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| RESEARCH ARTICLE

Survey of the Achievement of a ZnO Dye-Synthesized Solar Cell

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| ABSTRACT

The adoption of renewable energy resources is already becoming incredibly valuable if we are to make the appropriate changes to confront the effects of global warming. Because solar energy is the most widely known form of renewable energy, much focus has been placed on finding quality materials with high energy outputs to replace conventional fossil fuel energy sources. To utilize sun energy for power generation, the dye synthesis solar cell, which belongs to third-generation photovoltaic technology, is likely to compete with more mature silicon technologies. This paper attempts to convey the core idea of dye-synthesized solar cells and the material used to make photoanodes. To find out the contribution of the researcher to the achievement of the dye synthesis solar cell technology, previous studies were reviewed, and the factors that influence performance were analyzed. The research shows that proper optimizations relevant to dopant, light intensity, and type of materials and a new novel approach to increasing photo-electrochemical activity in dye synthesis solar cells could make the devices compete with silicon technology.

| KEYWORDS

Dye synthesis solar cell, Efficiency, TiO_2, ZnO

| ARTICLE INFORMATION

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1. Introduction

The burning of fossil fuels in urban areas and land use in tropical zones due to urban expansion account for roughly 70% of global CO_2 emissions. By 2050, urbanization is expected to spread to all regions of the world, with Africa and Asia leading the way (Ebhota & Jen, 2019). The energy and fuel crises are undeniably the most pressing highly concerns in this millennium (Sharma et al., 2017). Solar energy is a reliable, abundant, environmentally friendly, and cost-effective alternative energy source. As a result, determining how to efficiently convert solar energy into usable energy is a significant challenge (Liu et al., 2016), (Cao, 2022). Sun produces solar energy due to fusion reaction; this sun's energy is expected to remain stable for the next four (4) billion years (Kim et al., 2015). Solar energy has the potential to diversify the electricity supply, reduce pollution, mitigate reliance on fossil fuels, and spur job creation (Venkatachalam et al., 2017). Photocatalysis is one active research area aimed at converting and utilizing sunlight energy to address these issues (Hoang & Gao, 2016). Dye-sensitized solar cells (DSSCs) keep attracting public attention due to several factors, such as cost-effective photovoltaic devices when compared to high-cost conventional silicon solar cells (Gong et al., 2017) and unique transparency and coloration, allowing the design of efficient colorful devices

(Venkatachalam et al., 2017). The fabrication cost of DSSCs is roughly one-third to one-fifth that of silicon solar cells (Siwach et al., 2017).

The improvement of DSSC conversion from visible light to electricity is determined by the sensitization of wide bandgap semiconductors, photoelectrode, redox electrolytes, and counter electrodes (Abdin et al., 2013). It's crucial to demonstrate that DSSCs can compete with more mature silicon technologies in terms of power conversion efficiency. The DSSC technology was discovered by Grátzel and O'Regan in 1991. (Aksoy et al., 2020). The cell's power conversion efficiency (PCE) obtained by Grátzel and his collaborators was 7%, which was impressive in comparison to other cells. (Rho et al., 2015). Kakiage (et al., 2014) reported Lab scale efficiency of over 12% by TiO2 DSSC with ruthenium-based.

2. Dye synthesized solar cell Fabrication

In DSSC fabrication, firstly, clean FTO-coated glass substrates are prepared. Prepare the photoanode by depositing TiO_2 or ZnO using techniques such as doctor blade, spray, RF-magnetron sputtering, sol-gel spin coating, among others. In the case of TiO_2, another layer of metal oxide may be formed prior to the deposition of TiO_2, or a dopant is added to it so as to improve the electrode for efficient power conversion of the cell. Moreover, for good crystalline thin film, annealing is required. A number of dyes, both synthetic and natural, were available. After photoanode preparation, it is then immersed in a dye solution of known concentration at room temperature for some period of time. After that, a specific liquid is used to rinse the electrode and allowed to cool again. The second electrode is responsible for collecting electrons from the external circuit; it is called the photocathode. On the conducting side thin layer of noble metal (i.e., Au, Pt, Ag, etc.) can be deposited onto the FTO glass substrate after preparation; then, assembled photoanode with a photocathode using a small thin film layer as a spacer; Sealed the electrodes, and a small hall is drilled to allow inflow of the electrolyte, letter on sealed up the hole with resin

