

## **Exploration of Optimum Concentration of L-Ascorbic Acid for Modification of TiO<sub>2</sub> Surface of Photovoltaic Cells for High Photovoltaic Efficiency**

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### **ABSTRACT**

The effect of parametric alterations of photovoltaic cells was studied using L-ascorbic acid which is a colourless pigment as a surface modifier of nanocrystalline TiO<sub>2</sub> films in photovoltaic cells. TiO<sub>2</sub> films were soaked in series of ascorbic acid solutions varying the concentration for one hour to obtain the highest energy conversion efficiency at the optimum concentration. The photovoltaic characteristics and measurements of electrochemical impedance spectroscopy were utilized to analyze the performance of photovoltaic cells with ascorbic acid coated photoanodes. The highest photovoltaic efficiency was obtained for the ascorbic coated TiO<sub>2</sub> film at 0.14 moldm<sup>-3</sup> concentration. The short circuit current, open circuit voltage and efficiency of ascorbic acid coated photoanode at the above concentration were 1.98 mA, 377 mV and 0.29 % respectively. The impedance of TiO<sub>2</sub> film was also lowered after coating the ascorbic acid as evident from the impedance spectroscopy, since ascorbic acid is an electron donor.

### **1. INTRODUCTION**

Semiconductors such as Titanium dioxide (TiO<sub>2</sub>), have been shown to be suitable for a wide range of applications including constructions of thin film solar cells, catalytic and photocatalytic reactions, rechargeable batteries and degradation of organic and inorganic pollutants etc. [1]. TiO<sub>2</sub> has wide band gap of about 3.2 eV. It can therefore only absorb nearly-UV light which limits its use in application of solar energy, including heterogeneous photocatalysis and photovoltaics [2]. In order to overcome the limitations, TiO<sub>2</sub> can be further enhanced by surface modification, a very convenient method for altering the kinetic, redox and optical properties of the semiconductor [3-4]. Normally, surface modifiers, can affect the semiconductor characteristics by three ways: (a) by inhibiting charge recombination; (b) by expanding the wavelength response range; (c) by changing the selectivity or yield of a particular product. Appropriate modification such as metal doping or non-metal doping is used to modify surface or structure of TiO<sub>2</sub>. These types of modifications are employed to narrow the wide band gap of TiO<sub>2</sub>.

Furthermore, Titanium (Ti) atoms on the surface are very reactive, leading to the formation of charge transfer complexes with a red absorption shift, due to their binding with electron-donating ligands. The visible light activation of TiO<sub>2</sub> has been observed upon the surface modification of colloidal TiO<sub>2</sub> with L-Ascorbic Acid (AA) which is a colourless pigment [5]. Generally, ascorbic acid is known as a vitamin C which is an inexpensive single ring compound. The addition of ascorbic acid is one of the common approaches for surface modification of TiO<sub>2</sub> because it is a powerful antioxidant [6]. This study is based on the modification of the TiO<sub>2</sub> films with L-ascorbic acid used

as a photoanode in the photovoltaic cells. The main objective of current work is to find the optimum concentration of AA for the highest energy conversion efficiency of AA coated photoanodes and their impedance variations.

## 2. METHODOLOGY

### 2.1 Preparation of TiO<sub>2</sub> films

A Fluorine-doped Tin Oxides (FTO) glass plates were cut into a size of 1 cm × 2 cm which were cleaned in an Ultrasonic bath using distilled water with 1 drop of conc. HNO<sub>3</sub> for 5 minutes. Washed glass plates were boiled in ethanol and isopropyl alcohol solution, in a beaker on a hot plate at 70°C for 30 minutes. 0.5 g of P25 Degussa Titanium dioxide (TiO<sub>2</sub>) powder was mixed with 0.1 g of Citric acid in a mortar and pestle using 5 ml ethanol, one drop of triton-X-100 and one drop of PEG-400. Mixture was ground for 30 minutes to obtain uniform paste. The prepared TiO<sub>2</sub> paste was coated on cleaned FTO glass plates by using doctor blade technique and the area of the film was 1 cm<sup>2</sup>. Then the coated TiO<sub>2</sub> plates were sintered in a furnace at 450 °C for 30 minutes.

