Utilization of Metal Based Nanomaterials in DSSC: A Review

MD. Golam Sazid
Nano Research Centre

Shehab Ahamed Chowdhury Mitul
Bangladesh Army University of Engineering and Technology

https://doi.org/10.5109/7158003

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 9, pp.368-375, 2023-10-19. 九州大学大学院総合理工学府
バージョン：

Utilization of Metal Based Nanomaterials in DSSC: A Review

MD. Golam Sazid[1*], Shehab Ahamed Chowdhury Mitul[2]
[1] Nano Research Centre, Sylhet, Bangladesh
[2] Bangladesh Army University of Engineering and Technology
*Corresponding author email: mdgolamsazid@gmail.com

Abstract: *Renewable energy are now one of the most concerned topics in the world now. Photovoltaic cells are a crucial technology for harnessing this abundant resource and are poised to play a pivotal role in future sustainable energy system. Dye-sensitized solar cells (DSSCs) have gained recognition and credibility as a viable alternative to solid-state junction devices for the purpose of converting solar energy into electrical power. DSSCs operate by employing regenerating dyes to adsorb visible light and sensitize nanocrystalline metal oxide layers. The electrodes of DSSCs can be modified by various nanoparticles. This modification has shown increased efficiency. Adding several nanoparticles has shown higher* power conversion efficiency (PCE). *Many other nanoparticles can be used to modify DSSCs for increased efficiency and enhanced light harvesting capabilities. In this review article we will discuss about the Utilization of metal-based nanomaterials in DSSC.*

Keywords: DSSC; PCE; Higher efficiency; Conversion efficiency.

1. INTRODUCTION

Day to day Humans' activity depends upon nonrenewable energy all over the century. Huge energy is required as population of the world significantly increases [1]. Currently the world energy consumption rate is ten thousand times less compared to sun. This enormous resource can be put to use by a device named photovoltaic cell which will play a significant role in renewable energy systems in future. Because of having durability and stability solid state junction devices based on silicon control over photovoltaic solar energy converters. But it is a matter of fact that these amorphous or crystalline silicon based solar cells are expensive because of fabrication and designing cost [2]. DSSCs are a kind of photovoltaic cell poses some excellent properties such as easy preparation procedure, eco-friendliness, better performance under diffuse light conditions, good power conversion efficiency, colorful natures etc. As a result, this device appears to scientists as a promising technology which is low in cost since their discovery in 1991. DSSCs work by attaching regenerating dyes to nanocrystalline metal oxide sheets to make them sensitive to visible light. Power conversion efficiency of DSSCs is significantly affected by type of dye which is used in DSSCs [3]. Counter electrode, photoanode, electrolyte, semiconductor oxide layer and photosensitizer are basic compounds a DSSC consist of [4]. One of the feasible candidates for cost friendly counter electrode (CE) in DSSCs is the composite of iron carbide and Nitrogen-doped carbon [5]. In a study, the electrodes of DSSCs were subjected to modification by nanomaterials. Nanomaterials can be utilized in several sectors such as cosmetics [6], water treatment [7], food industry [8], clean environment [9], electrical sector [10], antimicrobial treatment [11], DSSCs [12] etc. After modification by nanomaterials, the DSSCs exhibit improved efficiency. The addition of a TiO_2/Ag NF layer on the photoelectrode of the DSSC resulted in a 28% increase in the photovoltaic conversion efficiency, as compared to the DSSC without the modification [13]. In another work scientists successfully synthesized Ti-doped ZnO NPs with a mesoporous structure by a simple synthetic method. This synthesized NPs used as photoanode in DSSCS and showed outstanding results. The use of Ti-decorated ZnO NPs as photoanode in DSSC enhanced the light harvesting capabilities and the highest efficiency obtained by these devices is 5.56% [14]. In this study we will discuss about the importance of nanomaterials in the case of DSSCs.

2. PROPERTIES OF DSSCs

In the field of solar energy conversion to electrical energy, DSSCs are recognized as a reputable alternative to solid-state junction devices [15]. The use of ruthenium complex dyes and electrolytes based on organic solvents on DSSCs has been found to possess some characteristics that are harmful for both humans and the environment. Organic dyes are found to be toxic and carcinogenic, and the generation of hazardous pollutants during their synthesis is a concern that needs to be addressed. In order to promote environmental sustainability, it is imperative to seek out alternative options for organic dyes and Ru-complex dyes. These alternatives should prioritize eco-friendly characteristics, such as the utilization of natural dyes and aquas electrolyte, among others. Anthocyanin, chlorophyll, carotenoid, beta lain, lawsone, curcumin, and indigo are examples of natural dyes that have the potential to serve as substitutes for hazardous organic dyes [16]. In a study, scholars have successfully created a unique eco-friendly adjustable quasi-solid DSSC which is based on mesh of stainless steel. In this cell they used electrospun ZnO nanofibers web as the photoelectrode as photoelectrode and chlorophyll used as photosensitizer. The utilization of environmentally friendly DSSCs has the potential to greatly expand opportunities for efficient solar energy capture in both commercial and rural settings [12] The fabrication procedures that are available for DSSCs are very straightforward, and the cost of DSSCs is very reasonable in comparison with solar cells that are based on silicon. The weight of DSSCs is low, and they can be fabricated to achieve different sizes, shapes, colors, appearances, and levels of transparency. These are effective in hazy lighting situations like dawn, overcast weather, and dusk. These may be embedded in a variety of goods to convert, gather, and store energy [4]. Mainly for modification of the CE in DSSCs results in reduced costs [17]. Through the use of a simple cyclic voltammetry approach, researchers create a Pt-Ni composite CE that is binary in nature. This led to a decrease in the expenses associated with DSSCs [18]. DSSCs have higher efficiency than traditional solar cells. Due to the incorporation of a redox mediator, DSCSs have demonstrated the ability to attain efficiencies exceeding 14%. The efficiency of perovskite solar cells is similar to this level [19]. DSSCs that are highly efficient have been developed by employing a distinctive gel polymer electrolyte that is composed of RbI salt, which is binary in nature, and tetrahexylammonium iodide (Hex_4NI). These are connected with a TiO_2 photoanode, which is multi-layered. The DSSCs in question have been acquired through the utilization of multi-layered TiO_2 photoelectrodes. The DSSCs exhibit a maximum overall efficiency of 7.5% [20].