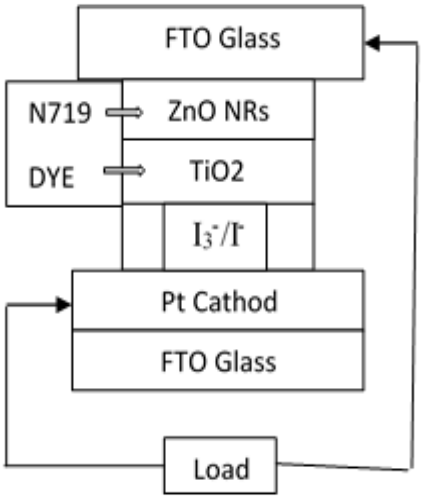


Fig 1. Structure of Dye synthesize solar cell

2.1 Operating Principles

The steps for photo charge carriers to flow in DSSC are: The light energy falls on photoanode and is absorbed by dye create electron-hole this caused by excitation of an electron from [highest occupied molecular orbital (HOMO) and transported to lowest unoccupied molecular orbital (LUMO)]. (Devadiga et al., 2021). As a result of oxidation, the excited electron jump into the conduction band of TiO_2 or any other semiconductor metal oxide (SMO); it then continuous flowing via a porous layer to the anode and subsequently to the cathode in the presence of an external loop, this creates current. The desorption of dye molecules from the photoanode has an impact on DSSC performance. An electrolyte is used to replenish dye after electrons are injected into the SMO conduction band and to transport positive charge to the counter electrode (Aslam et al., 2020). An electrolyte is usually containing iodide (I^-) and triodide (I_3^-) redox couple, this is to regenerate electrons by converting I^- into I_3^- so that oxide dye is ready for the next excitation. The photoexcited electrons reach the counter electrode when the working electrode is connected to it via an external load. Finally, the electron enters the electrolyte to maintain the electrolyte active and allow the oxidized dye to regenerate.

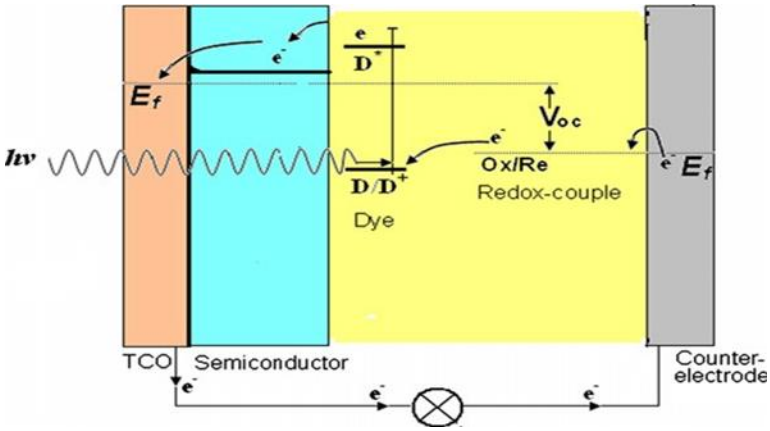


Fig 2. Principle of Dye sensitized solar cell

2.2 Steps for an Effective DSSC Fabrication

The following are the general considerations for producing DSSC:

I. To harvest as plentiful of the entering sunlight as possible, the dye ought to absorb through the full visible range and, if likely, a portion of the near-IR region.
II. Anchoring groups, such as carboxylic groups, should be present in order for the dye to bind strongly to the crystal surface (TiO_2), creating a direct contact for electron injection.
III. The dye's LUMO should be situated over the anchoring group and forcefully above the TiO2 conduction band edge (CBE) for the optimal driving force of the electron injection process.
IV. Electron recombination in the TiO_2 conduction band with the oxidized dye or with the redox couple should be eluded or diminished.
V. After the dye loses electrons to the external load, restoration of the dye by the redox couple ought to be quicker than recombination of the injected electrons in the semiconductor with the oxidized sensitizer.
VI. Choose an appropriate dye for optimal dye regeneration, whose HOMO should be lower than the energy level of the redox couple, allowing electrons to be accepted by the oxidized molecule.

3. **Dye materials**

The advancement in the efficiency of dye-sensitized solar cells is based on suited resources called "dye" for the light-capturing process. The dye sensitizer plays a key role in generating the primary charge separation via photo-excitation. Organic dyes have many advantages, which include simple design, appealing colors, reduced noble metal complexes, and higher molar extinction coefficients. Organic dyes, on the other hand, have a number of drawbacks, one of which is their lack of sustainability. Metal-free organic dyes are unstable, which means they have a tendency to degrade over time, and their production is time-consuming. The dyes themselves could be harmful, or by-products from the manufacturing process could pollute the environment (Kumara et al., 2017).

Synthetic dyes have high production and raw material costs. They also contain heavy metals, which pollute the environment. Despite the disadvantages listed above, it has been used by many researchers. Ruthenium (II) complexes are one of the most effective synthetic dyes used as charge-transfer sensitizers, allowing for greater solar radiation harvesting and reducing the recombination of excited electrons. These complexes have high chemical stability, good photoelectrochemical properties, and intense charge transfer absorption in the visible range. Several reports on ruthenium (II) complexes with various ligands have been published with the goal of improving device efficiency and stability (Sygkridou et al., 2015).

Ruthenium (II) bipyridyl (N3, N719, and N749) complexes were found to be important TiO_2 sensitizers among the compounds tested (Mendizabal et al., 2015). The N719 and N3 dyes absorb a broad range of visible light from 400 to 800 nm, while the N749 dye absorbs near-infrared light up to 900 nm. The structure of N719 dye is similar to that of N3. These dyes' absorption in the visible and near-infrared spectrums aids in the transfer of charges from metal to ligand in the complex (Shirkavand et al., 2018). The Cis-bis (isothiocyanato-bis (2, 2'- bipyridy1-4, 4'-dicarboxylato) ruthenium (II) bis-tetrabutylammonium (N719) dye contains two carboxylic acids and two carboxylate groups (-COOH and COO-). The carboxylate functional groups act as joining agents to immobilize the dye on the nano crystalline TiO_2 surface. The adsorption of N719 by TiO_2 layer alters the electronic communication between layer and the electrode, which is an important feature in DSSC (Bakr et al., 2017).

