Dye-Sensitized Solar Cells Nanostructures and Natural Colorants

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The history of sensitized cells began with the pioneering work of Brian O'Regan and Michael Grätzel, on the promising applications of nanosized TiO2porous film electrodes in dye-sensitized solar cells (DSSC); these devices convert solar energy into electricity through the photoelectric effect. The first devices worked with ruthenium-based dyes and their efficiencies were around 10%. DSSCs are low cost to manufacture, eco-friendly, and are considered to have a high photon-to-electricity conversion efficiency, so they soon became an intense field of research.

Keywords: renewable energy capture: solar energy ; Dye Sensitized Solar Cells natural dyes ; solar cells ; energy storage ; nanostructures ; efficiency

1. Introduction

The history of sensitized cells began with the pioneering work of Brian O'Regan and Michael Grätzel, on the promising applications of nanosized TiO_2 porous film electrodes in dye-sensitized solar cells (DSSC); these devices convert solar energy into electricity through the photoelectric effect [1]. The first devices worked with ruthenium-based dyes and their efficiencies were around 10% [2]. DSSCs are low cost to manufacture, eco-friendly, and are considered to have a high photon-to-electricity conversion efficiency, so they soon became an intense field of research.

DSSCs have great advantages compared to conventional silicon-based cells. Their construction is simpler as well as their maintenance; however, ruthenium (the predilect material) is a very scarce element in nature, leading to a very high price [3] in its acquisition and, therefore, it affects the overall price of the cell. Even if outputs are efficient, it is necessary to find a new material that addresses the requirements of low price and greater efficiency. For this reason, dye-sensitized solar cells (DSSCs) have been innovating. Thanks to numerous investigations, DSSCs have now reached an efficiency of approximately 13%, which has made them potential candidates to produce clean and renewable energy [4].

2. Dye-Sensitized Solar Cells (DSSCs)

In a system, for converting pure, nonconventional solar energy into electricity, dye solar cells (DSSCs) promote the production of photovoltaic devices that offer high conversion efficiency at a low cost. The dye as a sensitizer plays an essential role in evaluating the performance of DSSCs. Natural dyes (organic dyes) have become a valid and common substitute for rare and expensive inorganic sensitizers due to their cost-effectiveness, high availability, and biodegradability. Various parts of plants such as fruits, leaves, flowers, and petals have been used as sensitizers over the years. The properties of these pigments, as well as some other parameters, improve the operational level of the DSSC [5].

Furthermore, the article [6] reports the use of the solvent extraction method for the extraction of dyes, which was obtained from saffron, purple onion, mallow, and oregano. Regarding their low efficiency values fromsaffron0.51%; mallow—0.45%; purple onion—0.54%; and 0.51% for oregano, authors report that these dyes contain carbonyl and hydroxyl groups, which allow them to bind to TiO_2 structures, and thus, improve electron transfer and energy conversion efficiency.

Some studies combine natural dyes and synthetic dyes to improve the overall efficiency of the DSSC. For example, paper [7] employed anthocyanin (purple cabbage) and obtained an efficiency of 0.024%. Then, anthocyanin and synthetic dye combination N719 resulted in an efficiency of 0.054%. The amount of dye used for each cell is 10 mL. Nevertheless, the first case uses 10 mL of purple cabbage, while the second uses 8 mL of purple cabbage and 2 mL of synthetic dye. The use of jaboticaba dye extracted by ethanol as a solvent is presented in the paper [8], in which it is reported that TiO_2 is used to improve the efficiency. Two methods are used to coat the photoanode: the first is the doctor blade method, which presents an efficiency with this dye of 0.08% and the second method reported is the spin coating method, which, with this dye, shows an efficiency of 0.13%.

In some of the investigations carried out using natural dyes for DSSCs, the values obtained in terms of efficiency do not exceed the synthetic dyes; such is the case of the document [9], where the use of mangosteen as a base for the dye used is reported, which, by itself, presented an efficiency of 0.38%; to improve this value, different proportions chenodeoxycholic acid were added, and this was carried out to increase the performance of the DSSCs. The proportions that were added were 0.10, 0.50, 0.75, 1.00, 1.5, and 2.00 mM, the last one showing better results with 0.56% of efficiency.

3. More Efficient Innovations

Regarding DSSC technology, the efficiency value is the most important in the literature. Several pieces of research focus on improving these values through diverse approaches. It is worth mentioning that the efficiency value serves to compare different types of cells. In addition, it indicates progress and helps to identify, in an easier way, the approach used to achieve such results. Hence, efficiency values are beneficial for researchers since they have a standard to compare their work The more efficient innovations are summarized in the **Table 1** .

Table 1. High efficiency values reported on recent literature.

Innovation	Method	η (%)	Ref.
Ag nanoparticles doped with graphene-Ba_2GaInO_6	**Ag 4%**	**9.01**	[10]
	Ag 6%	**9.90**	
Kinetic combination of TiO_2 nanoparticles co-doped with Cu/S photoanodes	**0.1% CuS**	**9.05**	[11]
	0.3% CuS	**10.44**	
Polymer gel electrolyte containing binary salts of RbI and tetrahexylammonium iodide (Hex4NI) in combination with TiO_2 multilayer photoelectrodes	**Layer3**	**7.2**	[12]
	Layer4	**7.5**	
Asymmetric dendrimers with ethylene core as quasi-electrolytes	**TiO_2/N719/LiI/7/Pt**	**8.494**	[13]
	TiO_2/N719/LiI/8/Pt	**9.037**	
Hydrothermal treatment to synthesize highly water-soluble carbon dots from rosemary leaves	**CDs(5%)/TiO_2**	**7.32**	[14]
	CDs(6%)/TiO_2	**6.79**	

On the other hand, a sol–gel route is adopted for the synthesis of undoped TiO 2 nanoparticles co-doped with copper sulfide (Cu/S) with constant content of 0.05% nonmetallic sulfur and diverse content of 0.1 to 0.5% metallic copper. The above is presented in paper [11], and it shows one of the highest efficiencies recorded in this review, which means 10.44% to 0.3% CuS tested.

To conclude this section, we report the synthesis of asymmetric stilbenoid-conjugated dendrimers by Heck and Horner–Wadsworth–Emmons coupling in [13]. In this research, the authors state that the absorption intensity improves with an increase in dendrimer generation. Similarly, in this research, good efficiency results are obtained. This is shown in the first-generation asymmetric dendrimer (sample 8), where an efficiency of 9.037% is perceived.

Sometimes, the novelties presented by some researchers are out of the context of traditional research of the DSSCs. For example, reference [15] presents a study where authors use clathrinid protein obtained from a cow's brain. This research reported that the protein was deposited on a porous TiO 2 semiconductor at different concentrations (0%, 25%, 50%, and 75%). The highest result in terms of efficiency was 1.465%, which corresponds to a 75% concentration of this protein. In contrast, by not using this protein (0% concentration), an efficiency of 0.047% was obtained. Some of the conclusions that stand out in this research are: the addition of this protein forms amino acids, a higher concentration of this protein indicates a more pronounced absorbance of the transmission rate of the wavenumbers in the wave spectrum in the FTIR spectrum, and the increase in concentration of this protein increases the efficiency of the DSSCs.

4. Conclusions

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