3. METAL BASED NANOMATERIALS FOR DSSC

The two functional electrodes of plasmonic DSSCs were manipulated by researchers to create a cheap and effective solar electronic device. Using a simple one-step wet synthesis technique, reduced graphene oxide (rGO/Fe_3O_4) nanocomposite coated with copper-doped titania (Cu/TiO_2) nanocomposite and hybrid magnetite nanoparticles is produced. The Cu/TiO_2 nanocomposite utilized as photoanode and shows a power conversion efficiency of 3.89%. Here rGO/Fe_3O_4 nanocomposites were used to fabricate the Pt free low CE which shows power conversion efficiency (PCE) of 2.20% [21]. It has been shown that aggregation of ZnO nanocrystallites is an efficient way to cause light scattering inside the layer of photoelectrodes in DSSCs. The photoelectrode film constructed of polydisperse ZnO aggregates of nanocrystallites has a maximum PCE of 5.4% [22]. In another work, researchers used dual-layer photoanodes made of TiO_2 hollow fibers (HFs) doped with zinc and NPs of TiO_2 to build DSSCs. Conventional DSSC typically comprise single-layer photoanodes, which demonstrate comparatively modest efficiency levels. Specifically, TiO_2 NP-based DSSCs achieve an efficiency of 1.293%. DSSCs incorporating Zn-doped TiO_2 HF exhibit an efficiency of 0.89% [23]. Novel DSSC utilizing TiO_2 nanotubes has been fabricated and it exhibit a noteworthy level of efficiency, achieving a conversion rate of electricity at 6.97% [24]. The fundamental issue limiting DSSC, PCE is poor absorption for IR and near-IR light. Using the proper dye to increase the sunlight capturing range is one easy approach to increase the efficiency of DSSCs, however this sort of dye is always expensive and has a lack of stability. Upconversion composite nanofibers (UCNFs) with a double-shell made of CeO_2:Yb,Er@SiO_2@Ag were developed and created. With the help of a SiO2 coating and NPs of Ag CeO_2:Yb,Er@SiO_2@Ag UCNFs, they exhibit outstanding up conversion fluorescence capability. When used in DSSCs, CeO_2:Yb,Er@SiO_2@Ag UCNFs produce a PCE of up to 8.17% [25]. The addition of SnO_2/CeO_2:Yb,Er nanoparticles as a supporting layer in DSSCs has been found to significantly enhance the PCE to 8.66% [26]. DSSC photoanodes are constructed using a mesoporous framework composed of TiO_2 nanoparticles. These nanoparticles act as a substrate for the molecules of dye to absorb, which makes it easier to harvest light. Nevertheless, the presence of TiO_2 NPs leads to a dramatically decreases in the amount of incoming light, primarily caused by transmission of light through the photoanode. There is a need for high-performance photoanodes in DSSCs that can enhance light absorption and broaden the range of light intake, thereby enhancing the efficiency of conventional DSSC setups. The addition of a scattering layer to the exterior of the mesoporous $_{TiO2}$ film is one effective way to increase the photoanode's ability to absorb light. $CeO_2:Eu^{3+}$ nanocrystals which are octahedral can exhibit a relatively large size, falling within the range of 300-400 nm. Cerium oxide doped with europium ions ($CeO_2:Eu^{3+}$) exhibits characteristics of both light scattering and down conversion luminescence. In the DSSC device, a layer of $CeO_2:Eu^{3+}$ was incorporated into the TiO_2 layer of the photoanode. A considerable enhancement in PCE was observed in devices incorporating $CeO_2:Eu^{3+}$ nanocrystals, achieving an effectiveness of 8.36%. This represents a 14% increase when compared to conventional DSSCs utilizing TiO_2 nanoparticles [27].

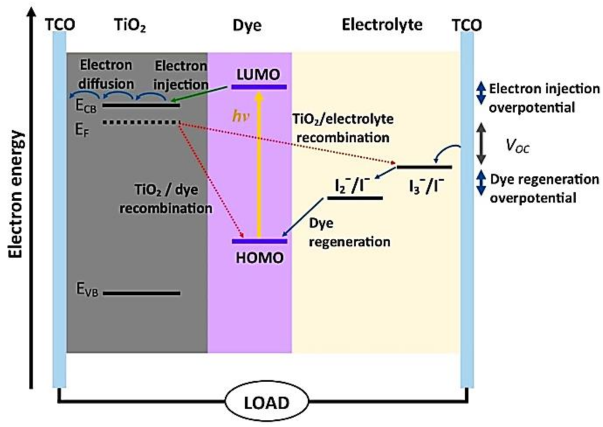

Fig 1. Schematic energy diagram and working mechanism of a DSSC [28].

Another novel DSSC was fabricated through the modification of its photoanode using a SnO_2-TiO_2 nanocomposite, and cost-effective platinum (Pt)-free hybrid Fe_3O_4@rGO nanocomposite was used as CE. When employing the hybrid Fe_3O_4@rGO as the CE, the PCE was measured as 1.96%. The increased effectiveness is due to the improved transfer of charges and increased dye-loading,which is facilitated by the synthesis of a broad band spacing SnO_2-TiO_2 nanocomposite. The homogeneous distribution of Fe_3O_4 NPs attached at reduced graphene oxide (rGO) nanosheets contributes to this improved efficiency [29]. In a study, the photoanode materials used in DSSCs were consisted of nanocomposites of graphene flakes (FLG) and oxides of metal (TiO_2, ZnO, CdO, SnO_2 CuO, and CeO_2). The photoanodes composed of FLG/SnO_2, FLG/CdO, FLG/ZnO, FLG/TiO_2, FLG/CeO_2, FLG/CuO, demonstrate PCE of 2.98, 1.79, 4.20, 2.71, 2.91, and 2.76, respectively [30]. The functionality of DSSCs is substantially impacted by the effectiveness of electron flow at the TiO_2-dye-electrolyte junction. The conventional working electrode (WE) arrangement using titanium dioxide NPs was changed to one using titanium dioxide nanotubes with the goal to increase the rate of charge transmission. The X-ray photoelectron spectroscopy (XPS) and photoluminescence (PL) analysis provided confirmation of a higher concentration of surface oxygen for TiO_2 NPs compared to titanium dioxide nanotubes TiO2 NTs. This suggests that the morphology of the nanotubes-based photoelectrode is more appealing for application in DSSCs due to a lower concentration of surface defects. The results indicated that the efficiency of DSSCs utilizing TiO_2 nanotubes were 10-15% greater compared to DSSCs employing TiO_2 NPs. Researchers improved the photo electrode built on Nb-doped TiO_2 nanotubes. As the photo-electrode material, Nb-doped TiO_2 nanotubes enable the creation of DSSCs with a productivity of 8.1%. This efficiency beats the one attained by a cell using TiO_2 NPs as the photo-electrode material by 35% [31]. Researchers have developed a method for synthesizing Nb-doped TiO_2 NPs in a scalable manner. This involves mixing TiO_2 paste with functionalized Nb_2O_5. The purpose of this synthesis is to create photoanodes for use in DSSCs. The DSSCs utilizing N-doped TiO_2 electrode demonstrate a notable increase in photoconversion efficiency of 8.44% [32].

