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Review

Recent advances in hybrid solar cells based on natural dye extracts from Indian plant pigment as sensitizers

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ABSTRACT

Alternate energy source has become imperative for green energy solution against ever growing demand. Hybrid solar cell is yet another promising option toward green energy providing opportunity to explore natural dye extracts from plants. This review explores recent developments in the field of hybrid solar cell technology specifically with sensitizer synthesized from plants which are also found in India. Anthocyanin, betalain, chlorophyll and carotenoids are among the most common plant pigments explored as sensitizers. The review of different attempts on fabrication of natural dye based solar cells implies that titanium dioxide (TiO_2) nano particles as photoanode, platinum (Pt) as counter electrode and iodine/iodide electrolyte is the most widely used combination so far. Plant pigments are highly pH sensitive and can alter solar cell performance based on its extraction method, concentration and its ability to anchor with photoanode. Stability of dye, absorption in near IR range and leakage of liquid electrolyte are few of the challenges ahead. However, natural dye is biodegradable and non-toxic having most of the extraction process harmless to environment. In addition, natural dye has the promising future as it is abundant. Genetic engineering will provide means of modifying plant DNA to render desirable concentration and type of plant pigments. Anthocyanin has been studied extensively and gives comparatively higher efficiency in a single dye cell. Co-sensitization can be one of the possible options to enhance solar cell efficiency in future.

Contents

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1. Introduction

This review intends to study recent development in the field of Dye Sensitized Solar Cells (DSSC) consisting of natural dye sensitizer extracted from plants which are found in India in order to explore the potential of Indian vegetation to serve as energy harvester, considering India's ambitious green energy goals. Additionally, India is the second largest in farm output. Approximately 60.6% of land in India is agricultural land with more than 50% of the population engaged in farming, thereby with potential to provide abundant source for natural dye from plants. Owing to favorable geographical and climatic conditions with required manpower, producing natural dye in India should be cost effective as compared to other developed nations.

Solar cells are classified into first, second and third generation (Green, 2006) as shown in Fig. 1. Third generation solar cells aim to decrease the cost and enhance efficiency (Gibbons et al., 1984) as high cost is the demerit for first generation solar cell and low efficiency for the second generation solar cells. Most of the third generation solar cell consists of Dye Sensitized Solar Cells (DSSC), polymer cells, quantum dot cells and hot carrier cells (Green, 2001; Mc Gehee, 2007; Trupke et al., 2002). DSSC combines inorganic and organic material in order to combine advantages of these two types of material (Xu and Qiao, 2011) called Hybrid solar cell (HSC). Advantages of inorganic material in hybrid solar cells are stability against solar irradiation (Ren et al., 2011), higher contribution toward light absorption as compared to material like PCBM (Fullerene derivative of the C60 Buckyball) (Dayal et al., 2009), its quantum confinement effect that helps to change band gap and absorption profile (Takagahara and Takeda, 1992) and Faster charge transfer as compared to recombination. Additionally organic material in hybrid solar cells makes them light weight, flexible with better efficiency permitting the use of even natural material extracted from plants. Desirable properties of organic material can be designed by altering band gap.

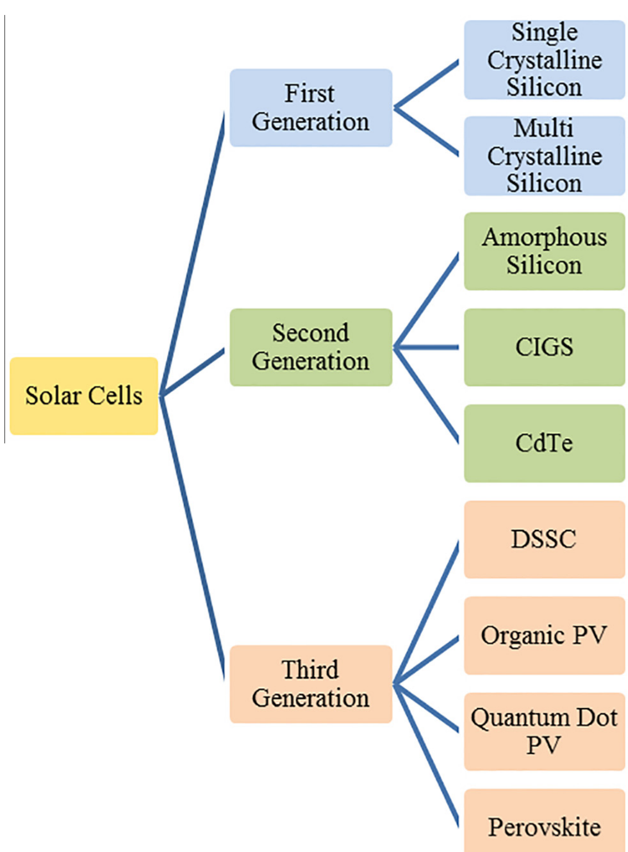

Fig. 1. Solar cell generations.

1.1. Advantages of DSSC

DSSC permits independent selection of light absorbing material and charge transport material to obtain better light harvesting and charge separation. Additionally organic material has advantages like cost effectiveness, easy to process and synthesize, flexible and can be bent, can be deposited on flexible substrate, can be selected based on absorption requirements and are environment friendly substances (Gratzel, 2001). The application of nano particles further improves dye absorption on semiconductor (Green et al., 2011).

1.2. Structure of DSSC

DSSC consists of conducting glass made of Transparent Conducting Oxide (TCO) (Bauer et al., 2002). Fluorine doped tin oxide or Indium doped tin oxide is generally used as TCO. TCO should have less resistance and high transparency for efficient solar cell operation. TCO is the substrate for photoelectrode, lets light pass through and collects electrons toward external circuit. It should be stable up to 450–500 °C to facilitate sintering of electrode.

Photoelectrode consists of metal oxide nanoparticles like TiO_2, ZnO or SnO_2 that is coated on conducting glass. Nanoporous photoelectrode provides maximum surface area for dye molecules absorption. Porosity of the electrode facilitates electron transport from dye to TCO. Grätzel and O'Regan developed Ruthenium bipyridyl complex as sensitizer and achieved approximately 7.1% efficiency under AM 1.5 (O'Regan and Grätzel, 1991). Photoanode is immersed in dye solution to allow maximum chemiabsorption and hence it forms sensitized nanoporous electrode.

Iodine/triiodide commonly used as electrolyte because electron transfer from photoanode to electrolyte is slower than from counter cathode to electrolyte (Peter, 2007). Counter electrode is formed by sputtering Pt on TCO and surface is further treated to form Pt colloids. Carbon materials can also be used as counter electrode. Electrodes and electrolyte are sealed using material that is stable against electrolyte and irradiation.

1.3. Working of DSSC

In DSSC photon absorption is accomplished by dye molecules sensitized on photoanode. Photo excitation of dye leads to transfer of electron from Highest Occupied Molecular Orbital (HOMO) to its Lowest Unoccupied Molecular Orbital (LUMO) and sensitizer is oxidized forming S^* as shown in Fig. 2. The energy level variation between LUMO of the donor and conduction band of the acceptor provides the force required to separate electron hole pair. The