FABRICATION AND OPTIMIZATION OF PARAMETERS FOR DYE SENSITIZED SOLAR CELL

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Abstract

The interest in the dye sensitized solar cell is due to its low cost, simple preparation techniques and benign effect on the environment. Thin film of TiO2 deposited on FTO (Fluorine doped Tin Oxide) acts as one electrodes, platinum coated FTO acts as the other electrode and eosin B solution acts as the sensitizer. Lithium iodide, iodine in acetonitrile solution is used as the electrolyte. It is noted that an efficiency of 7.4% was observed for a cell with Intensity 70 lux. Also the open circuit voltage of 0.5V, short circuit current of 150µA and a fill factor of 0.68 were observed for the cell of area 1X1 cm^2. The experimental model is checked with theoretical model using MATLAB software. It is noted that the simulated values follow a pattern which closely resembles the actual values of the experiment. The effect of the aging process on the overall performance of the device was analyzed by means of electrochemical impedance spectroscopy. The results shows that the electrolyte-TiO_2 capacitance of 20 µF (parallel) and the resistance of 14.74 k ohms (parallel) in series with the platinum resistance of 25.58 ohms.

Index Terms: *DSSC, efficiency, MATLAB and impedance spectroscopic studies*

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1. INTRODUCTION

Solar energy is the primary and abundant source of energy available from nature. Among the different types of solar cells, dye sensitized solar cell (DSSC) [1] falls under the category of solid/liquid type. DSSC differs from conventional semiconductor devices in that they separate the function of light absorption from charge carrier transport. These types of solar cells are new generation solar cells emerged in early 1990's targeting to achieve moderate efficiency devices with low cost [1,2], easy fabrication [3], low toxicity [4] and long term stability [5]. It consists of a porous nanocrystalline TiO_2 (Titanium dioxide) layer coated onto a Transparent Conducting Oxide (TCO) glass substrate using Dr.Blade [6] technique and platinum (Pt) coated FTO glass plate and the iodine based electrolyte is sandwiched between the two plates. Since TiO_2 is insensitive to light due to its wide bandgap (3.2 eV) [7], light absorption is accompanied by a monolayer of dye (sensitizer) which is chemically bonded to the surface of TiO_2 particle. In a typical DSSC, dye molecule are adsorbed on the surface of TiO_2 which does the function of photoelectric conversion over a wide spectral range of solar spectrum. When sunlight falls on DSSC, the electrons in the dye molecule excited from the HOMO (highly occupied molecular orbital) level to the LUMO (low unoccupied molecular orbital) level and injected into the conduction band of TiO_2 layer and into the TCO (transparent conducting oxide).The vacant level in HOMO is filled with electron supplied by the iodine (I^-) ions from the electrolyte and the iodine is oxidized to tri iodide (I^{3-}).Further , the platinum counter electrode acts as a catalyst for the redox reaction of the ions in the electrolyte solution and reduces from $I^{3-}$to I^-

2. EXPERIMENTAL SETUP:

The cell has three main parts (1) working electrode (2) counter electrode and the (3) electrolyte. Nanocrystalline TiO_2 (~20 nm –Zigma Aldrich) coated on the FTO (fluorine doped tin oxide SnO_2:F) acts as the working electrode (anode). Then it is immersed in eosin blue (Zigma Aldrich) for a period of 48 hours. The electrodeposited Platinum (Pt) on FTO acts as the counter electrode (cathode). The two electrodes are then sandwiched with a thin layer of iodine based electrolyte in between the electrodes and sealed together to prevent the electrolyte from leaking.

2.1 Preparation of TiO_2 electrode*:*

Cleaning of the FTO plate is done by immersing the FTO plate in acetone and sonicating for 10 min. 3.5 g of TiO_2 nano powder is added to 15ml of ethanol and it is sonicated for 30 min [8]. Then 0.5 ml of titanium tetra isopropoxide (binder) is mixed with the above solution until the suspension is uniform [9]. The resultant TiO_2 paste is coated on FTO glass by doctor blade technique. Sinter it for about 10 min at 450^0 C, repeat the above steps and change the sintering time to 20 and 30 min [10].

2.1.1 Doctor blade Technique:

It is one of the suitable methods to produce nanoparticle structure of wide bandgap material and it is the first technique used to create a TiO_2 layer and it is less sophisticated [1].This technique consists a flat sharp object (like a razor blade) or a round thin object (like a glass stirrer), which is used to lay a layer of slurry with a thickness determined by the spacer. The spacer is an adhesive tape normally with a thickness of 8-10 µm as an

average [11]. It is placed opposite sides of the area where the film is to be laid and the doctor blade dragged across. The surface structure and the thickness depend on how the blade is dragged across, position of the blade during the process and the flatness of the spacer material and the thickness of the film coated is the thickness of the spacer thickness. The limitation of this technique is, it is difficult to find an appropriate spacing material with thickness of 1-7µm [12].

