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Original article

Impact of photo electrode thickness and annealing temperature on natural dye sensitized solar cell

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ABSTRACT

Photo-electrode thickness and annealing temperature have significant effect on the energy conversion efficiency of dye sensitized solar cell (DSSC). This analysis intends to explore the optimum amount of binder (citric acid) required for the formulation of nano-crystalline TiO_2 semiconductor paste and annealing temperature of TiO_2 electrode for DSSC. Sensitizer was extracted from turmeric using methanol. Doctoral blade technique was used for the deposition of TiO_2 paste onto the indium doped tin oxide (ITO) conductive glass surface via glass rod and blade. Varied thicknesses of TiO_2 coating appeared for different doctoral blade techniques and binder amounts. Surface morphology of the TiO_2 films was determined for different coating type. The bonding of TiO_2 and dye molecule was determined using FTIR spectroscopy. Promising effects of binder amount and annealing temperature were valued in terms of elementary photovoltaic parameters such as short circuit current density (J_{SC}), open circuit voltage (V_{OC}), fill factor (FF) and efficiency ($\eta\%$). Overall optimum energy conversion performance of the cell achieved when TiO_2 coating thicknesses were ranging from 12 to 17 μm and annealed at 450 °C.

Introduction

Flourishing demand for energy crisis is one of the utmost challenges to economic growth and climate alteration around the globe. For hundred years, the world energy supplies are usually retrieved from various fossil fuels of finite resources like coal, petroleum and natural gas. Tragically, over combustion of these fossil fuels is the main “culprit” causing global warming. Therefore, for advancement of civilization with limited environmental hazards, sustainable energy sources are required essentially. In this concern renewable energy can be presumed as the best option. Mostly popular forms of renewable energies are wind power, hydro power, solar energy, biomass, bio-fuel and geothermal energy [1]. Among all of the renewable power sources, solar energy is the most easily exploitable, quite, non-polluting and adjustable to enormous applications. Currently, solar energy is engaging in several promising applications like portable power supply, wireless sensor, satellite and simple, rugged & low cost structure switched reluctance motor, etc. [2,3]. It has been estimated that the rapid demand of energy in the globe can be satisfied, if only 0.1% of earth is covered with solar cells having efficiency of 10% [4]. Economy, environmental concern, complex fabrication process, heavy weight, inflexibility etc. are the key constrains of commercial silicon type solar cells. In this regards, DSSC have been extensively investigated because of their attractive advantages including both economic and quality perspective [5]. DSSCs are under the class of third generation, which can be prepared through simple and economical solution processing route where dye employed as a sensitizer, which ingests daylight, gets energized and afterward offers electron to the semiconductor [6].

DSSCs are typically comprised of photo-anode, sensitizer, redox mediator/electrolyte and counter electrode. To build up the photo-anode, metal oxides, for example, TiO_2, ZnO and Nb_2O_5 are popularly exploited as semiconductor [7,8]. For DSSC, wide band gap enclosing materials whose band gap match with the vitality gap amongst highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital(LUMO) levels of dye is utilized. In this regards, TiO_2 is found as more proficient [9].

Polypyridyl complexes of Ruthenium (Ru) N3, N719 and black dyes exhibited promising photo-electrochemical performance which was developed by the Grätzel group [4]. Tragically, the Ru

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Nomenclature

DSSC	dye sensitized solar cell
ITO	indium doped tin oxide
J_{SC}	short circuit current density
V_{OC}	open circuit voltage
FF	fill factor
η%	efficiency
FTIR	Fourier Transform Infra-red
$C_6H_8O_7$	citric acid
TiO_2	Titanium dioxide (Degussa P25)
$C_8H_{17}C_6H_4(OCH_2CH_2)nOH$	Triton X 100
$HO(C_2H_4O)_nH$	Polyethylene glycol 6000 (PEG)
$Ti[OCH(CH_3)_2]_4$	Titanium (IV) Isopropoxide
CH_4O	Methanol
KI	Potassium iodide
I_2	Iodine
Ru	Ruthenium
HOMO	Highest occupied molecular orbital
LUMO	Lowest unoccupied molecular orbital
HCl	Hydrochloric acid
ZnO	Zinc oxide
Nb_2O_5	Niobium pentoxide
IDCOL	Infrastructure Development Company Limited