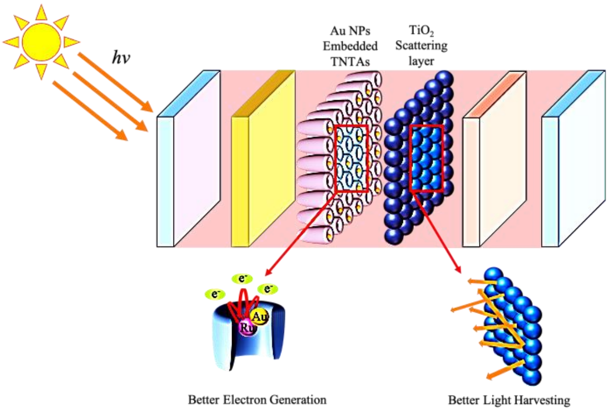

Fig 2. Increased electron generation and improved light harvesting ability of DSSCs based on the freestanding TiO_2 nanotube arrays (TNTA) with Au NPs [33].

The large surface area of the NPs makes it possible to load more dye onto them in order to increase the effectiveness of light absorption in a traditional photoanode that uses a TiO_2 NPs mesoporous film on a transparent conductive oxide (TCO) glass surface. Elevated scattering and recombination events are caused by the photoelectrons' stochastic irregular motion inside the disorganized NP structure, which is introduced into the TiO_2 material. As a result, the total effectiveness of electron collecting is reduced. For better DSSC performance, researchers want to incorporate TiO_2 NPs into titanium dioxide nanotubes. The fabricated DSSCs demonstrate enhanced overall photon conversion efficiencies of 152%, 107%, and 49% for nanotubes with lengths of 8, 13, and 20 μm, respectively. The efficiency of 8 μm long nanotubes after two cycles is measured to be 4.08% [34]. A DSSC have been manufactured using composites composed of TiO_2-B nanobelts (NB) and TiO_2 NPs. As the concentration of TiO_2-B NB got higher, the amount of adsorption of dye reduced. Until the quantity of TiO_2-B NB reached 2 weight percent, the rate of surface electron transmission was enhanced. The speed of surface electron transport then slowed down. These DSSCs' effectiveness ranged from 1.38% to 6.96% [35]. SiO_2/TiO_2 core/shell nanoparticles (STCS-NPs) with sizes of 110 nm, 240 nm, and 530 nm have been utilized in DSSCs. Diffuse reflection spectroscopy (DRS) was then used to analyze the dispersion characteristics of these STCS-NPs. The study found that the efficiency of the DSSC using STCS-NPs was 7.83%, whereas the efficiency of the DSSC employing TiO_2-NPs was 7.38%. According to the study's results, the PCE of the DSSC with STCS-NPs showed a 6% improvement over the TiO_2-NP-equipped device. The improved backscattering brought on by the altered light path in the core/shell structure may be responsible for this improvement. [36]. Radio frequency (RF) magnetron sputtering depositing method was employed to produce the ZnO/TiO_2 core/shell nanorods driven DSSC. In this instance, ZnO/TiO_2 core/shell nanorod photoelectrode's lateral surface is covered with TiO_2 NPs. A larger surface area was produced by the direct development of TiO_2 nanoparticles on the ZnO/TiO_2 nanorod framework, which enhanced the loading of molecules of dye and photon uptake. Consequently, the DSSC's photocurrent was improved as a result of this. The energy boundary that the core/shell structure has produced makes it easier to separate the supplied electrons off redox couples. The dark current reduced and the open-circuit voltage has increased as a consequence of this structural characteristic. The open-circuit voltage and increased photocurrent have considerably boosted solar efficiency. The improvement in open-circuit voltage and photocurrent led to a twofold of energy conversion efficiency, and a 2% gain [37]. The researchers generated nanoparticles of pure TiO_2, as well as TiO_2 nanoparticles doped with Au and Pt, using an extract derived from the bark of T. arjuna. The efficiency of Au-doped TiO_2 nanoparticles is seen to be around 3.44%, which is superior to the efficiencies shown by both pure TiO_2 nanoparticles and Pt-doped TiO_2 nanoparticles. The efficiency of DSSCs based on pure TiO_2 is reported to be 2.79%. Pt doped TiO_2 based DSSCs shows efficiency of 3.14% [38]. DSSCs which have been formed by incorporating TiO_2 nanorods with and without Au NPs were produced and afterwards compared. It was investigated how Au NPs affected the effectiveness of DSSCs. The overall cell effectiveness of the cell containing 1.54 atomic percent of Au NPs had a significant rise of efficiency, rising from 0.31% to 0.94%. This increase represents more than a twofold improvement [39]. A group of researchers created anatase TiO_2 nanoleaves (NLs) using hydrothermal synthesis and created DSSCs utilizing such NLs. Although NLs independently outperform NPs, they have shown that DSSCs produced with a mix of NLs and NPs work much better than cells manufactured with NLs and NPs individually. The NLs-based DSSCs' total PCE has risen by 16% and 24% in comparison with cells created with NPs and P25, respectively. It's interesting to note that cells created with a 50:50 (wt/wt) combination of NLs and NPs have the biggest enhancement in PCE (35%) of any cell type. The efficiency of the DSSCs based on NP, NL, and a combination of NP and NL is 4.8%, 5.6%, and 6.5%, respectively [40]. Researchers looked at the effect of composites made of TiO_2