### 2.2 Preparation of L-ascorbic acid coated films

The ascorbic acid solutions of 0.07 M, 0.14 M, 0.21 M, 0.28 M and 0.56 M were prepared using 50% (V/V) ethanol as a series of concentrations. Sintered TiO<sub>2</sub> films were soaked in 2ml AA solution of different concentrations for 1 hour. After that AA coated films were washed using distilled water to remove the excess ascorbic acid on the films and dry it using an air dryer.

### 2.3 Assembly of the solar cell

The conducting side of the counter electrode (platinum sputtered conducting tin oxide glass) and dye absorbed TiO<sub>2</sub> film as the working electrode were sandwiched and held with clamps. The capillary space in between two electrodes were filled with electrolyte which was prepared by using 0.83 g of potassium iodide (KI) and 0.127 g of iodine (I<sub>2</sub>) added into solution containing acetonitrile and ethylene carbonate at 8:2 ratio.

### 2.4 Characterization and measurements

The photovoltaic measurements of the dye synthesized solar cells (DSSCs) were taken under irradiance of the 1000Wm<sup>-2</sup> light illumination using a computer coupled with a galvanostat /potentiostat and Science workshop 750 interface. The open-circuit voltage (V<sub>oc</sub>) and short-circuit photocurrent (I<sub>sc</sub>), given by I–V curve, were used to calculate the photovoltaic efficiency (η) of solar cells with following formulas 1 and 2.

$$\text{Fill factor (FF)} = (\text{maximum current} \times \text{maximum voltage}) / (I_{sc} \times V_{oc}) \dots \dots \dots (1)$$

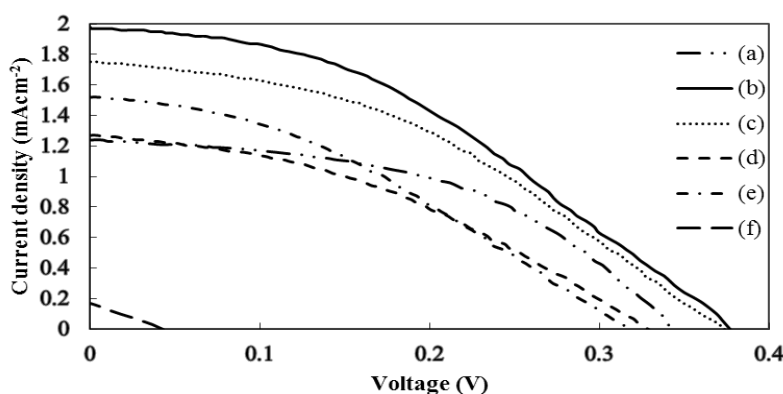
$$\text{Efficiency } (\eta) = [(FF \times I_{sc} \times V_{oc}) / 1000\text{Wm}^{-2}] \times 100 \% \dots \dots \dots (2)$$

The electrochemical impedance spectroscopy (EIS) analysis were performed under irradiance of the 1000Wm<sup>-2</sup> light illumination on solar cell using a computer coupled with Metrohm Autolab PGSTAT204.

### 3. RESULTS AND DISCUSSION

#### 3.1 Photovoltaic performance

Figure 1 shows the current density (J)– voltage (V) characteristics of the photovoltaic cells fabricated with ascorbic acid coated photoanodes. It is very clear from the figure that the introduction of ascorbic acid to  $\text{TiO}_2$  increases the photocurrent of the cells. The reasons for enhancement of photovoltaic characteristics is the presence of the ascorbic acid on  $\text{TiO}_2$  that caused the formation of a charge-transfer complex, resulting a red shift in  $\text{TiO}_2$  band gap for the region of visible light spectrum [5-6]. The figure clearly shows the highest short circuit current and open circuit voltage are given by the  $\text{TiO}_2/\text{AA}$  film with  $\text{TiO}_2$  film soaked in 0.14 M of ascorbic acid solution.

