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Effects of doping, morphology and film-thickness of photo-anode materials for dye sensitized solar cell application – A review

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ABSTRACT

Dye sensitized solar cells are attractive as simple and low cost renewable energy source. In dye sensitized solar cells, photo-anode plays significant role for collection and transportation of photo-excited electrons from dye to external electric circuit. Usually, wide band gap semiconducting metal oxides like titania, zinc oxide etc are deposited over transparent conducting substrate to prepare the photo-anodes. The performances of the photo-anodes depend on the band gap, morphology, composition of metal oxides and thickness of metal oxide layers. Enormous research efforts have been accomplished for studying the photo-voltaic characteristics of the dye sensitized solar cells by varying the aforementioned influencing parameters. However, the research activities executed towards the modification of photo-anode for dye sensitized solar cell application are quite scattered. It seems therefore important to summarize the research efforts executed towards the development of photo-anode for dye sensitized solar cell. In the present review, the effect of influencing parameters on the photo-voltaic characteristics of photo-anode for dye sensitized solar cell application is discussed. The descriptions have been made by summarizing the relevant literature reports.

Contents

Abbreviations: DSSC, Dye sensitized solar cell; J_{SC}, Short circuit current density; V_{OC}, Open circuit voltage; FF, Fill factor; FTO, Fluorinated tin oxide; ITO, Indium tin oxide; nm, Nanometer; μm, Micrometer; η, Efficiency; AM, Air Mass; NS, Nanospindles; NF, Nanofibers; NW, Nanowires; NeHS, Nano-embossed hollow spherical; PC, Photonic crystals; SEM, Scanning electron microscopy; FESEM, Field emission scanning electron microscopy; TEM, Transmission electron microscopy; EIS, Electrochemical impedance spectroscopy; 1/2/3D, One/Two/Three dimensional

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1. Introduction

1.1. Importance of renewable energy

Fossil fuels are the main source of energy consumed worldwide. Since the industrial revolution in the 19th century, coal, oil and gas remain the main fossil fuel resources. These fossil fuels generate electrical as well as thermal energy which are essential for various industrial and domestic applications. Electricity supply allows an increase in productivity as well as access to basic services, thus improving the life conditions of human communities [1]. However, the procedures for the production of energy from such fossil fuels are not sustainable. The critical fact is that such fossil fuel sources (coal, gas and oil) are finite natural resources which are depleting at a rapid rate. During the generation of power, the aforesaid non-renewable sources also emit carbon dioxide which is known as a green house gas [2,3]. The green house gases accelerate the formation of thermal insulating layers in the upper atmosphere of the globe and thus prevent normal heat dissipation resulting global warming. The consequences of global warming significantly influence the ecosystems, affecting the agricultural production, and causing rise in sea level. In accordance to a statistics, if the world population reaches 10 billion in 2050, a 75% decline in carbon emissions is required to limit global temperature rise about 2 °C [4].

In order to make the development of a civilization with limited environmental hazard, clean energy sources are required essentially. To achieve the goal, the use of renewable energy can be considered as prime step. Some of the popular forms of renewable energies are wind power, hydropower, solar energy, biomass, biofuel and geothermal energy. Most of these renewable sources of energy are considered fairly clean and non-polluting. In this perspective, solar energy can certainly be taken into account as most attractive renewable energy source since it is abundant, clean and safe. It has been estimated that if only 0.1% of earth's crust is covered with solar cells having efficiency of 10%, the immediate demand of energy in world can be met out [5]. Therefore, solar power is supposed to play a pivotal role as renewable energy source to meet the growing demand of energy worldwide.

1.2. Advancement of solar cell technology as renewable energy source

Till date, solar energy has been utilized mostly for the production of either thermal or electrical energy. Solar thermal technologies basically collect the solar light and produces heat directly. These technologies are used in domestic and industrial application for heating purpose. The technology for the conversion of solar to electrical energy is called photo-voltaic and thus the solar cells can be termed as photo-voltaic devices. Solar cell technologies are traditionally divided into three generations. (a) First generation solar cell: based on crystalline silicon (b) second generation solar cell: based on amorphous and hybrid silicon, cadmium telluride (CdTe), gallium arsenide (GaAs) or copper indium (gallium) selenide (CIS/CIGS) thin films and (c) third generation technology is mainly focused on the materials (e.g. wide band-gap metal oxide semiconductors TiO_2, ZnO, Nb_2O_5, SnO_2, etc.) [6–9] which can be prepared through simple and cost effective solution processing route. Organic solar cells, dye-sensitized solar cells, quantum dot solar cells etc are the key examples of third generation solar cells. This generation solar cell concepts allow for a more efficient utilization of the sunlight. The beauty of this new generation solar cells lies on the fact that these are made from variety of new materials besides traditional silicon. Dye-sensitized solar cells (DSSCs), quantum dot-sensitized solar cells (Q-DSSCs) and perovskite based solar cells are considered as popular third generation solar cells. Each of these various kinds of solar cells has their own advantages as well as limitations. The first generation solar cells are efficient photo-voltaic devices but their adaptability is limited due to high processing cost. In spite of having their promising photo-electric conversion efficiency, the toxic effect and complex processing of second generation cells make them difficult to be viable as photo-voltaic devices. As third generation solar cells, dye-sensitized solar cells (DSSCs) are currently attracting widespread scientific and technological interest because they are highly efficient, simple to fabricate and low-cost alternative to conventional photo-voltaic devices.

A typical DSSC is usually composed of photo-anode, counter electrode, electrolyte and photo-sensitizer. The principle of DSSC and role of each constituent have been discussed later. Briefly, upon light irradiation, the sensitizer (dye) becomes photo-excited and injects electrons into the conduction band of metal oxide. The electrons penetrate through the metal oxide film, reach to the conducting substrate and flow through an external circuit to the counter electrode. At the counter electrode, the oxidized component of redox couple (/electrolyte) is reduced and the oxidized form of the dye is finally regenerated by the reduced component of redox couple in the electrolyte. As discussed, all components of DSSC play important role in achieving their promising photo-conversion efficiencies of the solar cells. Among these components, photo-anode significantly contributes in charge collection and transportation of photo-excited electron from dye to external electric circuit. Usually, wide band gap semiconducting metal oxides (e.g. ZnO, TiO_2, etc.) are deposited over transparent conducting substrate to prepare the photo-anodes. The performances of the photo-anodes depend on the band gap, morphology, composition of metal oxides and thickness of metal oxide layers. Enormous research efforts have been accomplished in studying the photo-voltaic characteristics of the DSSCs by varying the band gap, morphology, composition of metal oxides and thickness of the metal oxide layer.

2. Objective of the present review

It is very important to examine the influence of each of above mentioned influencing factors to construct an efficient photo-anode. As envisaged from the literature, research activities executed towards the modification of photo-anode for DSSC application are scattered which often makes it difficult to design a new experiment in the same field. The summarization of the executed work on the photo-anode therefore seems necessary particularly for researchers working on the photo-anode for sensitized type solar cells. There are few articles which have reviewed either the role of every constituents (photo-anode, counter electrode, electrolyte and photo-sensitizer) or the kinetics of photo-excited electrons for dye sensitized solar cells; however, the detail