nanoparticles, TiO_2 nanotubes, and Ag nanoparticles on the effectiveness of DSSCs. The efficiency of the DSSC was found to be 8.04% when using a film composed only of TiO_2 NPs. However, when TiO_2 NPs were combined with nanotubes (NTs), the PCE increased to 8.78%. The increased electron flow made possible by the existence of nanotubes may be the cause of the improvement in efficiency. In comparison to the PCE of DSSCs using NPs of TiO_2, which was measured at 8.04%, a significant enhancement in PCE was achieved with the implementation of composites consisting of TiO_2 NPs and titanium dioxide nanotubes coated with silver. The PCE of these composites was measured at 10.60% [41]. A total of four DSSCs were produced and afterwards enhanced by the use of g-C_3N_4 and ZnO modifications. To create g-C_3N_4 as well as ZnO altered TNT arrays, a new solvothermal method was developed. This method is simple and very effective. The solution of ethylene glycol used in this specific manufacturing technique. Consequently, the PCE of the DSSC based on a combination of ZnO, germanium-doped carbon nitride (ge-C_3N_4), and titanium nitride (TNT) exhibited a significant improvement, increasing from 1.04% to 2.45% when compared to the DSSC solely based on TNT [42]. The fabrication and investigation of a hybrid ZnO nanowire-nanoparticle photoanode for DSSCs have been conducted having the intention of enhancing the PCE. The photoanode hybrid consists of arrays of ZnO nanowires, which facilitate efficient electron transport, and ZnO nanoparticles that are distributed and fill the gaps between the nanowires, resulting in a substantial amount of surface for efficient intake of dyes. The N3-sensitized ZnO composite photoelectrode has produced an outstanding efficiency of 4.2% for the DSSCs. A high open-circuit voltage (Voc) of 613 mV, a short-circuit current density (Jsc) of 15.2 mA/cm^2, and a fill factor (FF) of 46% are present in conjunction with this. These values significantly surpass the respective efficiencies of 1.58% for ZnO nanowire (NW) DSSC [43]. ZnO NPs with a radius of 15 nm were synthesized using the hydrothermal approach. Rehydrothermal treatment was used to create ZnO nanosheets from already present ZnO nanoparticles. Several uses for dye-sensitized solar cells have been documented. With a total efficiency of 1.55%, a fill factor of 0.55, a short-circuit current density of 2.059 mA/cm^2 and an open-circuit voltage of 0.593 V, solar cells built by ZnO nanosheet were able to convert light into energy [44]. A derivative of imidazolium and nanotubes which are single-walled named shortly as SWNTs have been included into plastic and solid-state DSSCs that have been successfully produced. Through a reduction in the series resistance, the incorporation of CNTs can help increase the performance of solar cells. Recently, DSSCs have used CNTs that have been covered with TiO_2. A CNT cell that has been covered with TiO_2 at a weight proportion of 0.1 produces a larger short circuit current intensity in comparison to a typical TiO_2 cell, which results in an improvement in PCE of around 50%. The photoconversion efficiency of a DSSC based on TiO_2 can be increased by a factor of 2 if SWNTs are used as conducting scaffolds in the device. The dispersion of TiO_2 nanoparticles on SWNT layers enhanced both the transit of electrons to the collecting electrode surface and the photoinduced separation of charges. ZnO is a material that can be used in DSSCs instead of TiO_2 in some applications. ZnO shares the same gap in the band (3.2 eV) and band edge position as TiO_2, although having crystallite sizes that are either comparable to or less than that of normal TiO_2. In some DSSCs, ZnO nanowires have been utilized. Nanoparticle films allow for a vast interior surface area to be attached by the molecules of dye and provide diffusion channels to electrons. Nanoparticle films can also be used as a substrate for electronic devices [45]. Polymers cannot be employed as substrates for TiO_2 nanoparticle production since a high-temperature heating is always required, which limits their application. The synthesis of ZnO nanoparticles at low temperatures makes it possible to fabricate DSSCs atop optically transparent polymers. To develop a continual roll-to-roll method for the industrial production of adaptive and light DSSCs, demonstrating the viability of this concept is extremely critical [45]. The investigation of the development of diverse ZnO nanostructures under simple and mild circumstances is based on experimental observations made by a growth process known as nucleation-dissolution-recrystallization. The discoveries provide a few fresh viewpoints on the mechanism behind the synthesis of ZnO nanostructures. The ZnO nanoparticles and nanorods are used as a layer for an n-type photoactive DSSC at the conclusion of the procedure. Despite showing promise in solar cell applications, cadmium selenide and cadmium telluride are dangerous and harmful for the environment. Another semiconducting substance that falls into the II–IV category is zinc selenide. ZnO-based solar cells are excellent prospects for affordable and eco-friendly power conversion technology. As people become more aware of the benefits of green and clean energy, the demand for these cells has increased [46]. It has been shown that the nanorods carrying the N3 dye had a stronger peak for absorption than NPs. The result shows unmistakably that the PCE of the cell may be effectively enhanced by modifying the aspect ratio of the ZnO nanostructures. The following are some of the possible explanations for the growth in. First off, the surface area of the solar cell containing the nanorods rises, and this rise corresponds with the quantity of dye that absorbs on the nanorods. Second, it is anticipated that the Isc will be increased by the rapid electron diffusion that occurs within the single-crystal nanorods. According to published results, electrons were shown to go through the nanorod around 100 times more quickly than they did via the linked ZnO nanoparticles. It must be emphasized that, as of this point in time, has not been optimized in terms of film thickness, dye loading, device architecture, and so on. The extremely acidic nature of the N3 dye with a presence of carboxylic acid binding groups, which caused the disintegration of ZnO, should be noted as one of the potential causes of the overall low efficiency of cells performance of each of the ZnO nanorods and the nanoparticles. High electron delivery efficiency cannot be attained because of the interference brought on by the formation of Zn-dye complex particles [46]. The DSSC that was constructed using ZnO nanoparticles and calcined at 600 degrees Celsius showed the best PCE in comparison with other DSSCs. This occurred as a result of its increased ability to adsorb molecules of dye and decreased recombination percentage [47]. Generally, a DSSC device which is typically made up of a wide band gap semiconductor nanocrystalline porous electrode, which has been applied as a coating on a substrate composed of transparent conducting oxide glass (TCO). This electrode is then modified with dye, an electrolyte solution and a counter electrode that is located between the electrodes. The influence of various attributes of the ZnO material, including the nature and concentration of defect states, on the operational efficiency of a nanostructured ZnO-based dye-sensitized solar cell (DSSC) is a plausible scenario. The temperature of the calcination step in the sol-gel process can have an effect the size and characteristics of the ZnO nanoparticles, which in turn can have an effect on the performance of the ZnO in a DSSC. The temperature at which the calcination was performed had an effect on various factors, including the nanoparticle's size, the area of the surface, the surface flaws, the ability to adsorb dye, and the rate of charge transfer/recombination. These characteristics all carried a significant impact in the performance of DSSC. The surface area of the nanoparticles shrunk as the calcination temperature rose from 500 to 700 degrees Celsius, and an increase in the defects of surface such as oxygen vacancies occurred at the same time. The observed enhancement in dye adsorption can be attributed to the existence of supplementary oxygen vacancies on the surface of the nanoparticles. Hence, it can be observed that the ZnO nanoparticles synthesized at a temperature of 600 °C exhibited a lower surface area compared to those synthesized at 500 °C. However, despite this disparity in surface area, both sets of nanoparticles displayed