2.2 Preparation of Pt electrode*:*

The counter electrode **(P**t) is prepared by Bulk electrolysis method [13]. In our experiment the working electrode (FTO glass plate) is kept at a constant potential of -0.4V with respect to the reference electrode (Pt wire) by adjusting current at the counter electrode and the current is monitored over a period of time. Choloroplatinic acid of 5 mM concentration is used as an electrolyte. In this experiment a current of -1.3 mA is passed over a period of 100 seconds. The amount of charge passed during the electrolysis can be calculated by integrating the current with respect to time. The area of the electrode is kept as $0.25cm^2$. The total charge passed during electrolysis is $-1.21x10^{-1}$ C. Using this value the weight of Pt deposited is found to be 0.233mg and the thickness of the Pt layer deposited is obtained by dividing the volume by area.

2.2 Preparation of sensitizer:

The light harvesting efficiency and hence the conversion efficiency depends on the properties of the sensitizer used. An ideal sensitizer should be capable of absorbing light below threshold wavelength of about 920nm.Its redox potential should be sufficiently high that it can be regenerated rapidly via electron donation from the electrolyte or a hole conductor. In the present investigation 14mg of Eosin b disodium salt is added to 20 ml of ethanol, acts as a sensitizer and the electrode is dipped in the sensitizer for 48Hrs.

2.3 Preparation of electrolyte:

The properties of the electrolyte also have great effect on the conversion efficiency and stability of the cell. In the present work 330mg of LiI and 33 mg of iodine in 5ml of acetonitrile act as the electrolyte.

2.4 DSSC assembly:

The two prepared electrodes are then sandwiched along with a tissue paper to let the iodine based electrolyte between the electrode and it is sealed to prevent the electrolyte from leaking (Fig.1). The area of exposure is $1x1cm^2$.

Fig .1 DSSC **A**ssembly

2.4 Photovoltaic measurements:

The voltage-current characteristic of the cells were carried out using an incandescent lamp as a source of power $100watts/cm^2$, operating at 230 V *ac.* The distance between the lamp and the test sample is adjusted to get the required input intensity on the cell. The measurements are noted for 1000 lux, 70 lux and also for the sunlight as the source.

3. RESULTS AND DISCUSSION:

The results and discussion focused on (1) the efficiency of the cell at different intensities after optimizing the sintering time (2) software (MATLAB) model to compare with the experimental part and (3) the Impedance spectroscopic studies to find the resistance and capacitance of the cell.

3.1 Efficiency:

Initially the parameters such as thickness of TiO_2 (~1000nm), thickness of Pt (228nm) and the dipping duration (48 hrs) in the sensitizer are kept constant. The sintering time is varied from 10 to 30 min at 400°C.it is noted that the film sintered at 30 min gave good efficiency. So the cells are fabricated using the above said parameters and it is exposed at different intensities (70 to 47000 lux).The cell parameters obtained at various intensities are shown in Table (1). The experimental observation shows that the efficiency for 70 lux was above 7.5 %. The calculated fill factor value of 0.68, open circuit voltage of 0.05V and the short circuit current of 150 µA were observed for the cell. From the tabulation it is noted that for higher intensities (47000 lux) the efficiency was found to be .00159%. This may be due to the evaporation of electrolyte at higher intensities as the electrolyte is send in between the two electrodes by a tissue paper which is extended outside. The electrolyte is send, drop by drop through the tissue paper and it is noted that at very high intensities it is evaporated very fast.

Table 1. Comparison of Cell Parameters at different Intensities

Light Intensity (Lux)	Open Circuit Voltage (mV)	Short Circuit Current (µa)	Efficiency (%)	Fill Factor
70	50	75.5	7.56	0.68
1000	51.3	166	0.28	0.2
47000	6	123	0.00159	0.79

