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An overview on the spectrum of sensitizers: The heart of Dye Sensitized Solar Cells

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Abstract

The development of hybrid solar cells such as Dye Sensitized Solar Cell (DSSC) opens up a new generation of thin film solar cells with high performance to cost ratio. They are expected to be one of the most economically viable energy devices, owing to the potential for realization of flexible and light weight, thin film photovoltaic devices with moderate efficiencies and good processability in non-vacuum settings. Sensitizers form the heart of DSSC since they trigger and maintain the electron transfer processes in a photo electro chemical system by absorbing solar radiation. This review focuses on recent advances in sensitizers developed/explored elsewhere. A comprehensive analysis of the performance of various light absorbing sensitizers based on their chemical structure, geometry and stereo chemistry is attempted.

Keywords: Dye Sensitized Solar Cell; Sensitizer; Photovoltage; Fill factor; Semiconductor; Quantum dot

1. Introduction

The quality of human life depends to a large degree on the availability of energy, which is threatened unless clean and renewable energy resources are developed in the future. Science is expected to make important contributions to identify environment friendly solutions for the energy problem. One attractive strategy is the development of photovoltaic (PV) cells which are promising source of renewable energy that converts sunlight to electricity, with high potential to contribute significantly for solving the energy problem (Grätzel, 2001). High cost and low conversion efficiency have been the major bottlenecks for the solar power to become a primary source of energy. New methods of harnessing the full spectrum of the sun's wavelength, multifunction solar cells (homojunctions and heterojunctions), and new cheaper materials for making solar cells are paving way for solar power to be the emerging power resource for the world at large (Andrews, 1879; Siemens, 1885). This review article covers the literature on DSSC employing different types of sensitizers developed/explored elsewhere. A comprehensive analysis of the performance of various light absorbing sensitizers based on their chemical structure, geometry and stereo chemistry is attempted.

2. Dye Sensitized Solar Cells

Dye Sensitized Solar Cells (DSSC) Lenzmann and Kroon, 2007 form a prominent member of the larger group of thin film photovoltaic technologies which together represent less than 10% of the annual PV module sales,

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currently. They are expected to gain growing market share in the years to come because of the potential for low cost fabrication involving nonvacuum processing at room temperature, flexible and light weight products and an access to new markets. Because of these advantages, dye-sensitized solar cells are expected to be the energy device for the next generation. The interest in DSSC took off with the landmark publication by *O'Regan and Grätzel* in the early 1990's (O'Regan and Grätzel, 1991).

Dye-sensitized solar cells operate differently from other types of solar cells in many ways, with some remarkable analogies to the natural process of photosynthesis. Similar to the role of chlorophyll in plants, a monolayer of dye molecules (sensitizers) absorbs the incident light, resulting in the generation of positive and negative charge carriers. The dye-sensitized solar cell constitute five components (O'Regan and Grätzel, 1991) including a mechanical support coated with transparent conductive oxide, a semiconductor film, a sensitizer adsorbed onto the surface of the semiconductor, an electrolyte containing a redox mediator and a counter electrode capable of regenerating the redox mediator. Fig. 1 illustrates the operating principle of dye-sensitized solar cell. The first step involves the absorption of photon by the sensitizer S (Eq. (1)), which leads to the excitation of the sensitizer S^* and the excited sensitizer subsequently injects an electron into the conduction band of the semiconductor, leaving the sensitizer in the oxidized state S^+ (Eq. (2)). The injected electron will flow through the semiconductor film to arrive at the back contact and then through the external load to reach the counter electrode in order to reduce the redox mediator (Eq. (3)) which in turn regenerates the sensitizer (Eq. (4)), completing the circuit (Nazeeruddin et al., 2011).

