Optik 127 (2016) 4400–4404

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Comparative study between dye-synthesized solar cells prepared by electrophoretic and doctor blade techniques

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ARTICLE INFO

Article history:
Received 30 December 2015
Accepted 25 January 2016

Keywords:
Sensitized solar cell
Electrophoretic technique
Doctor blade method
Natural dyes
Electrical parameters

ABSTRACT

Comparative study between solar cell sensitized by several naturel dyes and fabricated with two methods: electrophoretic deposition process (EPD) and doctor blade technique (DB) have been presented.

TiO_2 layers have been deposited on the glass FTO (Fluorine doped tin oxide: SnO_2: F) for the tow techniques. Structural and morphological properties were presented and correlated to deposition conditions of growing films. Natural dyes have been prepared and used to realize Dye-Synthetized Solar cells (DSSCs).

Developed electrical model was used to study and extract experimental parameters. The compared I – V measurements under 100 mW/cm^2 illumination have shown an increase in both filling factor (FF) to reach 58.85% and open circuit voltage (V_{oc}) value of 0.66 V for mallow sensitized solar cell fabricated with EDP technique. A decrease in short circuit current (I_{sc}) and efficiency (η) due to the TiO_2 layer thickness and the cracks appearing in the layer fabricated with EPD technique.

1. Introduction

Sunlight is the most promising source of energy to meet the demands of the growing population. The conventional silicon based photovoltaic devices are replaced by the novel dye sensitized solar cells due to their remarkable benefits. An attractive and cheaper approach for the conversion of solar light into electrical energy has been to utilize large-band-gap oxide semiconductors such as ZnO, SnO_2 and TiO_2 to absorb solar light [1–5]. TiO_2 is established as the most performing semiconductor metal oxide in DSCs, both in the form of the commonly employed sintered nanoparticles and nanotubes/nanorods [6,7]. Among three different crystal structures of TiO_2 (rutile, anatase, and brookite), the anatase structure has attracted much attention over the last decades for its technological applications such as photovoltaic solar cells and photocatalysis [8,9]. DSSCs with large-band-gap oxide semiconductors have been investigated for many years [10–12] because that can be produced at very low cost. A major photoelectrochemical solar cell development was obtained with the introduction of fractal thin film dye-sensitized solar cells devised by O'Regan and Grätzel [13].

Many studies are realized on the dye used for sensitizing DSSC since it is the principal source of the photogenerated current by the cell. Conversion efficiency of the dye solar cells achieved with synthetic dyes, such as N719 and black dye, has reached to 13% [14,15]. However, the price of this dye stays even higher. Nevertheless, the natural dye becomes more real concurrent to artificial dye, as cell efficiency sensitized with this dye remains low [16,17].

The major goal of the current study is to choose the suitable inexpensive method to prepare DSSCs using electrophoretic technique (EPD) and doctor blade method (DB). The comparative study concerns extracted parameters from experimental data.

2. Materials and experimental

2.1. Preparation of electrophoretic suspension

TiO_2 (P25) nanoparticles with a primary particle size of 21 nm, and the phase composition of 80% anatase and 20% rutile were purchased from Degussa Chemicals (Hanau, Germany) were used in this study.

The TiO_2 suspension consists of 0.1 g nanocrystalline TiO_2 powder in 20 ml of 2-propanol with 1 ml of acetic acid and it is magnetically stirred for 2 h at 25 °C at the rate of 400 rpm.

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http://dx.doi.org/10.1016/j.ijleo.2016.01.191
0030-4026/

2.2. Preparation of doctor blade suspension

5 g of nanocrystalline titanium dioxide (TiO_2) was mixed with 3 ml of diluted acetic acid (prepared by adding 0.1 ml concentrated acetic acid to 50 ml of distilled water). We alternated grinding and adding a few drops of a very diluted acetic acid until obtaining a colloidal suspension. We grinded about half an hour the titania paste.

2.3. Preparation of photoanodes

In this work, EPD and DB techniques were used to prepare the titanium dioxide nanoparticles films. EPD is an electrochemical method [18,19] that attracted increasing interest as a material processing technique. In the first step, an electric field is applied between two electrodes and charged particles suspended in a suitable liquid, move toward the oppositely charged electrode (electrophoresis). In the second step, the particles accumulated at the deposition electrode create a relatively compact and homogeneous film.

During the EPD process, the FTO glass had a negative potential (anode) while aluminum was used as the counter electrode (cathode). A distance of 1 cm was applied between the two electrodes. The used generator is DC power supplies HCS-3604 (SPS 60-15A) part of SPS MEDIUM POWER Series and the applied voltage was 60 V.

Finally, the TiO_2 films prepared were heat treated at 450 °C in air for 1 h. The TiO_2 colloid prepared was dropped on the FTO glass plate following DB technique. Finally, the DB electrodes were further sintered at 450 °C in air for 1 h and were allowed to cool down gradually.