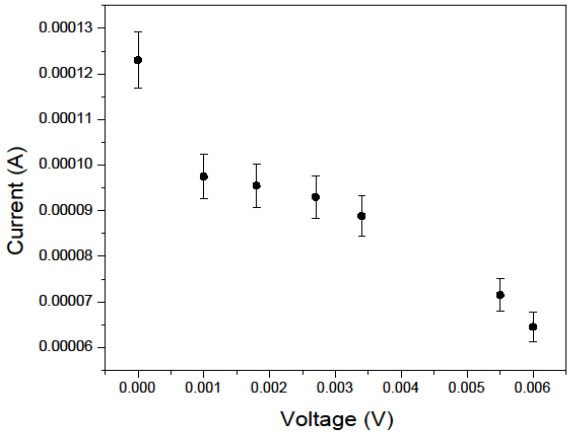

Fig2 Graph of Current Vs Voltage for intensity 70 lux

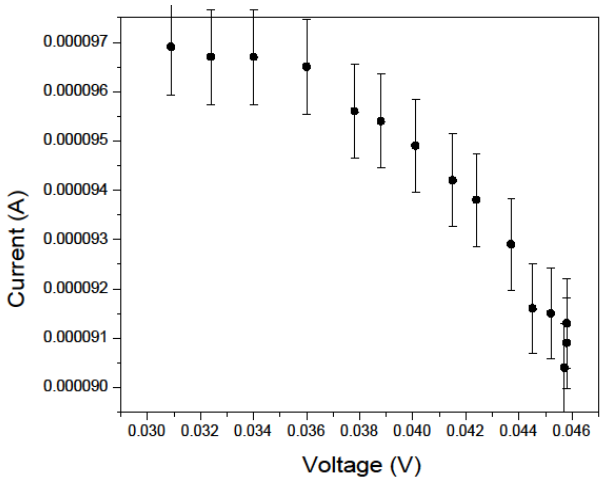

Fig-3 Graph of Current Vs Voltage for intensity 47000 lux

It is noted that the evaporation of the liquid electrolyte often caused some practical limitations of sealing and long term operation. It is suggested that the long term stability can be improved by using p-type semiconductor [14, 15] or hole transporting organic material [16] to replace the liquid electrolyte. But the conversion is low compared to the liquid electrolyte. Therefore quasi solid state ionic liquid electrolyte might be a better choice to increase the stability as it has good physiochemical properties such as high thermal stability, negligible vapor pressure, relatively high ionic conductivity and good stability. The current Vs voltage graph for 70 lux and 47000 lux is shown in the fig 2 and 3.

3.2 Software model (MATLAB)

The obtained experimental results were compared with the simulated results and it is noted that simulated values follow a pattern which closely resembles the actual values that have been obtained from the experiment conducted (Fig 4,5).The programme used is shown in the annexure 1.

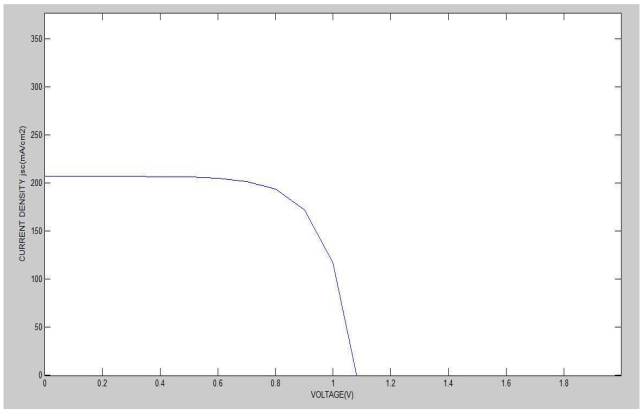

Fig 4 Simulated graph of **C**urrent density Vs Voltage for intensity 1.0e17 $cm^{-2}s^{-1}$

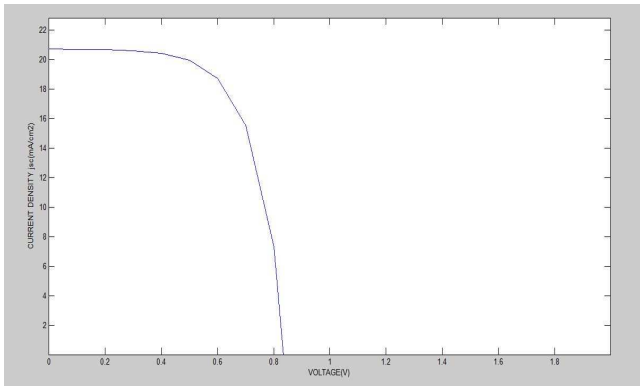

Fig 5 Simulated graph of **C**urrent density Vs Voltage for intensity 1.0e16 $cm^{-2}s^{-1}$

3.3 Impedance spectroscopic studies.

The effect of the aging process on the overall performance of device was analyzed by means of electrochemical impedance spectroscopy [18]. This technique allows to determine the charge-transfer resistances at the platinum counter electrode and at the TiO2/dye/electrolyte interface, as well as to determine the Nernstian diffusion within the electrolyte. In our present work, the impedance measurements were performed in the dark condition. Electrochemical impedance spectroscopy data is commonly

analyzed by means of equivalent electrical circuit models, which may consist of resistors, capacitors, inductors assembled in series or in parallel. The experimental data is fitted into the equivalent circuit in a specific arrangement of electrical elements and relevant information concerning the reaction kinetics, ohmic conduction processes and mass transfer phenomena occurring in DSSCs are known. The fittings of the experimental data were accomplished with the CH Electrochemical analyzer software. The results shows that the resistance of platinum is 25.58 ohms and for the working electrode-electrolyte interface capacitance is 20 µF connected in parallel with a resistance of 14.74K ohms.