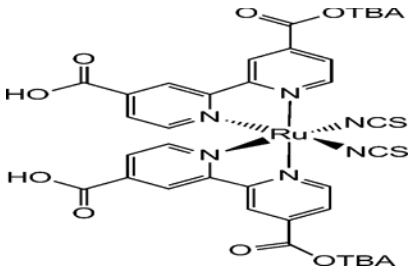


Fig 3. Structure of the N719 dye.

4. Photoanode materials

The metal oxide semiconductor is among the components of a photoanode. These wide-band gap metal oxides serve as both electron carriers and dye adsorption surfaces (Pallikkara & Ramakrishnan, 2020). Innumerable metal oxides have been studied, including TiO_2, ZnO, SnO_2, and Nb_2O_5. The energy levels of the valence band and conduction band are used to choose the said metal oxide for effective charge separation and reduced recombination.

4.1 Titanium Dioxide

TiO_2 has been proven to be the best semiconductor electrode material, and it is widely used in solar cells (Parisi et al., 2017). Anatase TiO_2 has absorption thresholds corresponding to 380 nm, implying easy excitation under solar light. Titanium dioxide was discovered in 1795. TiO_2 is polymorphic, which means that it can happen in more than one crystalline, rutile, anatase, and brookite. (Humayun et al., 2018). All three stages are prepared by TiO_6 octahedra with variable TiO bond spans (Chen et al., 2022). The insight of diverse polymorphs is subjective by in what way the TiO_6 octahedral units stake edges and corners. Each phase has distinct physical and chemical possessions, resulting in varying performance in device construction (Tamilselvan et al., 2012). However, TiO_2 polymorphs can be separated into two primary types based on the distinct configurations of oxide anions (O^{2-}) nearby the titanium cations (Ti^{+4}): (i) tetragonal structure (in rutile and anataseTiO_2) (ii) orthorhombic structure (in brookite-TiO_2)

TiO_2 is a white color found in synthetic fibers, rubber, paints, printing ink, plastics, painting colors, paper, condensers, ceramics, toothpaste, electronic components, food, and cosmetics (Haider et al., 2019). Its applications have broadened to include photovoltaics, supercapacitors, lithium-ion batteries, catalyst support, microwave absorbents, sensors, and biomedical applications (Yan & Chen, 2012). Titanium dioxide is referred to as a 'photosensitizer' because it was discovered that absorption of UV light causes the photobleaching of dyes on the surface of titanium dioxide. However, extensive TiO_2 material research has revealed that the bandgap energies of anatase, rutile, and brookite are 3.21, 3.0, and 3.13 eV, respectively. These findings indicated that the phases of TiO_2 are active in ultraviolet irradiation (Tiwari et al., 2019).

Due to the tunable properties of TiO_2 materials perhaps have semiconducting and dielectric features. TiO_2 has a great dielectric constant in the undoped phase, but when doped, it behaves like a broad bandgap semiconductor (Savio et al., 2012). Doped TiO_2 holds great promise for photovoltaic, photodetector, and chemical sensor practices. Undoped anatase, further, is a good dielectric with a variety of usages in electronics (e.g., capacitors, mos devices, field-effect transistors) and optical and protective coatings, among others. Titanium oxide is an n-type semiconductor with wide bandgap energy of (3.0 - 3.2 eV) (Dodoo-Arhin et al., 2018). The n-type conductivity of TiO_2 polymorphs was caused by oxygen vacancy defects (Padmini et al., 2021). Materials have been widely used as a photoanode active component in dye-sensitized solar cells (DSSC) and as an antireflection coating for solar cells.

4.1.1 Rutile and Anatase

Rutile and anatase have been widely investigated since brookite is difficult to extract and manufacture in its raw state (Rajabathar et al., 2021). The rutile is a naturally occurring phase; it can also be completed from anatase that has been heated and treated (Savio et al., 2012). Rutile and anatase TiO_2 have tetragonal and body-centered tetragonal crystal structures, respectively. Nevertheless, rutile and anatase crystal structures vary as a consequence of octahedron alteration and octahedron chain gathering. The properties of anatase TiO_2 are Brown to black, metastable polymorph, lustrous, lower absorption rate, hard, high density, and larger band gap, while rutile TIO_2 is Dark red, high refractive index, hard, UV-ray absorbent, excellent light-scattering efficiency, opacity, chemical inertness and superb photocatalytic properties (Tamilselvan et al., 2012). It is thermodynamically stable at ambient pressure and temperature. Therefore growing the rutile phase of TiO_2 in nanorods is essential.

