Study of Light Trapping Geometry for Different Structure of Photoanode in Dye-Sensitized Solar Cells

Swati Sahu, Mohan Patel, Anil Verma, Pooja Agnihotri and Sanjay Tiwari

Abstract— In dye-sensitized solar cells, light trapping or harvesting strategy has explored in order to increase the absorption of incident light on the photoanode of DSSCs and to reduce the recombination losses throughout charge carrier extraction retaining the charge carrier transport paths as short as possible. To stabilize the power conversion efficiency in dye-sensitized solar cells different light trapping geometries have been studied for the enhancement of light absorption, TiO_2 photoanode geometries like flat, pillar, prism has been used. One more approach for better charge collection is the alternative of the messy nanoporous TiO_2 layer by nanostructured photoelectrodes like nanotubes, nanowires. The main purpose of these nanostructures is to increase charge collection by the involvement of a direct pathway for electron transport and also squashed recombination loss. By changing the structural design of the TiO_2 photoanodes, more than 20% increment in light absorption along with photocurrent of DSSCs has been achieved.

Index Terms— *Dye-sensitized solar cells; Light trapping; Photoanode geometry; Enhancement of light absorption; Recombination losses*.

1. Introduction:

The improvement of a latest solar cells technology is focusing for system power applications. The Dye-Sensitized Solar Cells (DSSCs) is a most fascinating and promising skill in field of the photovoltaics conversion. The basics principle of dye-sensitized solar cell is that it converts solar electromagnetic energy in to electrical energy. The Dye-sensitized solar cells (DSSCs) are a striking alternative in favor of high-efficiency as well as low-cost power creation for energy source [1]. Aesthetic properties like transparency and colours of solar cells, and performance properties like the attainable output voltage and current density by selecting the suitable nanostructured metal oxide (generally TiO_2), sensitizer, and redox shuttle [2, 3,4]. Sensitizer is the most critical components in a DSC, light-harvesting properties of the DSC also determines the component as well as maintain the relations involving the redox shuttle with the TiO_2 [5,6].

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In solar cell technology, the light trapping or harvesting techniques has been broadly investigated due to the necessities for the reduction of active material thickness. It is also valuable to rise above the inherent restrictions related with diffusional path length for charge carriers along with the charge-carrier recombination happening during interfaces.[7-17] when the thickness of the film of a light absorbing active layer reduces with that the Light absorbance also reduces, which consequential low down power-conversion efficiency. For this reason light trapping or harvesting techniques have been testing to harvest light efficiently. [10–17] Furthermore, thin-film photovoltaic devices which have limited film thickness such as dye-sensitized solar cells (DSSCs) and organic photovoltaics (OPVs), the light-trapping technique is very valuable [18, 19].

2. *Operational Principle of Dye-Sensitized Solar Cells*

The schematic representation of working principle of DSSC is shown in figure (1). The dye-sensitized on which a wide band gap semiconductor (TiO_2, SnO_2, ZnO, etc) is deposited on the surface of photoanode and a monolayer of dye is adsorbed on the surface of semiconductor layer, an electrolyte like tri-iodide and iodide redox couple and finally conductive substrate is the cathode which is covered by a catalyst layer (like Pt, carbon, etc). The ultra-violet light is absorbed by wide band gap semiconductor. In the solar spectrum, more amount of visible range of light is absorbed by the dye molecule and thus makes efficient use of the sunlight [6]. The nanoparticles of the semiconductor supply a huge surface region for adsorption of the dye on it, primary to absorption of more quantity of light by the photoanode. On the other hand, these nanoparticles of the semiconductor have to be sintered together in order to have electronic contact between the particles and allow electronic conduction through the layer. The porous semiconductor (TiO_2) layer is made on a conducting glass substrate ($F:SnO_2$/FTO coated glass), which is externally connected to the cathode. The cathode is again a conductive glass substrate with a catalyst such as Pt deposited on it. The dye molecules commonly used [20, 21, 22].

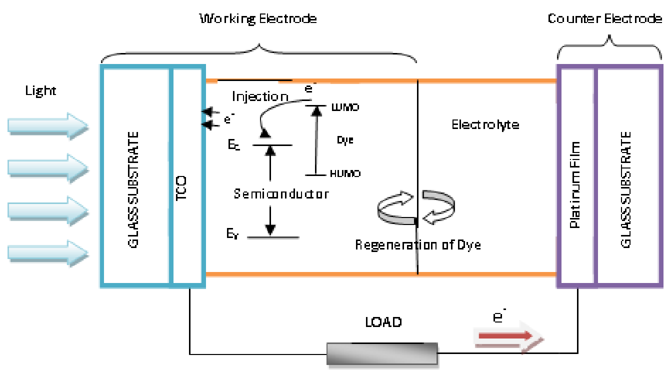

Figure 1: Schematics of DSSC Structure

In dye-sensitized solar cells, three are major barriers which preclude current for achieving greater efficiencies:

