Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 193 (2018) 467–474

Contents lists available at ScienceDirect

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

journal homepage: www.elsevier.com/locate/saa

Performance and stability analysis of curcumin dye as a photo sensitizer used in nanostructured ZnO based DSSC

D. Sinha [a,*], D. De [b], A. Ayaz [c]

[a] Department of Electrical Engineering, Dr. B C Roy Engineering College, Durgapur, India
[b] Department of Applied Electronics and Instrumentation Engineering, Dr. B C Roy Engineering College, Durgapur, India
[c] Department of Electrical Engineering, Shree Ramkrishna Shilpa Vidyapith, Suri, Birbhum, India

ARTICLE INFO

Article history:
Received 22 August 2017
Received in revised form 19 December 2017
Accepted 20 December 2017
Available online 26 December 2017

Keywords:
Chemical synthesis
Cyclic voltammetry
Dye sensitize solar cell
Energy band position
FTIR
Nanostructured zinc oxide
UV–Vis spectroscopy

ABSTRACT

Environmental friendly natural dye curcumin extracted from low-cost *Curcumina longa* stem is used as a photo-sensitizer for the fabrication of ZnO-based dye-sensitized solar cells (DSSC). Nanostructured ZnO is fabricated on a transparent conducting glass (TCO), using a cost-effective chemical bath deposition technique. Scanning electron microscopic images show hexagonal patterned ZnO nano-towers decorated with several nanosteps. The average length of ZnO nano-tower is 5 μm and diameter is 1.2 μm. The UV–Vis spectroscopic study of the curcumin dye is used to understand the light absorption behavior as well as band gap energy of the extracted natural dye. The dye shows wider absorption band-groups over 350–470 nm and 500–600 nm with two peaks positioned at 425 nm and 525 nm. The optical band gap energy and energy band position of the dye is derived which supports its stability and high electron affinity that makes it suitable for light harvesting and effortless electron transfer from dye to the semiconductor or interface between them. FTIR spectrum of curcumin dye-sensitized ZnO-based DSSC shows the presence of anchoring groups and colouring constitutes. The *I-V* and *P-V* curves of the fabricated DSSC are measured under simulated light (100 mW/cm^2). The highest visible light to electric conversion efficiency of 0.266% (using ITO) and 0.33% (using FTO) is achieved from the curcumin dye-sensitized cell.

1. Introduction

The dye-sensitized solar cell (DSSC), considered as a third generation solar cell, is a low cost promising photo chemical electric cell which is very simple in construction. The layer by layer construction of DSSC is made by stacking of transparent conductive oxide substrate, photo-anode, dye, electrolyte, and cathode from top to bottom layer. Such type of cells shows the maximum efficiency of >11% [1]. The main component of DSSC, photo-anode, serves the purposes of collecting and transporting of excited photo electrons from dye to the conducting substrate [2]. Nanostructured TiO_2 based photo-anode are more efficient for the conversion of incident photon to an electrical signal, but its relatively slow electron transport leads to the high interface recombination reactions and limits the efficiency of the system [3]. Longo and Paoli [4] reported that recombination of injected electrons with the electrolyte is the primary loss path in DSSCs and that decreases the efficiency of DSSCs. ZnO photo anode in a DSSC can make a direct electron flow path which leads to increase electron mobility and its life [5]. ZnO of different morphologies used as a photoanode are reported elsewhere [6,7]. The wide bandgap semiconductors like ZnO or TiO_2 can be sensitized by the natural dye due to high absorption of visible to UV light [8]. Under the sunlight, the dye molecules are excited and transfer one electron into the conduction band of the ZnO or TiO_2. In reduction, the electrolyte supplies one electron for regeneration of the dye. In oxidation, the electrolyte is regenerated by accepting one electron which is supplied by counter electrode by recapturing of the conduction band electrons when the circuit is completed through the external load [9]. One of the important components, dye sensitizer, plays as the backbone of the cell. The natural dyes used in DSSC embrace their availability, cost-effective, completely biodegradable, non-toxicity and simple synthesized process. Natural dyes extracted from different plants, leaf, flower, root, fruit etc. contain kinds of pigments such as anthocyanin, betalains, chlorophyll, etc., and shows different cell efficiencies [10–16]. There are two categories of betalain (i) betacyanin which include the reddish to violet betalain pigments and (ii) betaxanthin which appears yellow to orange [17]. The natural dye betaxanthin is available in different plants, including the stem of *Curcumina longa* (turmeric). This paper is mainly intended to exhibit the performance of the ZnO based DSSC using natural dye betaxanthin, extracted from *Curcumina longa*, as a photo-sensitizer. Syafinar et al. [18] showed the UV–Vis spectroscopy of curcumin dye at a wavelength of 400–550 nm and absorption maxima at 480 nm. Suresh et al. [19] have fabricated a