2.4. Preparation of natural dye sensitizers

Anthocyanin is extracted from Karkade flowers by crushing in a juice mixer. The resulting finely ground powder (20.00 g) was soaked in a 250 ml Erlenmeyer flask with 150.00 ml ethanol. The mixture was magnetically stirred gently at 60 °C for 30 min. The mixture was then cooled, for 20 min, and filtered.

The prepared procedure of mallow and henna powder was similar. In fact, the powder (4 g) was soaked into beaker with 40 ml of ethanol and the mixture was magnetically stirred for 30 min, and filtered.

2.5. DSSC assembling

Six different DSSCs were fabricated by EPD and DB technics using anthocyanin, mallow and henna as sensitized dyes. All photoelectrode cells have area equal to1.5 cm^2.

For different cells, each counter-electrode was covered with a Pt catalyst layer deposited on the conductive face of the FTO glass using DB method. The rubber seal, 1 mm thick, was sandwiched with the TiO_2 and Pt electrodes in order to avoid the electrolyte leakage. Then, an electrolyte liquid containing the I^-/I_3^- redox couple was injected into the space between two electrodes. We have used two syringes: one to inject the electrolyte and the other to absorb the air.

2.6. Technical measurements

X-ray diffraction measurements were given by an X'pert Pro X-ray diffractometer, with $2\theta = 10 - 70^\circ$, 0.033° as increment, integration time 50 s and Cu Kα1 radiation, $\lambda = 1.5406$ Å. Electronic absorption spectra were measured for the resulting pigment solution, on a Shimadzu UV-1601 spectrophotometer from 400 to 800 nm. The optical microscopically observations were done using an ultra nanoindenter CSM Instruments.

The current – voltage (I – V) curves of realized DSSC were measured under AM1.5 using a density of power 100 mW/cm^2 and Keithly electrometer 6517A at room temperature. Reading parameters were carried out by developed software using LabVIEW through the RS232 serial intelligent and operator procedures Keithly device.

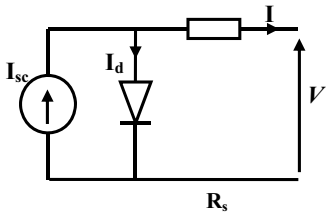

Fig. 1. Equivalent electrical circuit.

3. Results and discussion

3.1. Extraction of experimental parameters

In order to improve DSSCs performance and optimization, detailed electrical and physical models based on diffusion, recombination and charge transport phenomena have been developed to illustrate its operation [20,21]. Therefore, in this investigation, the electrical circuit, presented by the Fig. 1, is used an equivalent circuit model for our DSCCs.

In this case, we neglected the effect of shunt resistance because usually the leakage current modeled by the shunt resistance at the anode/electrolyte interface, is forbidden by blocking layers that avoid direct contact between FTO/electrolyte. Various types of blocking layers can be used made of semiconductors and insulating materials such as TiO_2, Nb_2O_5, ZnO, $CaCO_3$ and $BaCO_3$ [22].

The current – voltage equation was given by:

$$I = I_{SC} - I_S\left(\exp\left(\frac{q(V + R_S I)}{mkT}\right) - 1\right) \tag{1}$$

where, $\boldsymbol{k}$ is Boltzmann's constant, $\boldsymbol{T}$ is the absolute temperature, $\boldsymbol{m}$ is the ideality factor, $\boldsymbol{I_{sc}}$ is the short circuit-current, $\boldsymbol{I_s}$ is the saturation current of the junction, $\boldsymbol{q}$ is the electron charge and $\boldsymbol{R_s}$ the sheet resistance due to the TCO layers. To determine the experimental values of $\boldsymbol{R_s}$, $\boldsymbol{I_s}$ and $\boldsymbol{m}$ we have used simplified explicit method [23,24] and experimental data $\boldsymbol{I_{sc}}$, $\boldsymbol{V_{oc}}$, $\boldsymbol{I_m}$, and $\boldsymbol{V_m}$ deducted from the measured $I - V$ curve.

From the open circuit voltage we can deduce the saturation current $\boldsymbol{I_s}$

$$I_S = \frac{I_{SC}}{\exp\left(\frac{qV_{OC}}{mkT}\right) - 1} \tag{2}$$

The sheet resistance $\boldsymbol{R_s}$ is given by:

$$R_s = \frac{\frac{mKT}{q}\log\left(1 - \frac{I_m}{I_{sc}}\right) + V_{oc} - V_m}{\exp\left(\frac{qV_{oc}}{mKT}\right) - 1} \tag{3}$$

The last parameter to be determined is the ideality factor ($\boldsymbol{m}$), exploiting the fact that the derivative of the maximum power is zero and using Eq. (2) we can find:

$$m = \frac{(2V_m - V_{oc})}{\frac{KT}{q}\left[\log\left(1 - \frac{I_m}{I_{sc}}\right) + \frac{I_{sc}}{I_{sc} - I_m}\right]} \tag{4}$$