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Recent improvements in dye sensitized solar cells: A review

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ABSTRACT

Dye Sensitized Solar Cell (DSSC) is considered to be one of the most promising technological developments in the field of Solar Cells. It is basically a cell that imitates the process seen in plant cells to produce energy. It is a photo-electrochemical cell, considering the electron moments caused by the combined effect of the photon energy and the chemical reactions. The DSSC being transparent to some extent and comparatively cheaper than conventional solar photo-voltaic, can be a potential energy source for the future. But there are many aspects that need to be worked upon before declaring it as a feasible commercial product. The paper emphasizes on these aspects and the various improvements that the DSSC has gone through in recent years. This is a detailed review of the work done to improve the performance of DSSC, with supporting data. A comparative study of the effect of various suggested modification to the different components of DSSC has been done. This would give a clear idea about the most recent improvements done in DSSC with respect to the various components. It includes a summary of the suggested improvements by various researchers, bifurcated into different sections with respect to the different components of the DSSC. It was observed that incorporating graphene sheets of various sizes in the photo anode helped to improve the efficiency of DSSC significantly, giving a maximum efficiency of 6.62%. In case of novel dyes used in the DSSC fabrication the D-A-pi-A indoline dyes showed a great enhancement in the cell efficiency, with efficiency of up to 6.9%. Incorporation of Pt in counter electrodes and 3D-CE also showed notably good efficiency in DSSC, the efficiency improving up to 8.8%.

Contents

1. Introduction 55
2. Working of DSSC 55
3. Review of improvements in photoanode 56
   3.1. Improvements in nano structures of photoanode 56
   3.2. Experiments with seed layer and preparation methods 58
   3.3. Experiments with semiconductor materials 58
4. Review of improvements in sensitizers 59
   4.1. Development of novel dyes 59
   4.2. Other improvements 60
5. Review of improvements in electrolyte 60
6. Review of improvements in counter electrode 61
7. Other improvements 62

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1364-0321/

8. Fill factor . . . 62
9. Result and discussion . . . 62
10. Scope for further research. . . . 62
11. Conclusion . . . 63
References . . . 63

1. Introduction

Solar PV technologies have gone through significant development over the years. Starting from the First-generation PV cells which are the most developed set of solar PV cells which dominate the market and fully commercial in nature, examples being single-crystalline (sc-Si) or multi-crystalline (mc-Si). Then the Second-generation PV systems that are in the early stages of development, these cells are slowly growing and occupying the markets. The main attraction being the comparatively low manufacturing costs and finally the Third-generation PV systems comprising of technologies, such as concentrating PV (CPV) and organic PV cells that are still in the developmental phase or have not yet been widely commercialized. It also includes novel concepts under development. The dye –sensitized solar cells may be considered to be a part of the third generation cells. A number of experiments were carried out to improve the performance of the solar PV for applications in Building integrated photo voltaic (BIPV) [1–3]. The DSSC finds fairly good application in BIPV.

O'Regan and Grätzel first reported the pioneering work on the promising applications of nano-sized TiO_2 porous film electrodes in Dye Sensitized Solar Cells (DSSCs) [4]. The DSSC was low cost and considered to have very high photon to electricity conversion efficiency and so soon became an intense field of research. Penetrating research work was carried out and a notable amount of work has been reported.

The basic components of DSSC include photoanode, sensitizer, electrolyte, and counter electrode. Semiconductor nano structures are employed to develop the photoanode. Various nano structures such as nano-rods, nano-tubes, nano-wires, nano-cones, nano-leaves or their mixture has been fabricated on transparent conductive glass [5]. For many years, TiO_2 nano-structured materials and the ruthenium-bipyridyl dye families such as N719, N3 and C101 are the most efficient materials for the photoanode, and have subjugated the highly efficient solar cells [6,7]. Some researchers consider ZnO as the most promising alternative to TiO_2. Many recent studies show the application of ZnO nano structures for photo-electrodes with enhanced photovoltaic performance of Dye-sensitized solar cells. DSSC developed using network structure of electron-spun ZnO nano fiber mats [8], ZnO nano-sheets derived from growth mechanisms directed by surfactants [9], effects of annealing on the performance of DSSC using ZnO [10], effects of morphology of nano structures of ZnO films on efficiency on DSSC [11], ZnO nano structures for DSSC [12] are some of the works involving application of ZnO in DSSC.