* Corresponding author.
E-mail address: dola.sinha@bcrec.ac.in (D. Sinha).

https://doi.org/10.1016/j.saa.2017.12.058
1386-1425/

DSSC with betaxanthin dye sensitized nanostructured ZnO photo anode, and it is shown that the light absorption wavelength range of 350–490 nm with a peak at 423 nm and it has the maximum efficiency of 0.13%. Sengupta et al. [16] showed that betanin dye could provide efficiency of 0.194% using ZnO. Ruhanea et al. [20] showed that with curcumin dye the efficiency of DSSC could be varied from 0.079–0.11% by changing the annealing temperature of TiO_2 based photo anode. Kim et al. [21] show that UV–Vis absorption spectra of curcumin are in 350–500 nm range and with different pH values, the efficiency of the fabricated cell varies from 0.28–0.6% with TiO_2 as photo anode. At acidified condition betaxanthin dye extracted from prickly pear can enhance efficiency upto 2.06% using TiO_2 [22]. The molecular structure, anchoring groups present in the dye, redox properties of electrolyte, as well as band positions of each components of DSSC [23] and driving force energy changes from a donor to acceptor level [24] etc., are the important parameters of the dye which predict stability and performance as a dye sensitizer in DSSC. In this present paper, the solar cell is fabricated using nanostructured ZnO as a photo anode, deposited over TCO glass substrate and curcumin as the natural dye sensitizer. Nanostructured ZnO is synthesized by a simple and cost-effective wet chemical method, and the synthesized material is directly grown on TCO substrate. The electrical performance parameters are evaluated for this solar cell. The efficiency of the fabricated cell is shown the highest efficiency as compared to the report available with DSSC made of ZnO photo anode on indium tin oxide (ITO) and fluorine doped tin oxide (FTO) and betaxanthin natural dye sensitizer extracted from curcumin. The experimental procedure for fabrication of DSSC is explained in Section 2, and some results and discussions are made in Section 3.

2. Experimental Procedure

2.1. Synthesis of ZnO Photo-anode

The TCO (ITO with a resistivity of 12 Ω/sq and FTO with a resistivity of 8 Ω/sq) coated glass slides of rectangular shape are properly cleaned and immersed in a beaker consisting of aqueous $Zn(NO_3)_2 \cdot 6H_2O$ and NH_4OH solution via chemical bath deposition technique. The detail synthesis process for fabrication of nanotower shape ZnO is published in our paper [25]. The ZnO coated substrates are ringed by de-ionized water until it becomes neutral and is kept for drying. The coated TCO substrates are annealed at 450 °C for 2 h in air. A schematic representation of synthesis process is shown in Fig. 1.

The X-ray diffraction (XRD) of ZnO coated ITO glass substrate is carried out using Cu Kα radiation in a Bruker D8 Discover diffractometer to study the phase formation behavior. The morphological and elemental analyses of the sample are performed using scanning electron microscope (SEM, JEOL JSM-6480 L V) equipped with energy dispersive X-ray spectroscopy (EDX).