equivalent dye adsorption capabilities. Consequently, the ZnO-600 photoanode demonstrated a superior dye-coverage, thereby indicating its enhanced performance in dye-sensitized solar cells. This was due to the fact that the ZnO nanoparticles which were prepared at 600 °C were heated to a higher temperature. Because the ZnO-600 photoanode had a better coverage of dye, the recombination rate was reduced as a result. In addition, the findings demonstrated that an elevation in the calcination temperature led to an elevation in the rate of charge transfer. When examining the relative differences between the other photoanodes, the ZnO-600 photoanode had a significantly greater conversion efficiency as a result of all of these variables [47]. Since the pioneering work, Dye-sensitized solar cells (DSSCs) have been widely regarded and extensively studied as viable substitutes to the conventional silicon-based photovoltaic cells. In recent times, there has been a growing interest in the subject matter, primarily driven by the cost-effectiveness and uncomplicated manufacturing techniques associated with it. DSSCs are a novel clean solar-to-electricity conversion and renewable system [48]. In addition, ZnO, which has a flat band potential that is greater than that of TiO_2, is advantageous for increasing the open-circuit photovoltage of the cell. As a consequence of this, porous ZnO films have been receiving an increasing amount of focus in the field of DSSCs. There has been observed a reduction in the quantity of dye that is adsorbed can result in a drop in the amount of light that is harvested, which can then lead to a fall in the Isc value. On the other hand, an increase in the crystallinity of ZnO films can result in a more productively able electron injection, which can then lead to a raise in the level of the Isc value. As a result, the ZnO electrode which is annealed at 400 degrees Celsius yielded the highest Isc value possible due to the combined effects of the parameters discussed above. Because of this, the DSSC that was manufactured using this electrode has the lowest possible Isc value. The observed efficiency of 3.92% demonstrates a significant improvement compared to previously reported values. For instance, the efficiency of ZnO nanocrystalline structures ranged from 1.5% to 2.4%, while ZnO nanowires exhibited efficiencies between 0.5% and 1.5%. Additionally, ZnO aggregate films achieved efficiencies ranging from 2.7% to 3.5%. The findings suggest that optimizing the annealing temperature could be a promising approach to enhance the efficiency of cells. However, it is important to note that the achieved efficiency is still lower compared to the previously reported highest efficiency of 7.2%. One of the causes could be that the current DSSCs have a lower FF and a larger dark current than they did in the past. According to the findings of the experiments, both the surface and bulk traps in the porous electrodes have significant effects on recombination reaction. These effects, as a result, have an effect on the Isc and Voc values of the ZnO-based DSSCs [48]. The cells constructed of a titania (TiO_2) nanoparticulate thin film which is sensitized by a ruthenium polypyridine complex dye (N3 and various derivatives) have achieved the highest levels of performance that have been documented in the scientific literature to this point. The 1D-ZnO arrays provide the potential to overcome the aforementioned shortcomings and unquestionably obtain higher properties of DSSC [49]. DSSCs with ZNPs had an efficiency of 1.80%, DSSCs with ZNRs had an efficiency of 0.90%, and DSSCs with both ZNPs and ZNRs had an efficiency of 2.19%. The performance of the device is severely hindered whenever just ZNRs are employed in the photoanode of the DSSC. The observed surface area of the ZNRs exhibits a notable insufficiency, as a significant portion of approximately forty percent of the film's volume remains unoccupied owing to the presence of slits or gaps amidst the nanorods. Due to the limited surface area of the ZNRs film, only a limited amount of the dye can be adsorbed, which results in a limited amount of JSC for the matching DSSC. Additionally, the electrolyte completely fills the space that would otherwise be empty between the gaps or slits that are present among the ZNRs, which would result in a high rate of recombination occurring within the cell. On the other hand, the DSSC with the hybrid film of ZNRs and ZNPs has better FF (0.52) and VOC (0.60 V) than the cell with just ZNRs in its photoanode (VOC = 0.48 V and FF = 0.45). In this investigation, the greatest results were obtained from the DSSC that utilized a composite film consisting of ZNRs and ZNPs. At all frequencies, the IPCE values of the DSSC with ZNRs/ZNPs were higher than those of the cells with just ZNPs and ZNRs. This suggests that the DSSC with ZNRs/ZNPs has a larger surface area for absorbing dye and can move electrons more quickly. This is because the DSSC with ZNRs/ZNPs have a higher ratio of ZNRs to ZNPs. The photovoltaic properties of the cells are consistent with the laser-induced photo-voltage transients, electrochemical impedance spectra, and IPCE spectra of the DSSCs [49]. The bandgap of the optical characteristics was determined to be 3.55 eV by the use of UV-visible spectroscopy in the research process. This bandgap can be linked to the use of semiconductor materials, which makes them a possible contender for use in solar cell applications. For this reason, researchers manufactured DSSC by using ZnO nanoparticles that were produced using green synthesis. Researchers used the J-V curves to determine DSSC parameters like open-circuit voltage (Voc), short-circuit current density (Jsc), fill factor (FF), and efficiency. For 100 mW/cm^2, the values were 0.65V, 6.26mA, 48.5%, and 1.97%, respectively [50]. To sustain the activities of our modern civilization, there is a significant demand on a global scale for energy that is both clean and renewable. The direct transition of solar energy into electric energy is made possible by the utilization of DSSC, which is the most effective method for meeting the demand for electric energy. The successful fabrication of a dye-sensitized solar cell (DSSC) utilizing zinc oxide (ZnO) nanoparticles as the key component has been achieved. The performance assessment of this DSSC was conducted by analyzing its current density-voltage characteristics under simulated solar irradiation conditions. Because of a considerable elevation in the amount of dye molecules that are absorbed onto the surface of ZnO nanoparticles, the manufactured DSSC is able to operate at a very high efficiency. As a result, the utilization of green produced ZnO nanoparticles in the fabrication of DSSC is a straightforward technology that has a great deal of promise for the well-being of our future [50]. In DSSCs, electron transport is facilitated by nanoparticulate localized minima (lms), which take place as a result of a series of hopping events that take place between the trap states on nearby particles. Recent research has shown that the use of single-crystal and vertical ZnO nanowires (NWs) can increase electron transport in the photoanodes of DSSCs [51]. The ZnO Nano Wires were produced by a hydrothermal batch process that took place at temperatures ranging between 60 and 90 degrees Celsius. Long lengths are required for ZnO NW photoanodes used in DSSCs in order to achieve the desired increase in dye absorption. A multi-batch method is utilized in order to lengthen the ZnO NWs as much as possible [51]. The performance of Sn-doped and undoped ZnO nanoparticles was examined for use as the photoanode of DSSCs. These nanoparticles were manufactured using the hydrothermal process. X-ray diffraction and energy dispersive X-ray spectroscopy both demonstrated that tin atoms had been introduced into the lattice of zinc oxide. It was discovered that doping with tin causes photoluminescence spectra to move to the red end of the spectrum. The experimental results indicate that the efficiency of DSSCs was significantly improved with the introduction of tin (Sn) doping. The photocurrent density-voltage curves obtained from the DSSCs demonstrated a remarkable enhancement in efficiency, reaching up to 140% on a bare fluorine-doped tin oxide (FTO) substrate and 105% on a substrate consisting of a zinc oxide (ZnO) compact layer deposited on FTO. This improvement can be attributed to the incorporation of Sn dopants into the DSSC structure. Also highlighted by both Sn-doped and undoped DSSCs was the impact of the ZnO compact layer on the device's performance [52].

