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BIO POLYMER BASED DYE SENSITIZED SOLAR CELLS FOR IMPROVED EFFICIENCY: A REVIEW

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ABSTRACT

Depleting energy resources and environmental conditions have prompted the use of greener energy resources. Solar cells have been utilized since decades to overcome this worldwide problem. We are now in third generation solar cells with the use of Dye Sensitized Solar Cells (DSSC's). This new technology has utilized nano semiconductors and dye stuff varying from synthetic origin to naturally available ones from various plant sources. The major limitation of such DSSC's is its longevity. As soon as the electrolytes dry up the efficiency of these cells reduces. This chapter tries to sum up few important inventions in modern DSSC's that utilize bio polymer composites to embed both semiconductor and dye material. Such an arrangement has proven to be highly efficient, durable and greener.

KEYWORDS: Dye sensitized solar cells, Bio Polymer, Green technology, Cell efficiency.

INTRODUCTION

Solar energy is widely available form on natural resources, striking the earth at 120,000 TW per annum. Its energy never depletes with usage. Conversion of solar energy to electrical energy with reduction in footprints of carbon is sustainable growth. Solar fuel, solar electricity (photovoltaics), solar electricity (thermal e.g. thermoelectric, CSP-steam turbine) and Solar Thermal solutions are some ways of using this form of energy.

Advanced technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis are the crux of the hour.

"Photovoltaic solar plants" are the most common form of solar energy used nowadays. The system absorbs sun's light to create electricity. These solar plants are used as primary or secondary sources of electric power in homes. A dye sensitized solar cell (DSSC) is one such photovoltaic solar plant. DSSC's are an efficient type of thin-film photovoltaic cells. It is also called as 'GRATZEL CELLS'. This concept is based on a concept invented by O 'Regan and Michael Gratzel in 1988. But the concept dates back to the 1960's and 70's. A typical DSSC contains five parts as illustrated in Figure 1.

The semiconducting material, usually TiO_2 or ZnO nano adsorbed with dye solution containing an electrolyte (redox system) is sandwiched between two conducting glass substrates coated with transparent conducting film. These transparent conducting film coated glasses are commercially available. They may be ITO i.e. Indium Tin Oxide ($R = 18\ \Omega/cm^2$) or FTO i.e. Flourine Tin Oxide ($R = 8.5\ \Omega/cm^2$).

Semiconductor oxides like TiO_2, ZnO, Nb_2O_s etc. are used. TiO_2 films are widely used as best semiconducting material for DSSC because of its less toxicity level, low cost and abundant availability.

Dye sensitizers help in absorbing radiation and transferring electrons to conducting band of the semiconductor. Innumerable synthetic and natural dyes are used for this purpose. At present research is widely concentrated on natural dye sources with better absorption coefficient. Such advanced technologies have widened the scope of natural dyes in various disciplines (Shahid-ul-Islam and Faqeer, 2013). Anthocyanins found in berry fruits are purple, blue or red in colour, these are water soluble. When a DSSC was prepared using these anthocyanins with bio polymer, the conversion efficiency of the DSSC prepared with 750 mg of anthocyanin/L was 0.14%, with an open-circuit voltage (V_{OC}) of 0.43 V, a short-circuit current density (J_{SC}) of 0.38 mA/cm^2, and a fill factor (FF) of 0.450. The conversion efficiency attained with 1500 mg of anthocyanin/L was 0.19%, with (V_{OC}) of 0.45 V, (J_{SC}) of 0.44 mA/cm^2 and FF of 0.55. Higher concentration of the coloring substance brought about a higher photosensitized performance (Julio et al., 2016).

Counter electrode is used to complete the redox system. A good reducing agent like carbon or platinum is employed. Due to higher level of transparency and effective reducing ability platinum is preferred over carbon.

Electrolyte is the heart of any DSSC. These may be liquid electrolytes, quasi electrolytes or solid-state electrolytes. Liquid electrolytes are organic or ionic electrolytes. Both of these electrolytes have a major disadvantage of leakage; solid-state electrolytes lead to lowering of performance, hence many researchers are concentrating on improving the quasi electrolyte systems.

Most efficient DSSCs and batteries are available in market in-corporate liquid electrolytes. The advantages of liquid electrolytes are: having high conductivity and good electrode-electrolyte interface. Disadvantages like corrosion and evaporation limit their future sustainability. Biopolymer electrolytes are proposed as novel alternatives which may overcome the problems stated above (Rahul et al., 2016).A flow chart of different parts of a dye sensitized solar cell (DSSC) and the types of each part employed in recent years is shown in Figure 2.