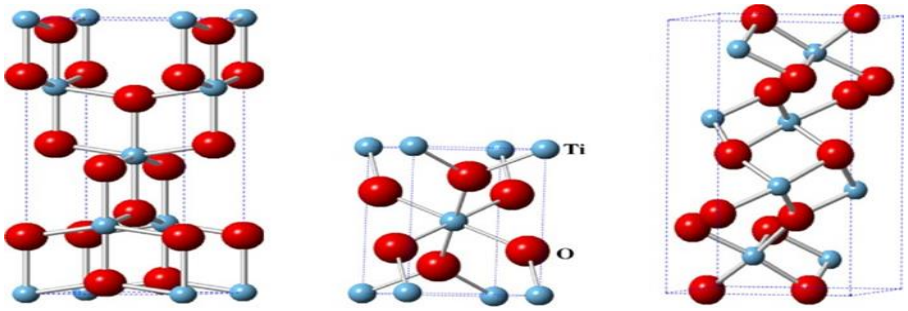
4.1.2 Differences between Rutile and Anatase

I. The rutile has an octahedron, which reveals slight orthorhombic alteration; however, the anatase phase exhibits significant alteration.
II. The anatase has a longer distance between Ti-Ti atoms than the rutile phase but a shorter distance between Ti-O.

III. Every octahedron in the rutile configuration is in connection with ten (10) immediate octahedrons, but each octahedron in the anatase structure is in contact with eight neighbors' octahedrons.
IV. In macroscopic sizes, the rutile phase is firm at ambient pressure and temperature; however, the anatase phase is more constant in nanoscopic dimensions.
V. Rutile has a melting temperature of 1,825 °C; nevertheless, the anatase phase irreversibly transmutes to rutile at around 500 °C. The anatase–rutile shift is powerfully trusting on the creation condition (temperature, particle size) and other factors such as component purity, specific surface area, porosity, and so on.
VI. Anatase attains to be more appropriate than rutile for the variability of applications

4.1.3 Brookite

Brookite-TiO_2 is a brittle, non-fluorescent, and dark brown to greenish-black metastable polymorph (Verma et al., 2017). Phase brookite is extremely difficult to synthesize, with low scientific interest. Brookite has a more disordered structure than rutile and anatase. The bond lengths between the titanium and oxygen atoms are all different, this resulted in its orthorhombic crystal structure, and the unit cell was demonstrated by the space group P/bca. Three edges of the octahedral are shared in the brookite formation.



Anatase Rutile Brookite

Fig 4. Unit cells of anatase TiO_2, rutile TiO_2, and brookite TiO_2. Large red and small light blue spheres are Ti^{4+} and O^{2-} ions, respectively

5. Zinc oxide (ZnO)

A ZnO is a different photoanode material with a similar conduction band edge and work function as TiO_2 but has higher carrier mobility, making it the material of choice. However, ZnO corrodes in an acidic environment, and the formation of dye aggregates degrades its performance, limiting its use as a photoanode in DSSC (Shakeel Ahmad et al., 2017). The strategy for developing highly efficient DSSC is to maximize light harvesting while minimizing electron losses. The ZnO-based DSSC studies show that it has good photocatalytic activity, light absorption, photocurrent generation, and photo-induced charge carrier transportation and separation (Savari et al., 2021). When compared to TiO_2 -based DSSCs, ZnO-based DSSCs have a lower energy conversion efficiency (Chandiran et al., 2014). Pure ZnO nanostructures have weak optical properties due to point defects like oxygen vacancies or interstitial Zn. (Singh et al., 2017). Due to its wide band gap can only interact with UV light with wavelengths below 387 nm (Kareem et al., 2022). The doping of ZnO with metallic elements such as Au, Ag, Co, and Cu may cause a narrowing bandgap leading to a shift in the photo-absorption edge of ZnO toward the visible region, increasingly increasing its optical properties (Karuppaiah et al., 2019). ZnO nanostructures can be generated in solution or in gaseous form. Water is typically used in solution phase synthesis for its simplicity and reasonable growth conditions.

6. Reexamine of Literature Relevant to the study

Dye synthesized solar cell is a solar energy transformation device starting from nanostructured constituents that use the principle of photosynthesis to yield electric current. The DSSC functioning depends chiefly on three processes, including charge carrier generation, charge collection, and electron transportation (Sharma et al., 2017). Dye-sensitized solar cells (DSSCs) have been proposed as viable alternatives to silicon-based Solar cells. As a result, the major challenge is to improve the DSSC performance. Researchers have attempted to improve efficiency by optimizing the various components, making it one of the most promising and Low-cost concepts for solar-to-electricity conversion. A few examples of key research in this area are as follows: Mosalagae et al. (2020) used the Chemical Bath Deposition method to grow ZnO nanorods, and his findings show that the length and diameter of the nanorods increased as the growth time, temperature, and precursor concentration increased. Indicating that the controllability of the properties of ZnO nanorods by varying growth parameters allows their application in photovoltaic cells as electron transporters. Kouhestanian et al. (2021) investigated the effect of thickness on the performance of the ZnO photo-anode of ZnO/N719-based DSSC. The finding shows that a photo-anode of thickness 19 µm produces 3.22%.