4. CONCLUSION

In conclusion, we have summarized from various research articles about utilizing various nanoparticles in DSSCs. Even the simplest nanoparticle has shown greater efficiency. These nanoparticles can be modified and after modification, it had been seen that the electrodes had become more efficient and had enhanced light harvest capabilities. ZnO based nanomaterials had shown excellent efficiency than other metal based nanomaterials. We would like to conclude by saying that this utilization of metal based nanoparticles in DSSCs has many more aspects. Our research is a mere guide towards the goal.

5. REFERENCES

[1] G.F.C. Mejica, Y. Unpaprom, R. Ramaraj, Fabrication and performance evaluation of dye-sensitized solar cell integrated with natural dye from Strobilanthes cusia under different counter-electrode materials, Appl. Nanosci., 13 (2023) 1073–1083.

[2] S.K. Das, S. Ganguli, H. Kabir, J.I. Khandaker, F. Ahmed, Performance of Natural Dyes in Dye-Sensitized Solar Cell as Photosensitizer, Trans. Electr. Electron. Mater., 21 (2020) 105–116.

[3] N.Y. Amogne, D.W. Ayele, Y.A. Tsigie, Recent advances in anthocyanin dyes extracted from plants for dye sensitized solar cell, Mater. Renew. Sustain. Energy, 9 (2020) 1–16.

[4] S.M. Faraz, M. Mazhar, W. Shah, H. Noor, Z.H. Awan, M.H. Sayyad, Comparative study of impedance spectroscopy and photovoltaic properties of metallic and natural dye based dye sensitized solar cells, Phys. B Condens. Matter, 602 (2021) 412567.

[5] H. Xu, C. Zhang, Z. Wang, S. Pang, X. Zhou, Z. Zhang, G. Cui, Nitrogen-doped carbon and iron carbide nanocomposites as cost-effective counter electrodes of dye-sensitized solar cells, J. Mater. Chem. A, 2 (2014) 4676–4681.

[6] M. Subhan, K. Choudhury, N. Neogi, Advances with Molecular Nanomaterials in Industrial Manufacturing Applications, Nanomanufacturing, 1 (2021) 75–97.

[7] M.A. Subhan, N. Neogi, K.P. Choudhury, Industrial Manufacturing Applications of Zinc Oxide Nanomaterials: A Comprehensive Study, Nanomanufacturing, 2 (2022) 265–291.

[8] Kristi Priya Choudhury, Tahzib Ibrahim Protik, N. Neogi, Sabbir Hossain Nipu, CNT based nanomaterials for food industry: a review, Proc. Int. Exch. Innov. Conf. Eng. Sci., 8 (2022) 68–75.

[9] N. Neogi, Kristi Priya Choudhury, Sabbir Hossain Nipu, Tahzib Ibrahim Protik, Utilization of ZIF based nanomaterials for clean environment purposes, Proc. Int. Exch. Innov. Conf. Eng. Sci., 8 (2022) 323–329.

[10] Sabbir Hossain Nipu, N. Neogi, Kristi Priya Choudhury, Advances with Metal Organic Framework based nanomaterials in 4th industrial revolution, Proc. Int. Exch. Innov. Conf. Eng. Sci., 8 (2022) 161–168.