$$S + h\lambda \rightarrow S^*_{(\text{adsorbed})} \quad (1)$$

$$S^* \rightarrow S^+_{(\text{adsorbed})} + e^-_{\text{injected}} \quad (2)$$

$$I_3^- + 2e^-_{(\text{cathode})} \rightarrow 3I^- \quad (3)$$

$$S^+ + 3/2I^- \rightarrow S + 1/2I_3^- \quad (4)$$

Some undesirable reactions including, the recombination of the injected electrons either with oxidized sensitizer (Eq. (5)) or with the oxidized redox couple at the semiconductor (TiO_2) surface (Eq. (6)) can also occur, resulting in lower cell efficiency.

$$S^+_{(\text{adsorbed})} + e^-(TiO_2) \rightarrow S_{(\text{adsorbed})} \quad (5)$$

$$I_3^- + 2e^-(TiO_2) \rightarrow 3I^-_{(\text{anode})} \quad (6)$$

For measurement, air mass 1.5 (AM 1.5) spectra were chosen by ASTM because they are representative of average conditions in the 48 contiguous states of the United States. The overall efficiency of the dye-sensitized solar cell depends on optimization and compatibility of each of the components, in particular the spectral responses of semiconductor film along with the dye constituting DSSC (Nazeeruddin et al., 2011; Barbé et al., 1997). This can be expressed in terms of the incident monochromatic photon-to-current conversion efficiency (IPCE) or the external quantum efficiency (EQE) which is defined as the number of electrons generated by light in the external circuit to the number of incident photons as a function of excitation wavelength, as given in Eq. (7) Hagfeldt and Grätzel, 1995. The IPCE can be used to compare the higher harvesting capability of various sensitizers using devices with the same ambitecture.

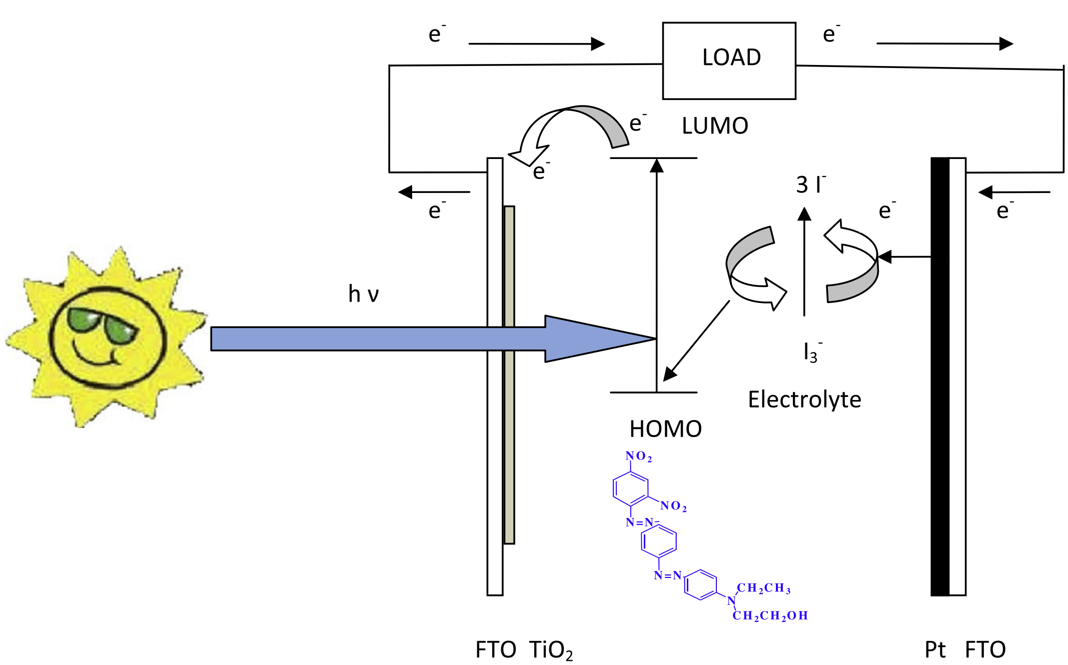

Fig. 1. Operating principle and energy level diagram of dye-sensitized solar cell.