Ansir et al. (2021) investigate the impact of annealing temperature on the efficiency of DSSCs made from Ag@C@ZnO and Pd@C@ZnO composites as photoanode materials. The efficiency of the cells based on Pd@C-ZnO and Ag@C-ZnO photoanodes was found to be 1.93% and 3.60%, respectively. Due to the presence of noble metals and valonea, the efficiency of ZnO is improved due to a decrease in electron-hole recombination and an increase in photo-generated e-/h+. Kabir et al. (2019) research focused on the study of DSSC using red (Red spinach) and yellow (Turmeric) natural dyes as sensitizers. The yellow and red dyes have efficiency rates of 0.378 % and 0.134 %, respectively, while an optimal combination of the two dyes has an efficiency rate of 1.078 %. As a result, the optimal dye combination is an effective strategy that might improve the efficiency of DSSCs. The influence of bath temperature on hydrothermal development of ZnO nanorods was investigated. According to the FESEM results, the average nanorod length and diameter increase linearly, indicating highly anisotropic growth. The nanorods manufactured at 80°C had the highest PCE (3.62%) (Kannan et al., 2020). Raïssi et al. (2020) fabricated semi-transparent DSSCs using a new digital printing technique. This technology produces cells with a 7.4 % better solar energy conversion efficiency than the usual screen-printing technique, which produces cells with a 5.48 % efficiency. This approach streamlines the DSSC production process by reducing material consumption and making it rapid and efficient, resulting in a new and appealing method of producing DSSCs.

7. Result and discourse of some of the findings

7.1 The consequence of light intensity on the effectiveness of ZnO DSSC

A well-optimized ZnO base DSSC possesses a good electron transport mechanism and low recombination rate between the conduction band of ZnO and the redox electrolyte. Pietruszka et al., (2015) fabricated a DSSC. The efficiency of the device was studied by considering light intensity between $20mWcm^{-2}$ to $100mWcm^{-2}$. Figure 5 show that J-V curves measured at different light intensity. The highest current density was seen when the light intensity was $100mWcm^{-2}$ while the least occur at $20mWcm^{-2}$ from table 1. The values of $J_{sc,}$ V_{oc}, and efficiency steadily increase with increasing light intensity but the fill factor did not flow the trend. It is obvious that light intensity significantly influences the efficiency of ZnO DSSC. The differences in FF values suggest that light intensity affects the shunt and series resistance in the junction.

Table 1. The photovoltaic parameters of ZnO-DSSCs. Reproduced from (Shashanka et al., 2020) with permission, copyright@2020, Elsevier

Lighting Intensity ($mWcm^{-2}$)	**$J_{sc}(mAcm^{-2})$**	**$V_{oc}(V)$**	**FF (%)**	**ɳ (%)**
20	**0.67**	**0.49**	**61.3**	**1.01**
40	**1.90**	**0.59**	**35.9**	**1.11**
60	**3.37**	**0.61**	**41.3**	**1.41**
80	**5.10**	**0.62**	**41.6**	**1.65**
100	**6.26**	**0.65**	**48.5**	**1.97**

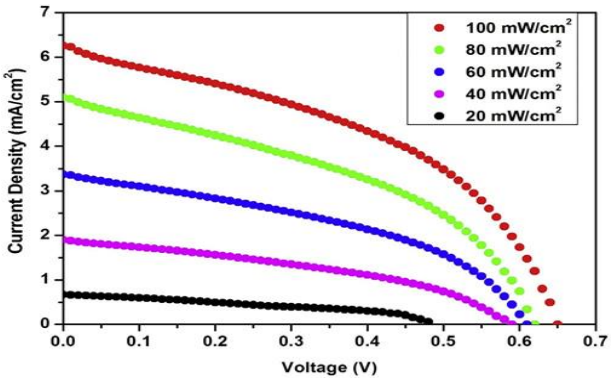


Figure 5. J-V curve of ZnO DSSC at different light intensities. Reproduced from (Shashanka et al., 2020) with permission, copyright@2020, Elsevier

7.2 The influence of the seed layer on the behavior of ZnO DSSC

Developing vertical alignment nanorods has the ability to boost the electron transport rate in DSSC. The seed layer is an essential part of growing nanorods. As a result, an investigation was carried out to assess the impact of the seed layer on the efficiency of ZnO nanorods. Meng et al. (2014) described a two-step electrochemical deposition technique for the manufacture of ZnO nanorods modified by surface attachment with ZnO nanoparticles and their dye-sensitized solar cell applications. The improved ZnO film electrode cell has a power conversion efficiency of 1.66% for its ordered ZnO nanorod arrays attached by ZnO nanoparticles for better dye absorption, direct electronic transportation, and charge recombination reduction. Sufyan et al. (2021)

fabricated ZnO nanorods-based DSSC aims to improve the light scattering and charge transport capabilities of ZnO nanoparticles-based DSSC; the result of his finding reveals 2.08% efficiency, which is higher than the 1.19% efficiency of standard ZnO nanoparticles-based DSSC. The improvement in efficiency might be due to the better conductivity and higher charge recombination resistance owing to the 1D structure of ZnO NRs. As a result, ZnO NRs could be used as an alternative photoanode material in efficient third-generation DSSCs.

Vertically aligned zinc oxide (ZnO) nanorods were electrochemically deposited on the FTO substrate seeded with ZnO. The solutions were synthesized with varying percentages of hexamethylenetetramine (HMTA). The efficiency of DSSCs based on ZnO photoanodes deposited in 0.0mM and 9.0mM HMTA solutions was 1.79 and 3.75%, respectively. Hence HMTA has an influence on efficiency(Marimuthu et al., 2018). Figure 6 depicts the J-V curve of ZnO NRs DSSC produced on top of the ZnO seed layer and without the seed layer. When the seed layer was not present, the efficiency was 1.0%; however, when the seed layer was introduced, the efficiency increased to 1.60%. The results show that the effect of a seed layer improves the alignment of nanorod arrays. The open circuit voltage V_{oc} was improved by reconfiguring the nanorods. This may perhaps imply that vertically aligned nanorods can potentially improve the charge transfer rate.