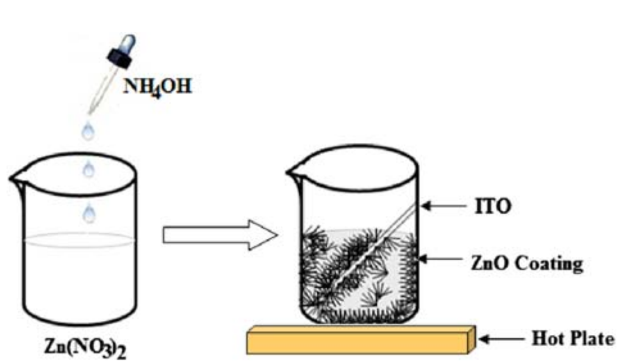

Fig. 1. Model diagram of ZnO synthesis in Chemical bath deposition technique.

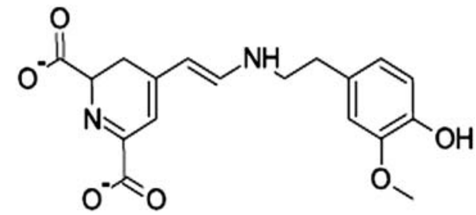

Fig. 2. Chemical structure of Betaxanthin dye [12].

2.2. Natural Dyes Extraction

Betaxanthin pigments are extracted from curcumin stem by cutting into small pieces and mashed into a paste using a mortar then the sample is placed in an ultrasonic cleaner for 15 min with a frequency of 37 Hz using 'degas' mode at the temperature of 30 °C. The colouring of the sample is segregated by 2500 rpm centrifugal force for 30 min. In the ethanolic solution (1:1), the pH of the prepared betaxanthin dye comes as 8.5. The ZnO coated ITO is then placed into the dye for 24 h. The chemical structure of this dye is shown in Fig. 2.

2.3. Fabrication of DSSC

The sandwiched type DSSC (effective cell area 1 cm^2) is fabricated using prepared nanostructured ZnO as photo anode and extracted curcumin as dye sensitizer. The redox couple I^-/I^-_3 is used as the electrolyte. The electrolyte is prepared by mixing (0.5 M) KI solution with (0.05 M) I_2 and stirring the mixture for 3 h. The carbon coated TCO is used as a counter electrode for the cell. Silver paste is used to make the electrical contacts from the fabricated solar cell. The photo-current (I) and voltage (V) characteristics of the prepared cell are measured using a source meter (2400, Keithley, USA) and a solar simulator (100 mW/cm^2 from Air Mass 1.5 G). The fill factor and the photo conversion efficiency are also derived from analyzing the performance of the cell. The fill factor (FF) of a DSSC is defined as the ratio of the actual maximum power P_m (product of voltage V_{mp} and current I_{mp} at maximum power) obtains to the product of short circuit current I_{sc} and open circuit voltage V_{oc}. P_m is an important parameter for evaluating the performance of a solar cell.

The power conversion efficiency (η) is the ratio of the maximum energy output from a DSSC to input solar energy (P_{in}) incident on the total surface area of the solar cell as shown in Eq. (1). The input power (P_{in}) depends on the solar spectrum and intensity of incident light.

$$\eta = \frac{\text{Fill factor} \times I_{sc} \times V_{oc}}{P_{in}} \times 100\% = \frac{P_m(\text{mW/cm}^2)}{\text{Light intensity (mW/cm}^2)} \times 100\% \quad (1)$$

A model diagram of a different components arrangement in DSSC is shown in Fig. 3.

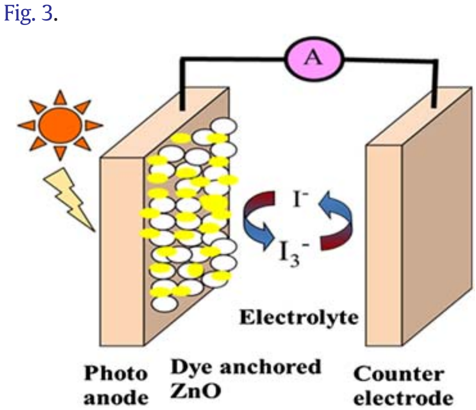

Fig. 3. Different components of DSSC.