- Electrons to move down to the TCO substrate is not easy because the recombination losses in the extremely disordered nanoporous TiO_2 layer.
- Major potential losses arises when electrons are transferred from the redox couple to dye molecules that consequential the open circuit voltage (V_{OC}) become poorer,
- In the near-infrared range of the spectrum, there is the weak absorption of photon that restricting the short circuit current density (J_{SC}),

These are the three major problems in which most of the research work is going on and many of the research paying attention on solving the dilemma in DSSCs. In this paper, we focus only on the content related to collection of charge and light. This review aims to demonstrate that the DSC performance is closely related to the structure of photoelectrode film. A rational design of the photoelectrode structure may lead to optimal light harvesting and electron transport. Aside from the creation of new organic dyes that is a direct way of improving the DSC efficiency, the tailoring of materials for a defined purpose is herein also emphasized to be an important way of speeding up the development of DSSCs.

3. PRESENT DSSC RESEARCH AND DEVELOPMENT:

3.1. Nanostructured photoelectrodes:

One of the most challenging approaches for the improvement of charge collection is the replacement of the disordered nanoporous TiO_2 layer by a nanostructured photoelectrode [23]. In Dye-sensitized solar cells, Nanotechnology offers to investigate materials as well as make different nanostructures. This review work on DSSCs categorizes by means of different nanostructured photo-electrodes layer: Firstly nanoparticles for dye-adsorption which provide wide surface area to photoelectrode layer [24-32]. Secondly 1D nanostructures like nanowires as well as nanotubes, which offer shortest possible trail for electron transport and which is possible more quicker than nanoparticle layers and Nanotube arrays which have the conversion efficiencies in between 6–8% [33- 38].Thirdly core-shell like structures, though with a deliberation by forming a coating layer which are obtained from the nanoparticles is supportive to decrease charge recombination [39, 40]. Lastly 3D nanostructures like nanotetrapods wherein oxide aggregates are most challenging structure which gives higher efficiency [42,43]. It generates light scattering along with the large surface area, so that photoelectrode layer become much thinner and it also decreases the charge recombination in DSSCs [32].

3.2. Nano-patterned FTO Electrodes:

In optoelectronic devices, transparent conductors (TCs) are one of the most essential factors. It is also valuable for optimization of the device performance throughout enhanced light trapping in nanoscale engineering [44]. FTO (Fluorine-doped tin oxide) by means of nanoimprint lithography was patterned with the shape of periodic range of nanopillars as well as nanolines of pitch size of around 700 nm and reactive ion was done by etching by means of environmentally friendly gases. Wavelength of the incident light corresponding to Periodic structures of pitch size will offer efficient lights scattering, which is also suitable to enlarge the optical path length of light through diffracting incident light and it is also propagating enormously oblique angles in the adjacent active layer. By the designed periodic structure, photon momentum is able to scattered away as of the specular direction [46-48]. The patterned FTO which was using on dye sensitized solar cells (DSSCs) was demonstrated better feat in fill factor as well as power conversion efficiency (PCE), and that can be recognized to enhance light absorption in the range 400−650 nm. Experimentally, the cell of 4 μm TiO2 layer in the wavelength range of 400−650 nm which offer outcome of around 2−5% improvement of IPCE% efficiency. In patterned electrodes, both J_{SC} and V_{OC} are found to be higher and which resulting in improved power conversion efficiency as matches up to to the unpatterned electrodes [47].

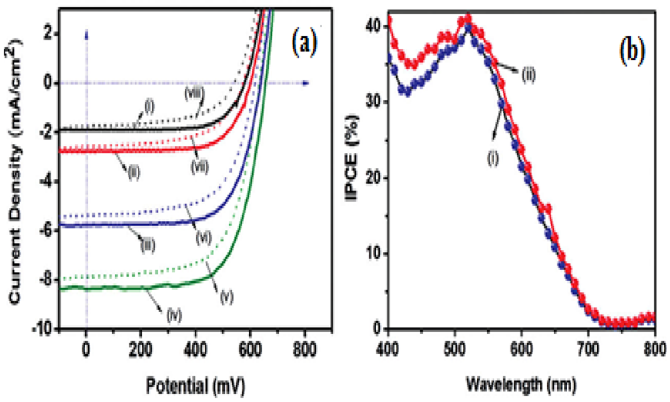

Figure 2: (a) Graph plotted for Current density and Potential characteristics of the patterned (solid line i−iv) and unpatterned (dashed line v to viii) of FTO/TiO_2/N3 in the presence of I^-/I_3^- redox mediator in acetonitrile under different light power density for the 4 μm thick TiO_2 electrodes, lastly (b) Incident photon-to-current conversion efficiency (IPCE%) for patterned (ii) and unpatterned (i) [47].