Experiments have been carried out with a number of metal-free organic photosensitizes for DSSCs [13]. Few dyes used for fabrication are, coumarin [14], indoline [15], merocyanine [16] and hemicyanine [17], showing prominent photovoltaic performance.

Commonly used counter electrode is the Pt deposited TCO substrate, as it has been the most fruitful combination for the counter electrode. Since both these materials (Pt and TCOs) are very expensive, it is extremely important to find new cost effective materials and approaches to replace the Pt and TCOs in CEs. Carbon based nano-materials (e.g. carbon nano-tubes, graphene or graphene nano-plates) are potential substitutes as these materials have good electric conductivity and high surface area [18,19]. A characteristic DSSC consists of a liquid electrolyte containing an iodide/triiodide redox mediator and a Pt metal counter electrode [20].

The efficiency of the DSSC as a unit depends on the individual performance of its components; hence improvement in each of these can contribute to the enhancement in overall performance of the DSSC. A substantial amount of work has been done for improvement at different levels which has been elaborated further. Other work including development of Poly epinephrine (PEP) and poly dopamine (PDA) in a novel approach, in an alkaline solution containing tris (hydroxymethyl) aminomethane (THAM) buffer with pH=8.5 under nitrogen atmosphere, were also experimented with [70].

This paper aims at bringing together the various works done by researchers to improve the efficiency of the DSSC. There is a proper bifurcation of the suggested improvements and experiments based on the different components of the DSSC. The review suggested that graphene sheets of various sizes in the photo anode could help to improve the efficiency of the DSSC. Some novel dyes such as the D-A-pi-A indoline dyes showed good results, with up to 6.9% efficiency. Incorporation of Pt in counter electrodes and 3DCE also showed notably good efficiency in DSSC.

2. Working of DSSC

An efficiency of about 12% has been achieved in DSSCs [21]. The photon incident on the dye, excites the dye. Electrons from excited state of the dye, enters the conduction band of TiO_2(or any semiconductor material used) [22,23]. The electrons then flow through the porous TiO_2 thin film to the transparent conducting oxide (TCO). This electron flow depends on the incident intensity and trapping–detrapping effect [24–26]. The oxidized dye molecules are regenerated, when the dye receives electrons from a redox mediator (I^-/I_3^-). The mediators are oxidized in the process. Further, these oxidized redox mediators (I_3^-) are diffused to the counter electrode where they are regenerated by reduction due to the electrons reaching the counter

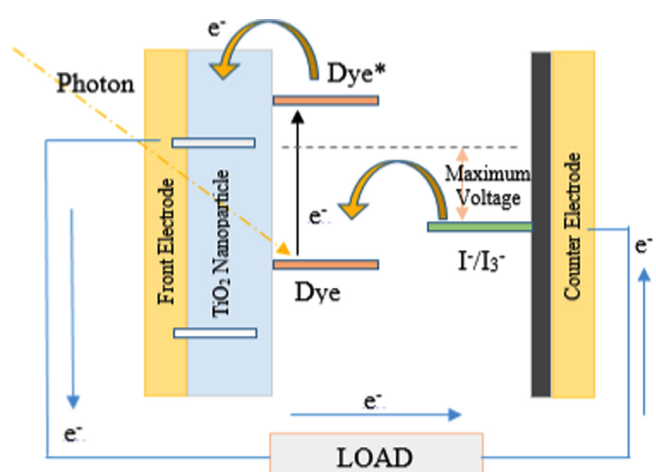

Fig. 1. DSSC schematic band diagram [28].