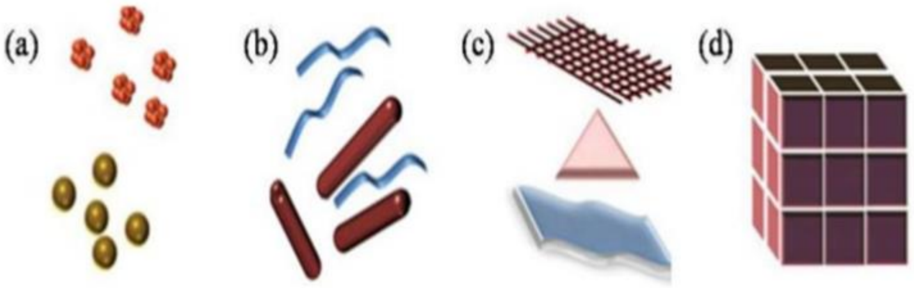

Figure 1 : Siegeli's definition of nanomaterials [29].

a.0D b.1D c.2D d.3D

A very high surface-to-volume ratio is required of nanoparticles. As a result of this unique quality of nanomaterials, novel quantum mechanical phenomena may emerge [29]. As was previously noted, nanomaterials may be sorted into distinct classes according to their chemical composition and shape (dimensionality) [27]. Finally, nanotechnology is one of the most important technologies of the present and future. Physicists, chemists, biologists, and engineers alike see this cutting-edge technology as a crucial research area because of its potential to revolutionise their respective disciplines and bring about positive change for all of mankind [30].

Conclusion

The use of nanomaterials in solar cell technology is only one example. Increasing the Jsc of textured screen-printed solar cells by more than 2.5% through the use of plasmonic light-trapping is challenging.

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When trying to beat the Jsc enhancement limit, a novel approach that takes into account the nanostructure's parasitic absorption is required. Solar cells may also benefit greatly from the incorporation of ultrawide band gap oxide semiconductor nanoparticles.

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