3.3. Micropatterned 3D Pyramidal Photoanodes:

wooh et al in 2013 has developed a 3D photoanode structure which is extremely efficient and easy light trapping approach to improve the energy conversion efficiency of DSSCs. The soft molding technique with poly (dimethyl siloxane) PDMS molds was used to prepare the 3D TiO_2 Photoanodes structures [49]. In the present study, Pyramid-shaped TiO_2 photoanode gives the highest light absorbance, rather than other geometries of photoanode, and thus the performance of photocurrent-voltage became excellent. By varying the structural design of the TiO_2 photoanodes from 2D flat surfaces to 3D pyramids, more than 20% absorption of light on the surface have been achieved due to the total reflection of incident light on the surfaces of the pyramid shape structures and enhancement of photocurrent in DSSCs [50-51]. As the result, the enhancement of photocurrent and power conversion efficiency up to 40% and 36% for the efficient combination approach of the 3D random pyramid-patterned photoanode in the company of an additional scattering layer, and it is match up to the assessments for a 2D flat photoanode, are achieved from the increase of the light path length by the reflection of the scattered light on the tilted facets of the pyramid structures [52].

3. 4. Semi-closed tubular light-trapping geometry:

In this studied, a chain of works of DSSC has been reported for the enhancement of the PCE under irradiation. Most of the works had done for common cells in planar geometry. The circumventing irradiated light loss is one of the major approaches. Zeng et al. in 2015 has developed geometrical approached for dye sensitized solar cell which is semi-closed tubular light-trapping geometry to enhance it power conversion efficiency in broad light intensity range [53].

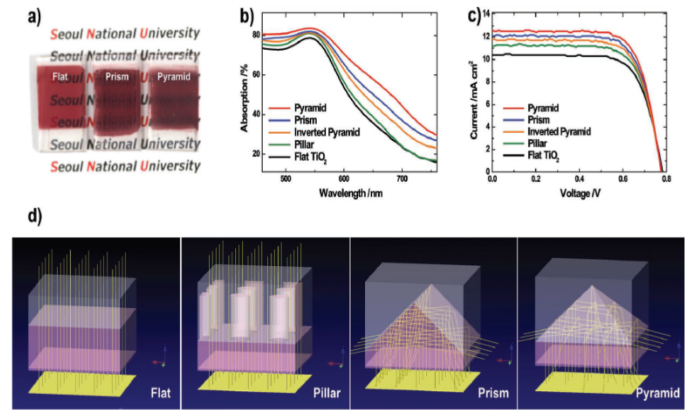

Figure 3: a) A snap shown TiO_2 photoanodes having N719 dyes for three different geometries like flat (2D), prism-patterned, and pyramid-patterned. b) A graph for the characteristic of Light-absorption of 2D and 3D TiO_2 photoanodes for different Geometries, c) Graph plotted between photocurrent and photovoltage characteristics of DSCs with different geometries of photoanodes, measured under 1 sun illumination (AM 1.5 and 100 mW cm^{-2}) with shading masks (active area: 0.25 cm^2). d) The light path results from the optical simulations with different photoanode geometries with a light source of 650 nm wavelength [52].

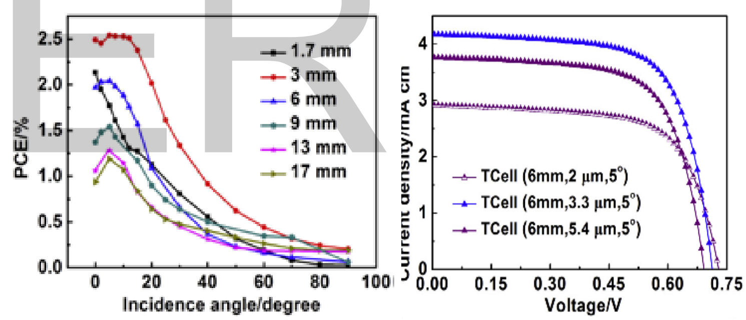

Figure 4: (a). Graph Plotted for the PCE vs light incident angle for TCells, by different tube length, with 3.3 mm PTL thickness. (b). Corresponding J-V curves [54].

4. DISCUSSION:

In summary, light trapping or harvesting strategy has explored in order to increase the absorption of incident light on the photoanode of DSSCs. This review aims to demonstrate that the DSC performance is closely related to the structure of photoelectrode film. A rational design of the photoelectrode structure may lead to optimal light harvesting and electron transport. To stabilize the power conversion efficiency in dye-sensitized solar cells different light trapping geometries, and for the enhancement of light absorption, TiO_2 photoanode geometries like flat, pillar, prism has been used. One more approach for better charge collection is the alternative of the messy nanoporous TiO_2 layer by nanostructured photoelectrodes like nanotubes, nanowires. The main purpose of these nanostructures is to increase charge collection by the involvement of a direct pathway for electron transport and also squashed recombination loss. By changing the structural design of the TiO_2 photoanodes, more than 20% increment in light absorption along with photocurrent of DSSCs has been achieved.

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