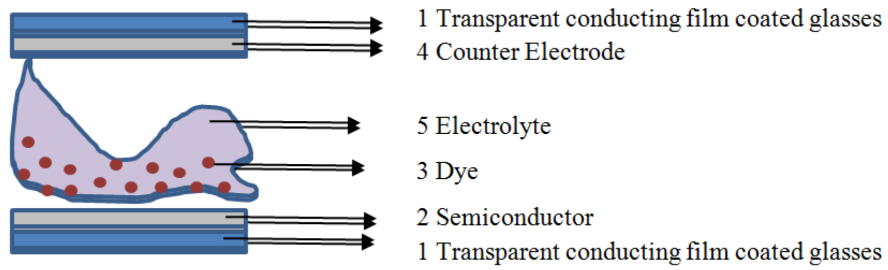

Figure 1: A typical dye sensitized solar cell.

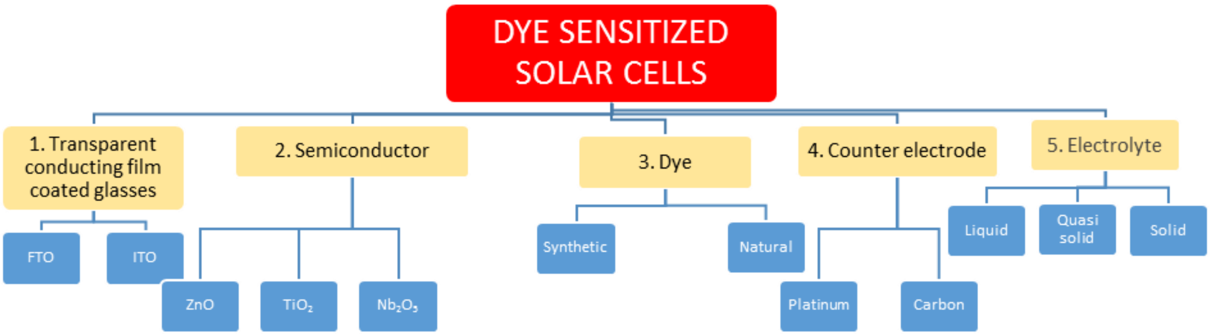

Figure 2: Flow chart of different parts of a dye sensitized solar cell.

Clean energy and green technology are talk of the day. The challenge is in maintaining its sustainability. To make a DSSC sustainable the most important part of the cell is electrolyte. When DCCS's are made up of liquid electrolytes, the problem of spill and drying reduced the efficiency of these cells. Alternatively, solid-state and quasi solid types of electrolytes came into existence. We shall in this paper discuss few recent trends in solid-state and quasi solid electrolytes.

Naturally occurring bio polymers such as chitosan, starch and cellulose, due to their electronic properties have given rise to organic transient bioelectronics. Starch based biopolymers can be effectively utilized as self-powered systems. These are economic and environmental friendly with added advantage of thermo electronic and photovoltaic properties (Osama and Faris, 2020). Polymers due to their complex structures are fine host cells for ionic conduction. These have found application in sensors, solar cells, batteries and super capacitors. Polymer electrolytes can be Solid Polymer Electrolytes (SPE) and Gel Polymer Electrolytes (GPE). GPE have higher ionic conductivity than SPE (Yusuf et al., 2019).

When a polymer material is complexed with salt and its ionic conductivity is determined there is enhanced ionic conductivity. Polyionic liquids (polyILs) will dominate the polymer electrolyte application in DSSCs due to its unique characteristics (Ahmad 2015). The light weight, flexible nature, biocompatible, cost efficiency increases its market value and applicability (Mohiuddin et al., 2017; Teo et al., 2021, Noriah et al., 2021, Mohd Fairul Sharin Abdul Razak et al., 2022).

Few bioplastics investigated for their ionic properties and cell efficiency is reported here.

Starch bioplastics

Composite bioplastics were fabricated using starch, vinegar, glycerol and titanium di oxide. Tensile strength of biopolymer increased from 3.55 to 3.95 MPa and there was a decrease in elongation from 88 % to 62 %. These composite bio plastics can be used as packing material (Ruhul and Arefin, 2019). Potato starch modified with 1-glycidyl-3-methylimidazolium chloride ionic liquid and KI/I_2, resulted in higher thermal stability and higher gelatinization temperature. It also showed high conductivity and efficient ion migration. DSSC using this biopolymer were 0.514 % efficient. This low efficiency was outweighed by its relative stability (Michaela and Drexel, 2019).

Two types of bio plastics were synthesized a) Starch bioplastics: Starch + Vinegar + Glycerol and b) Composite bioplastics: Starch + Vinegar + Glycerol + Titanium di oxide. There was improved tensile strength in case of b) from 3.55 to 3.95 MPa and decreased elongation from 88% to 62%. Decomposition temperature also showed considerable increase. Limitations like voids, holes and crack seen in a) were overcome by b) (Ruhul and Arefin, 2019).

A potato composite with 1-glycidyl-3-methylimidazolium chloride (GMIC) ionic liquid was prepared to give yellowish colour, higher water solubility, thermal stability and gelatinization temperature. It had high conductivity and ion migration capabilities. When used in DSSC as quasi-solid- state electrolyte 0.514 % efficiency was obtained. The cell showed slightly low performance but relatively high stability (Michaela and Drexel, 2019).