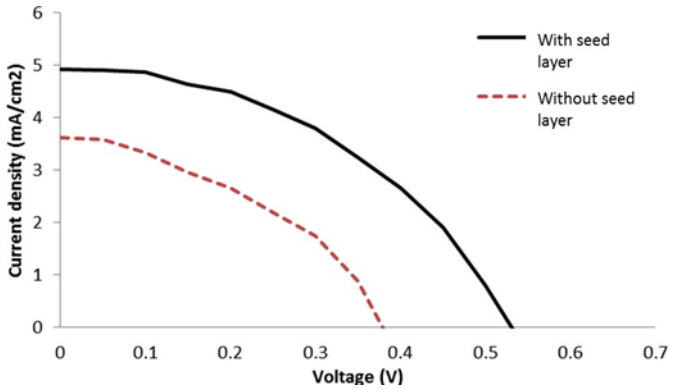


Figure 6. J-V curve on vertically aligned nanorods. Reproduced from (Winantyo & Murakami, 2017) with permission, copyright@2017, IJTech

7.3 The contribution of dopants in the efficiency of ZnO DSSC

ZnO is acknowledged as an example of nanocrystals used as a part of a photoanode in the construction of DSSC. ZnO based DSSCs could provide a direct pathway for the transport of photogenerated electrons to the anode and provide higher efficiencies. On the other hand, ZnO films naturally contain oxygen vacancies and zinc interstitials, so dopants can change the properties of ZnO (Aksoy et al., 2020). Therefore elemental doping on ZnO could increase the electron transport rate and make considerable changes in the band gap of the material. Thus, doping metal ions in ZnO might be considered electron trapping sites, preventing electron recombination (Rajan & Cindrella, 2019). Actually, several aspects, such as the ions' dimensions, the electronegativity, the coordination state, etc., all contribute to determining the final properties of the doped material (Carofiglio et al., 2020). ZnO could be doped with various impurities such as In, B, Mg, Mn, Ni, Al, Ga, Li, N, C, S, Se, etc. to create the required functionalities, such as changing the band structure, establishing defect sites, and enhancing charge carrier mobility (Rini et al., 2020). Tyona (2013) successfully synthesized Eu-doped ZnO nanorods, which resulted in a 45% increase in DSSC conversion efficiency from 0.34% for undoped nanorods to 0.50% for doped ZnO nanorods. The improvement could be attributed to a higher electronic injection efficiency from the dye to the CB of ZnO nanorods, i.e., a shift in the CB following europium incorporation in the crystalline lattice.

Supriyanto et al. (2021) examine the addition of Ag on the photoanode of DSSC; the efficiency attained was 6.30 percent, indicating that dopant has significantly influenced increasing DSSC performance. Esgin et al. (2021) look at the effects of Cu doping on DSSC; observations show that the greatest cell efficiency of 2.03 % was achieved for a photoanode constructed of 0.1 % Cu doped ZnO. On the way to advance electron transfer in the TiO_2 semiconductor layer in DSSC-based natural dyes, Trihutomo et al. (2019) added different amounts of clathrin protein to TiO_2, yielding an efficiency of 1. 465 % Isc = 5247 mA, and Voc = 657V. The addition of clathrin protein to solar cells reduces the barrier to electron transport between TiO_2 molecules by way of increasing the amount of carbon, oxygen, and phosphorus in the DSSC. The presence of carbon, oxygen, and phosphorus elements in TiO_2 shortens the charge delivery distance, allowing for an increase in electric current. The J-V characteristics of TiO_2 benchmark DSSC and DSSC altered with Ag-ZnO-TiO_2 NFs can be seen in Figure 7. The voltage is almost unaffected by adding a dopant. Table 2 showcases photovoltaic variables. The efficiency of the DSSC altered with Ag-ZnO-TiO_2 NFs, which is 18.20% higher than that of the unmodified photoanode. The addition of Ag, which has high conductivity, and ZnO, which has a high electron transfer ability, strengthens electron transfer in DSSC.

Table 2. J–V Measurements of TIO_2 standard DSSC and DSSC modified with Ag–ZnO–TiO_2 NFs. Reproduced from (Nien et al., 2020) with permission, copyright@2020, IEEE

DSSC	$J_{sc}(mAcm^{-2})$	$V_{oc}(V)$	**FF**	**η (%)**
TiO_2 Standard	$\mathbf{10.7 \pm 0.28}$	$\mathbf{0.78 \pm 0.01}$	$\mathbf{0.66 \pm 0.01}$	$\mathbf{5.44 \pm 0.12}$
Ag-ZnO-TiO_2 NF/TiO_2	$\mathbf{12.78 \pm 0.07}$	$\mathbf{0.76 \pm 0.01}$	$\mathbf{0.66 \pm 0.01}$	$\mathbf{6.43 \pm 0.19}$