[11] Kristi Priya Choudhury, N. Neogi, Sabbir Hossain Nipu, Tahzib Ibrahim Protik, A mini overview of miscellaneous uses of TiO_2 based nanomaterials, Proc. Int. Exch. Innov. Conf. Eng. Sci., 8 (2022)

221–227.
[12] V.P. Dinesh, R. Sriram kumar, A. Sukhananazerin, J. Mary Sneha, P. Manoj Kumar, P. Biji, Novel stainless steel based, eco-friendly dye-sensitized solar cells using electrospun porous ZnO nanofibers, Nano-Structures & Nano-Objects, 19 (2019) 100311.
[13] Y.H. Nien, H.H. Chen, H.H. Hsu, M. Rangasamy, G.M. Hu, Z.R. Yong, P.Y. Kuo, J.C. Chou, C.H. Lai, C.C. Ko, J.X. Chang, Study of How Photoelectrodes Modified by TiO2/Ag Nanofibers in Various Structures Enhance the Efficiency of Dye-Sensitized Solar Cells under Low Illumination, Energies 2020, Vol. 13, Page 2248, 13 (2020) 2248.
[14] M.U. Rahman, M. Wei, F. Xie, M. Khan, Efficient Dye-Sensitized Solar Cells Composed of Nanostructural ZnO Doped with Ti, Catal. 2019, Vol. 9, Page 273, 9 (2019) 273.
[15] M. Grätzel, Conversion of sunlight to electric power by nanocrystalline dye-sensitized solar cells, J. Photochem. Photobiol. A Chem., 164 (2004) 3–14.
[16] J.-H.; Kim, D.-H.; Kim, J.-H.; So, H.-J. Koo, J.-H. Kim, D.-H. Kim, J.-H. So, H.-J. Koo, Toward Eco-Friendly Dye-Sensitized Solar Cells (DSSCs): Natural Dyes and Aqueous Electrolytes, Energies 2022, Vol. 15, Page 219, 15 (2021) 219.
[17] M.Z. Iqbal, S. Khan, Progress in the performance of dye sensitized solar cells by incorporating cost effective counter electrodes, Sol. Energy, 160 (2018) 130–152.
[18] B. He, Q. Tang, L. Yu, P. Yang, Cost-effective alloy counter electrodes as a new avenue for high-efficiency dye-sensitized solar cells, Electrochim. Acta, 158 (2015) 397-402.
[19] F. Bella, S. Galliano, C. Gerbaldi, G. Viscardi, Cobalt-Based Electrolytes for Dye-Sensitized Solar Cells: Recent Advances towards Stable Devices, Energies 2016, Vol. 9, Page 384, 9 (2016) 384.
[20] T.M.W.J. Bandara, L.A. DeSilva, J.L. Ratnasekera, K.H. Hettiarachchi, A.P. Wijerathna, M. Thakurdesai, J. Preston, I. Albinsson, B.E. Mellander, High efficiency dye-sensitized solar cell based on a novel gel polymer electrolyte containing RbI and tetrahexylammonium iodide (Hex4NI) salts and multi-layered photoelectrodes of TiO2 nanoparticles, Renew. Sustain. Energy Rev., 103 (2019) 282–290.
[21] A.A. Qureshi, S. Javed, H.M. Asif Javed, A. Akram, M. Jamshaid, A. Shaheen, Strategic design of Cu/TiO2-based photoanode and rGO-Fe3O4-based counter electrode for optimized plasmonic dye-sensitized solar cells, Opt. Mater. (Amst)., 109 (2020) 110267.
[22] Q. Zhang, T.P. Chou, B. Russo, S.A. Jenekhe, G. Cao, Aggregation of ZnO Nanocrystallites for High Conversion Efficiency in Dye-Sensitized Solar Cells, Angew. Chemie, 120 (2008) 2436–2440.
[23] Z. Arifin, S. Suyitno, S. Hadi, B. Sutanto, Improved Performance of Dye-Sensitized Solar Cells with TiO2 Nanoparticles/Zn-Doped TiO2 Hollow Fiber Photoanodes, Energies 2018, Vol. 11, Page 2922, 11 (2018) 2922.
[24] P. Gnida, P. Jarka, P. Chulkin, A. Drygala, M. Libera, T. Tański, E. Schab-Balcerzak, Impact of TiO2 nanostructures on dye-sensitized solar cells performance, Materials (Basel)., 14 (2021) 1633.
[25] R. Zhao, Q. Wu, D. Tang, W. Li, X. Zhang, M. Chen, R. Guo, G. Diao, Double-shell CeO2:Yb, Er@SiO2@Ag upconversion composite nanofibers as an assistant layer enhanced near-infrared harvesting for dye-sensitized solar cells, J. Alloys Compd., 769 (2018) 92–95.
[26] R. Zhao, D. Tang, Q. Wu, W. Li, X. Zhang, R. Guo, M. Chen, G. Diao, Double-shell SnO2/CeO2:Yb,Er hollow nanospheres as an assistant layer that suppresses charge recombination in dye-sensitized solar cells, New J. Chem., 42 (2018) 14453–14458.
[27] J. Roh, S.H. Hwang, J. Jang, Dual-functional CeO2:Eu3+ nanocrystals for performance-enhanced dye-sensitized solar cells, ACS Appl. Mater. Interfaces, 6 (2014) 19825–19832.
[28] S.N.A. Zaine, N.M. Mohamed, M. Khatani, M.U. Shahid, Nanoparticle/Core-Shell Composite Structures with Superior Optical and Electrochemical Properties in a Dye-Sensitized Solar Cell, Nanomater. 2022, Vol. 12, Page 3128, 12 (2022) 3128.
[29] A.A. Qureshi, S. Javed, H.M.A. Javed, A. Akram, M.S. Mustafa, U. Ali, M.Z. Nisar, Facile formation of SnO2–TiO2 based photoanode and Fe3O4@rGO based counter electrode for efficient dye-sensitized solar cells, Mater. Sci. Semicond. Process., 123 (2021) 105545.
[30] S. Bykkam, D.N. Prasad, M.R. Maurya, K.K. Sadasivuni, J.J. Cabibihan, Comparison study of metal oxides (CeO2, CuO, SnO2, CdO, ZnO and TiO2) decked few layered graphene nanocomposites for Dye-Sensitized solar cells, Sustain., 13 (2021).
[31] N. Tsvetkov, L. Larina, J.K. Kang, O. Shevaleevskiy, Sol-gel processed tio2 nanotube photoelectrodes for dye-sensitized solar cells with enhanced photovoltaic performance, Nanomaterials, 10 (2020) 1–12.
[32] H. Su, Y.T. Huang, Y.H. Chang, P. Zhai, N.Y. Hau, P.C.H. Cheung, W.T. Yeh, T.C. Wei, S.P. Feng, The Synthesis of Nb-doped TiO2 Nanoparticles for Improved-Performance Dye Sensitized Solar Cells, Electrochim. Acta, 182 (2015) 230–237.
[33] K.-H. Lee, S.-H. Han, A. Chuquer, H.-Y. Yang, J. Kim, X.-H. Pham, W.-J. Yun, B.-H. Jun, W.-Y. Rho, K.-H.; Lee, S.-H.; Han, A.; Chuquer, H.-Y.; Yang, J.; Kim, X.-H.; Pham, W.-J.; Yun, B.-H.; Jun, Effect of Au Nanoparticles and Scattering Layer in Dye-Sensitized Solar Cells Based on Freestanding TiO2 Nanotube Arrays, Nanomater. 2021, Vol. 11, Page 328, 11 (2021) 328.
[34] X. Pan, C. Chen, K. Zhu, Z. Fan, TiO2 nanotubes infiltrated with nanoparticles for dye sensitized solar cells, Nanotechnology, 22 (2011).
[35] K. Pan, Y. Dong, C. Tian, W. Zhou, G. Tian, B. Zhao, H. Fu, TiO2-B narrow nanobelt/TiO2 nanoparticle composite photoelectrode for dye-sensitized solar cells, Electrochim. Acta, 54 (2009) 7350–7356.
[36] S. Son, S.H. Hwang, C. Kim, J.Y. Yun, J. Jang,