Rice starch bioplastics

A biopolymer gel prepared with rice starch and Lithium iodide in water were prepared. This system was highly porous and hence facilitated faster movement of ions. Greater increase in Open circuit voltage (Voc) and Efficiency (η) for gel electrolyte compared to liquid electrolyte was observed (Yogananda et al., 2017).

In another reported study, sodium iodide salts were added to the composite, 1-methyl-3-propylimidazolium iodide (MPII) ionic liquid was later on added to it. The highest ionic conductivity of 1.20×10^{-3} S cm^{-1} i.e. 2.09 % efficiency (with DSSC) was achieved upon addition of 20 wt.% of MPII ionic liquid. Complexation between polymer and ionic liquid helped in increasing the efficiency of DSSC (Mohammad et al., 2015).

Algal bioplastics

Algae are natural sources of dyes and hence are eco-friendly. When these algal polysaccharides are employed in modern electrochemical applications as solid polymer electrolytes they give high-performance, cost efficiency and biodegradability (Fernando and Gabriel, 2021).

Agarose bioplastics

Biopolymer electrolytes made with two solvents Dimethyl formamide and dimethyl sulfoxide and agarose + potassium iodide separately were impregnated with ionic liquid (IL) and used during fabrication of DSSC with agarose. The results obtained after evaluation for Fill factor and V_{oc} affirm that biopolymer – IL gel electrolytes were promising candidates as energy devices (et al., 2017).

To agarose biopolymer matrix polymer electrolyte and salt potassium iodide were added. This electrolyte was used during development of DSSC. Electrical conductivity film showed 0.54% efficiency at 1 sun condition (Rahul et al., 2013).

Polyurethane bioplastics

To Poly urethane (PU) obtained from palm 1-methyl-3-propylimidazolium iodide (MPII) in Iodine was added, Platinum was taken as the counter electrode. This electrolyte system was used in DSSC and its properties were investigated. Ionic conductivity of 9.07×10^{-4} S cm^{-1} for PU-25 wt. % MPII system was obtained. The I-V studies of these solid state DSSC’s showed high power conversion efficiency of 1.00 % under standard 1.5 G illumination (Su’ait., 2018).

Chitosan bioplastics

Piezoelectricity is a requirement for a good electrolyte. Chitosan qualifies this necessity. In such cases photo electric effect can be activated and enhanced Power Conversion Efficiency (PCE) is obtained in solar cells (Praveen et al., 2019).

When chitosan biopolymer membrane composites are doped with ionic liquid 1-ethyl 3-methylimidazolium thiocyanate (EMIm SCN) enhanced ionic conductivity has been observed (Singh, et al., 2010).

ZnO/ZnS nanocomposite of chitosan photo-anode were used to fabricate DSSCs and tested with LED lamp for the chitosan-based polymer electrolyte. The maximum PCE of 1.6% was achieved. (Praveen et al., 2019).

High efficiency of 9.61% has been produced for dye sensitized solar cell using a phthaloyl chitosan based gel polymer electrolyte. The optimized gel polymer electrolyte (Ionic Liquid incorporated) exhibits the highest short circuit current density of 19.68 mA cm^{-2} (Buraidah ., 2017).

Cellulose fibers bioplastics

Methylcellulose (MC) combined with succinonitrile, LiBOB and dimethyl sulfoxide resulted in a gel. This gel was used to setup a DSSC. Photovoltaic studies showed an efficiency of 3.46 %. On addition of 1.0 wt. % butyl-methyl imidazolium iodide ionic liquid, the efficiency of cell increased to 3.08 mS cm^{-1}. When all of LiBOB was replaced with ionic liquid an excellent increase in conductivity of 23.5 % and Cell efficiency of 5.72 % was observed (Yusof et al., 2018).

Polymeric cellulose fibers are suitable components for bio-derived photo anodes and electrolytes used in DSSC’s.

The laboratory-scale quasi-solid state paper-DSSCs assembled with cellulose-based electrodes and electrolytes guarantee sunlight conversion efficiencies as high as 3.55 and 5.20% at simulated light intensities of 1 and 0.2 sun, respectively, along with an excellent efficiency retention of 96% after 1000 h of accelerated aging test (Federico et al., 2017).

CONCLUSION

Use of biopolymers like: starch, agarose, chitin, cellulose, polyurethane, agarose etc. in devising Dye Sensitized Solar Cells is environmental friendly and enhance ionic conductance capacities due to complex structures. When used for preparing a solid state electrolyte system, these polymers lose their porosity and result in decreased conduction ability. However, these limitations can be overcome by creating quasi solid electrolyte composites i.e. blending, doping or plasticizing with ionic liquids and TiO_2 nanoparticles and improve in its efficiency.

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