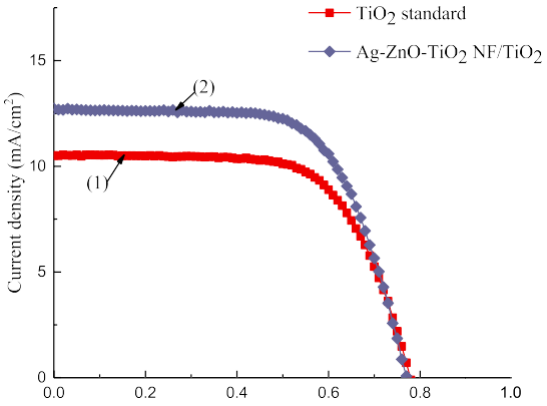


Figure 7. J–V curves of TiO_2 standard DSSC and DSSC modified with Ag–ZnO–TiO_2 NFs. Reproduced from (Nien et al., 2020) with permission, copyright@2020, IEEE

Figure 8. Show the J-V curve for pure ZnO and Sr doped ZnO. The result reveals that the open circuit voltage for pure ZnO is the highest, but low efficiency refers to Table 3. Introducing various portions of Strontium, the efficiency changes depending on the amount present; the ZS3 recorded the highest efficiency and current density. This means that as current density goes up, so also does the efficiency. Thus, in this case, there is less recombination of electrons and better flow of charges, and an increased region of dye adsorption. It can be concluded that adding small content of Sr in the ZnO photoanode improves the electron-injection and electron-transfer rates of ZnO DSSC.

Table 3. Photovoltaic parameters of pure ZnO and Sr-doped ZnO photoanode-based DSSCs. Reproduced from (Rajan & Cindrella, 2019) with permission, copyright@2019, Elsevier

Sample	$J_{sc}(mAcm^{-2})$	$V_{oc}(mV)$	FF	η (%)	$P_{max}(mW)$
ZO	1.37	845	0.69	0.80	798.78
ZS1	1.54	799	0.68	0.84	835.54
ZS3	1.93	809	0.65	1.02	1022.39
ZS5	1.60	794	0.68	0.86	864.65

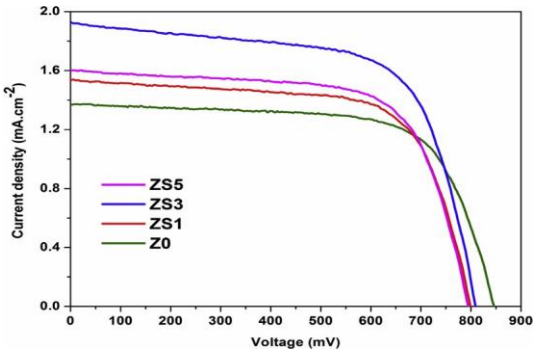


Figure 8. J-V curve of fabricated DSSC using ZnO and Sr doped ZnO based photoanodes Reproduced from (Rajan & Cindrella, 2019) with permission, copyright@2019, Elsevier

As previously stated, cell ability can be enhanced by embedding nanoparticles as ions or dopants. Cho et al. (2022) used silver in the form of an ion to generate a positive charge on the ZnO nanorod surface. Figure 9 and Tables 4 explain the results of DSCs made of silver-ion-deposited electrodes [Ag^+ (20)-ZnO/FTO] developed for eight hours on FTO glass, as well as DSCs made of

pristine ZnO nanorods developed for eight hours on FTO glass. As a result, the PCE value of the DSSC with the Ag^+ (20)-ZnO/FTO electrode was 1.138%, which was higher than the PCE value of the DSSC with the pristine ZnO/FTO electrode (0.629%). The increase in short circuit current densityJ_{sc}, open circuit voltageV_{oc}, and FF were credited to the enhanced PCE.

Table 4. Photovoltaic parameters of the champion cells with the pristine ZnO/FTO and Ag^+ (20) – ZnO/FTO electrodes. Reproduced from (Cho et al., 2022) with permission, copyright@2022, MDPI

Photoelectrodes	$J_{sc}(mAcm^{-2})$	$V_{oc}(V)$	FF	PCE	R_s	$R_{sh}(\Omega cm^2)$
Pristine ZnO/FTO	2.346	0.662	40.52	0.629	72.3	700.4
Ag+(20)–ZnO/FTO	3.362	0.675	50.14	1.138	37.6	1532.8

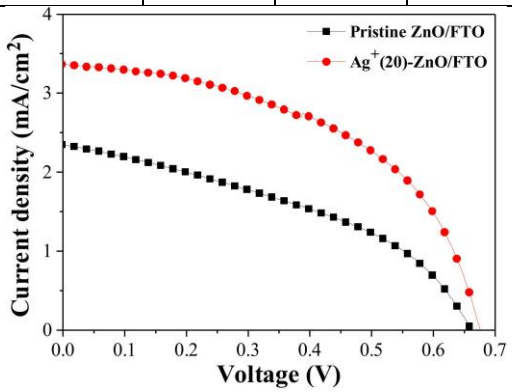


Figure 9. J–V curve of the DSCs with the pristine ZnO/FTO and Ag+ (20) ZnO/FTO photo- electrodes, measured under AM 1.5 condition. Reproduced from (Cho et al., 2022) with permission, copyright@2022, MDPI