Designed synthesis of SiO2/TiO2 core/shell structure as light scattering material for highly efficient dye-sensitized solar cells, ACS Appl. Mater. Interfaces, 5 (2013) 4815–4820.
[37] M. Wang, C. Huang, Y. Cao, Q. Yu, Z. Deng, Y. Liu, Z. Huang, J. Huang, Q. Huang, W. Guo, J. Liang, Dye-sensitized solar cells based on nanoparticle-decorated ZnO/TiO 2 core/shell nanorod arrays, J. Phys. D. Appl. Phys., 42 (2009).
[38] K. Gopinath, S. Kumaraguru, K. Bhakyaraj, S. Thirumal, A. Arumugam, Eco-friendly synthesis of TiO2, Au and Pt doped TiO2 nanoparticles for dye sensitized solar cell applications and evaluation of toxicity, Elsevier Ltd, 2016.
[39] M. Ghaffari, M.B. Cosar, H.I. Yavuz, M. Ozenbas, A.K. Okyay, Effect of Au nano-particles on TiO 2 nanorod electrode in dye-sensitized solar cells, Electrochim. Acta, 76 (2012) 446–452.
[40] V. Dhas, S. Muduli, S. Agarkar, A. Rana, B. Hannoyer, R. Banerjee, S. Ogale, Enhanced DSSC performance with high surface area thin anatase TiO2 nanoleaves, Sol. Energy, 85 (2011) 1213–1219.
[41] W.Y. Rho, H.S. Kim, W.J. Chung, J.S. Suh, B.H. Jun, Y.B. Hahn, Enhancement of power conversion efficiency with TiO 2 nanoparticles/nanotubes-silver nanoparticles composites in dye-sensitized solar cells, Appl. Surf. Sci., 429 (2018) 23–28.
[42] I. Mohammadi, F. Zeraatpisheh, E. Ashiri, K. Abdi, Solvothermal synthesis of g-C3N4 and ZnO nanoparticles on TiO2 nanotube as photoanode in DSSC, Int. J. Hydrogen Energy, 45 (2020) 18831–18839.
[43] S. Yodyingyong, Q. Zhang, K. Park, C.S. Dandeneau, X. Zhou, D. Triampo, G. Cao, ZnO nanoparticles and nanowire array hybrid photoanodes for dye-sensitized solar cells, Appl. Phys. Lett., 96 (2010) 44–47.
[44] A. Elkhidir Suliman, Y. Tang, L. Xu, Preparation of ZnO nanoparticles and nanosheets and their application to dye-sensitized solar cells, Sol. Energy Mater. Sol. Cells, 91 (2007) 1658–1662.
[45] D. Wei, H.E. Unalan, D. Han, Q. Zhang, L. Niu, G. Amaratunga, T. Ryhanen, A solid-state dye-sensitized solar cell based on a novel ionic liquid gel and ZnO nanoparticles on a flexible polymer substrate, Nanotechnology, 19 (2008).
[46] Z.L.S. Seow, A.S.W. Wong, V. Thavasi, R. Jose, S. Ramakrishna, G.W. Ho, Controlled synthesis and application of ZnO nanoparticles, nanorods and nanospheres in dye-sensitized solar cells, Nanotechnology, 20 (2009).
[47] A.M. Golsheikh, K.Z. Kamali, N.M. Huang, A.K. Zak, Effect of calcination temperature on performance of ZnO nanoparticles for dye-sensitized solar cells, Powder Technol., 329 (2018) 282–287.
[48] L. Lu, R. Li, K. Fan, T. Peng, Effects of annealing conditions on the photoelectrochemical properties of dye-sensitized solar cells made with ZnO nanoparticles, Sol. Energy, 84 (2010) 844–853.
[49] L.Y. Lin, M.H. Yeh, C.P. Lee, C.Y. Chou, R. Vittal, K.C. Ho, Enhanced performance of a flexible dye-sensitized solar cell with a composite semiconductor film of ZnO nanorods and ZnO nanoparticles, Electrochim. Acta, 62 (2012) 341–347.
[50] R. Shashanka, H. Esgin, V.M. Yilmaz, Y. Caglar, Fabrication and characterization of green synthesized ZnO nanoparticle based dye-sensitized solar cells, J. Sci. Adv. Mater. Devices, 5 (2020) 185–191.
[51] L.Y. Chen, Y.T. Yin, Hierarchically assembled ZnO nanoparticles on high diffusion coefficient ZnO nanowire arrays for high efficiency dye-sensitized solar cells, Nanoscale, 5 (2013) 1777–1780.
[52] N. Ye, J. Qi, Z. Qi, X. Zhang, Y. Yang, J. Liu, Y. Zhang, Improvement of the performance of dye-sensitized solar cells using Sn-doped ZnO nanoparticles, J. Power Sources, 195 (2010) 5806–5809.