AC impedance spectrum of DSSC is measured from the frequency range of 0.1Hz to 1MHz is shown in the Fig6. The semicircles in the frequency regions of 1000-100000 Hz, 1000-1 Hz, 1-0.1 Hz correspond to platinum coated TCO glass, TiO_2 -electrolyte interface, Electrolyte resistance respectively. The capacitance in the AC impedance spectroscopy results not only from the chemical factors but also electrical potential. Impedance spectroscopic studies shows the conversion efficiency depends on the series resistance (in this case that of platinum coating) ,the resistance of FTO glass.

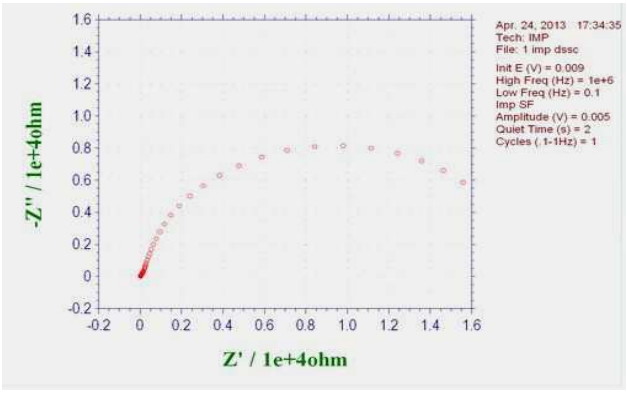

Fig.6. Impedance spectra obtained for the fabricated DSSC

4. CONCLUSION:

Nano crystalline (20nm) TiO_2 solar cell is fabricated and the cell parameters are calculated at different intensities. The obtained experimental results were compared with the simulated results and it is noted that simulated values follow a pattern which closely resembles the actual values that have been obtained from the experiment conducted. There may be a slight variation in values which is attributed to the various external factors such as the drying up of electrolyte, temperature of surrounding etc.

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ANNAXURE-1

3.2.1 Parameters used to define the characteristic of DSSC:

L - electron diffusion length

J_{SC} - short circuit current.

Φ - light intensity

D - diffusion co-efficient of electrons

n(x) - excess concentration of the photo generated electrons at a position x within the film measured from the TiO_2 / transparent conducting oxide interface.

A - light absorption co-efficient of the porous film.

m - ideality factor

t – Life time of free electrons.

3.2.2 Modeling:

A simple mathematical model of the DSSC can be done using two equations [17]. The first one is a continuity equation that describes the transport, recombination, and generation of electrons within the nano porous film:

$$D\frac{\partial^2 n(x)}{\partial x^2} - \frac{n(x)-n_0}{\tau} + \Phi_0 \alpha \exp(-\alpha x) = \frac{\partial n}{\partial t}$$

When the DSSC is irradiated the equation becomes,

$$D\frac{\partial^2 n(x)}{\partial x^2} - \frac{n(x)-n_0}{\tau} + \Phi_0 \alpha \exp(-\alpha x) = 0$$

Moreover there are two boundary conditions,

Under short-circuit conditions, electrons are easily extracted as photocurrent and none of the electrons are drawn directly to the counter electrode.

Therefore,

$$n(0) = n_0$$

And,

$$\frac{dn}{dx}\Big|_{x=d} = 0$$

Where *d* is the porous electrode thickness.

The excess concentration of photo generated electrons at the back contact, $n_{contact}$, and the photo voltage, V_{ph}, are related by the following equation:

$$\left|V_{ph}\right| = \frac{kT}{q} m \ln \frac{n_{contact}}{n_0}$$

The short circuit current density is given by

$$J_{sc} = \frac{q\Phi L\alpha}{1-L^2\alpha^2}\left[-L\alpha + \tanh\left(\frac{d}{L}\right) + \frac{L\alpha \exp(-d\alpha)}{\cosh\left(\frac{d}{L}\right)}\right]$$

Where L is the diffusion length given by,

$$L = \sqrt{D\tau}\,.$$

The voltage and current density are related by the following equation,

$$V = \frac{kTm}{q}\ln\left[\frac{L(J_{sc}-J)}{qDn_0 \tanh\left(\frac{d}{L}\right)} + 1\right]$$

The open circuit voltage and the voltage at maximum power point are given by

$$V_{oc} = \frac{kTm}{q}\ln\left[\frac{LJ_{sc}}{qDn_0 \tanh\left(\frac{d}{L}\right)} + 1\right]$$