The influence of graphene in ZnO was also studied in this work. A study was conducted to compare DSSC with Platinum counter electrodes and a composite of Pt/rGO counter electrode thin films Grafin et al., (2017). The efficiency of the non-composite counter electrode increased from 4.46 % to 5.5 % for the composite counter electrode. This illustrates that using graphene increased DSSC performance. Savari et al. (2021) created a DSSC using Sr-doped ZnO/rGO nanocomposites. The results outlook a novel method for increasing photo-electrochemical activity in ZnO-based DSSCs. Table 5 shows the outcome of his investigation, and the corresponding interpretation is depicted in graph 10. Because of the presence of different weight percent of Strontium and reduced graphene in ZnO, the efficiencies of nanocomposite change. The effectiveness of pure ZnO<ZG1<ZG2<ZG3>ZG4. Thus, pure ZnO has the lowest efficiency, while ZG3 has the highest efficiency due to the high short circuit current. From the same table, the I-V measurement of ZnO with different weight ratios of strontium and reduced graphene is also presented. Viewing the table, efficiency changes as the current density increases. When the current density is $18.4 mAcm^{-2}$, the highest efficiency of 7.98% is obtained. It can be concluded that the nanocomposite with the chemical formula $Zn_{0.92}Sr_{0.08}O$/G3 has the highest efficiency. This is due to the low electrode resistance and high anodic reaction rates of the dye on ZnO-based photo-anodes, which might increase electron transport.

Table 5. Results of J-V characterization of fabricated ZnO based DSSCs. Reproduced from (Savari et al., 2021) with permission, copyright@2021, Elsevier

Sample	***rGO content* (*wt*%)**	V_{OC} (V)	J_{SC} ($mAcm^{-2}$)	***FF***	η (%)
ZnO	0	0.581	6.4	0.511	1.90
ZG 1	0.01	0.711	7.51	0.601	3.20
ZG 2	0.1	0.63	9.11	0.576	3.30
ZG 3	0.5	0.73	8.15	0.602	3.58
ZG 4	1	0.632	7.49	0.619	2.93
$Zn_{0.98}$ $Sr_{0.02}$ O/G 3	0.5	0.73	10.39	0.571	4.33
$Zn_{0.96}$ $Sr_{0.04}$ O/G 3	0.5	0.702	13.45	0.530	5.00
$Zn_{0.94}$ $Sr_{0.06}$ O/G 3	0.5	0.711	12.15	0.639	5.44
$Zn_{0.92}$ $Sr_{0.08}$ O/G 3	0.5	0.702	18.4	0612	7.90

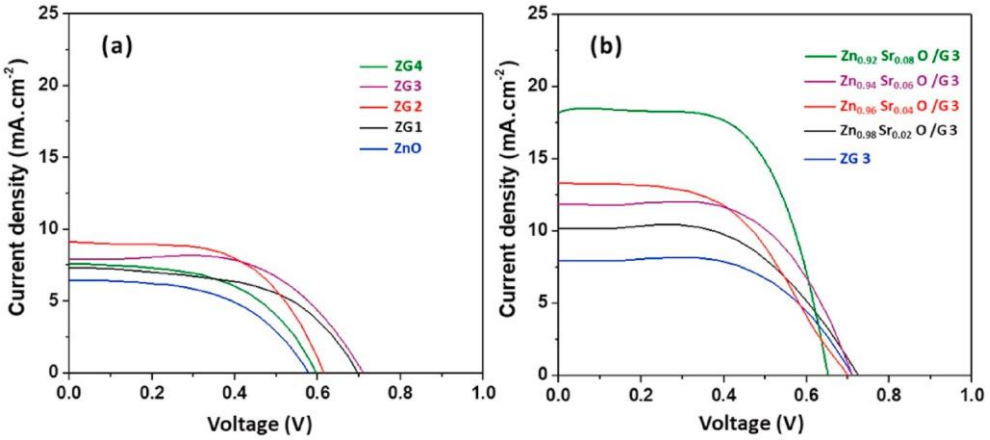


Figure 10. J-V curve of (a) ZnO and different content of rGO in the ZnO/rGO and (b) different content of Sr in Sr-doped ZnO/rGO DSSCs. Reproduced from (Savari et al., 2021) with permission, copyright@2021, Elsevier

8. Conclusion

The development of dye-sensitized solar cells began in 1991. Consequently, while technology is not novel, its potential presents a challenge to modern researchers. DSSC is economical, and the fabrication techniques are frank. The photoanode material's properties can be varied and controlled by enhancing the synthesis materials and deposition settings. This paper discusses several recent developments in dye-sensitized solar cells. Working principles and general considerations for producing DSSC and photoanode materials are included. These advancements have reformed the possibilities of the dye-sensitized solar cell and established it as the preferred method of producing electricity. A number of recent fundamental studies in this field have also been included, and several factors influencing cell performance have been discussed. Generally speaking, an overview of ZnO dye-sensitized solar cells and the previous result were reexamined. It concluded that the conversion efficiency is dependent on the light intensity, dopant, and proper optimization during fabrication. The survey shows that elemental doping on ZnO could increase the electron transport rate and make considerable changes in the band gap of the material. Thus, doping metal ions in ZnO might be considered electron trapping sites, preventing electron recombination.

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