metals are retrieved from rare natural resources which are relatively heavy, ecologically encumbrance and expensive as well. Hence the use of natural dye as photosensitizer in DSSC is an emerged soaring awareness of sustainability, ease of availability, abundance in supply, can be applied without further purification, and economy [10]. Among several natural dyes, researchers found significant energy conversion ability of curcumin [11–21]. Curcumin was used not only in nano-crystalline TiO_2 electrode but also in nano sized ZnO electrode [11]. Different acid treatment for prolonging the curcumin stability [13], optimization of photo-electrode sensitization time [15], mixing of different dye sources with curcumin [16], uses of various parts of turmeric plant [18], comparison of efficiency with other sources [17,19–21], the influence of extracting solvent [22] and surface pretreatment of sintered photo-electrode with HCl and TiO_2 [22] had studied to enhance photovoltaic response. Optimization of binder amount for preparing semi-conductor slurry intends to obtain the desired film thicknesses and annealing temperature in case of turmeric sensitizer may have effects on photovoltaic response that had not been studied yet.

Researchers are continually trying to improve the efficiency of DSSC by optimizing various working parameters of DSSC. Among them the semi-conductor coating thickness [23,9,24,25,31] and annealing condition [24–34] has significant impact on photovoltaic response. Thicker coating assists to adsorb more dye molecule but thickness increment beyond the light infiltration depth yields more recombination, which focuses to bring about a higher electron loss and therefore falling of photovoltaic characteristics. So, optimization of thickness is necessary for the best performance. Regarding temperature, the cell performance increases due to improved crystallinity, grain size, transparency and anchoring geometry of dye up to a certain limit and begins to wane. So, optimization of temperature is also necessary for the photo electrochemical properties of DSSC.

So, this study attempts to express a favorable impact of TiO_2 photo-anode fabrication parameters such as optimization of semi-conductor layer thicknesses by binder amount variation in the preparation of slurry. The role of annealing temperatures on the energy conversion efficiency of the dye sensitized solar cell using turmeric as sensitizer was also optimized.

Experimental

Materials

Citric acid ($C_6H_8O_7$), TiO_2 (Degussa P25), Triton X 100 ($C_8H_{17}C_6H_4(OCH_2CH_2)nOH$), Polyethylene glycol (PEG), Titanium IV Isopropoxide, Methanol (CH_4O), Potassium iodide (KI), Iodine (I_2) were purchased from Merck, Germany. ITO glass was purchased from Dyesol, Australia. All chemicals were analytical grade and used without any further purification.

Methods

Film fabrication

The film was fabricated according to our previous work [31]. Briefly, requisite amount of Degussa P25, citric acid, PEG, and Triton X-100 and Titanium IV Isopropoxide were mixed homogeneously to prepare nano-crystalline TiO_2 semiconductor slurry. Prepared slurry was deposited onto the ITO glass surface by doctoral blade technique employing glass rod and NT cutter blade and sintered at 450 °C in a muffle furnace. To observe the effect of annealing temperature, TiO_2 coated films were annealed for 1 h at 350, 400, 450, 500 and 550 °C respectively [26]. Varied thicknesses of TiO_2 coating were appeared for different doctoral blade techniques and binder amounts variation using 3, 4 and 5 mL citric acid (0.1 M) solution. The thickness of TiO_2 layer was measured by surface profilometer, Decta 150, USA.

Dye extraction

Firstly, turmeric root was washed very well and then peeled off. After that it was kept in air for two days in absence of sun light for drying. This dried turmeric was then weighted and immersed into methanol. After 24 h, the extract was filtered and collected for application.

Cell preparation

The annealed TiO_2 film (about $10cm^2$) was immersed in 15 mL dye for one hour. By this time dye molecules were adsorbed by TiO_2 film and the film was colored. Then the film was dried in an oven at 60 °C for 10 min. Another ITO glass was coated with carbon of candle nip for counter electrode. Potassium iodide and iodine were mixed in ethylene glycol for making electrolyte solution. Photo-anode and counter electrode were then combined together and electrolyte solution was added drop wise between the arrangements [31].

Characterization and measurement

Surface morphology of TiO_2 film having varied thicknesses were analyzed by Inverted Microscope (Dewinter Technologies, Italy) keeping 10x magnification. Bonding between TiO_2 and curcumin were determined using PerkinElmer Spectrum Two FTIR spectrophotometer, UK. The fabricated DSSC was illuminated under $100\ mW/cm^2$ radiation from a handmade solar simulator for assessing the photovoltaic response. The overall solar energy to electricity conversion efficiency of a solar cell is defined as the ratio