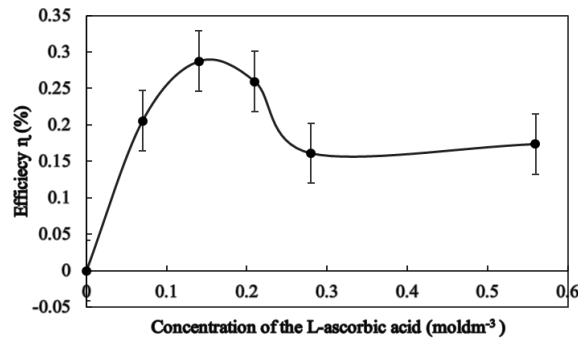


**Figure 2:** Photocurrent-voltage curves for  $\text{TiO}_2$  films soaked in different concentrations of L-ascorbic acid (AA) of photovoltaic cells ( $\text{TiO}_2/\text{AA}/\text{electrolyte}/\text{Pt}$ ) (a) 0.07 M (b) 0.14 M (c) 0.21 M (d) 0.28 M (e) 0.56 M and (f) only  $\text{TiO}_2$  film ( $\text{TiO}_2/\text{electrolyte}/\text{Pt}$ )

Table 1 shows short circuit current density ( $J_{sc}$ ), open circuit voltage ( $V_{oc}$ ) and calculated results using equation 1 and 2 for fill factor (FF) and the energy conversion efficiency ( $\eta$ ) of DSSCs with  $\text{TiO}_2/\text{electrolyte}/\text{Pt}$  and  $\text{TiO}_2/\text{AA}/\text{electrolyte}/\text{Pt}$ . The photovoltaic efficiencies for modified photoanodes from L-ascorbic acid with concentration series of AA is shown by figure 2. Results of table 1 and figure 2 clearly show that highest efficiency is given for  $\text{TiO}_2/\text{AA}$  photoanode soak in 0.14 M of ascorbic solution for one hour.

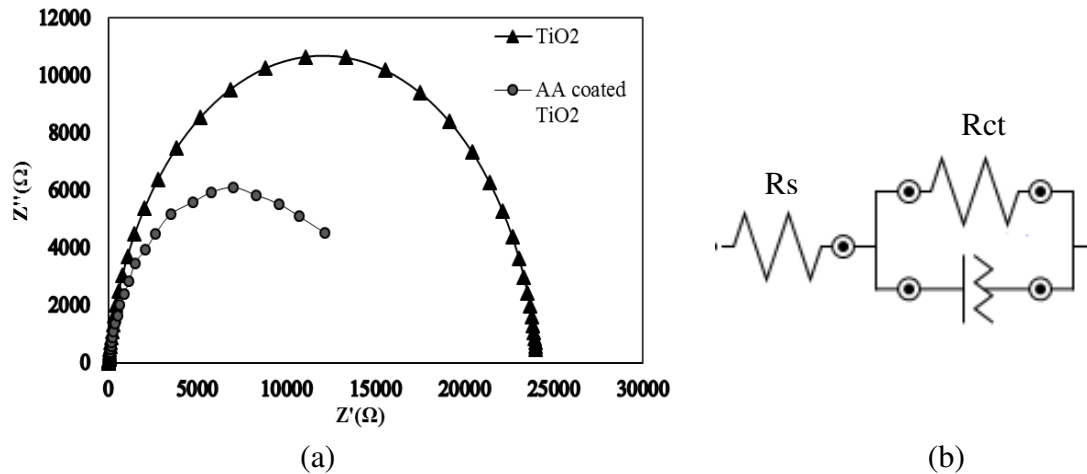
**Table 1:** Photovoltaic parameters of DSSCs with  $\text{TiO}_2/\text{electrolyte}/\text{Pt}$  and  $\text{TiO}_2/\text{AA}/\text{electrolyte}/\text{Pt}$

Concentration of the L-ascorbic acid ( $\text{mol dm}^{-3}$ )	$V_{oc}$ (mV)	$J_{sc}$ ( $\text{mA cm}^{-2}$ )	FF%	$\eta\%$
0	43	$1.7 \times 10^{-4}$	25.9	$1.89 \times 10^{-6}$
0.07	342	1.24	48.5	0.21
0.14	377	1.98	38.5	0.29
0.21	374	1.75	39.7	0.26
0.28	329	1.27	38.6	0.16
0.56	320	1.52	35.7	0.17



**Figure 3:** Photovoltaic efficiency versus concentrations of L-Ascorbic acid for  $\text{TiO}_2/\text{AA}/\text{electrolyte}/\text{Pt}$

### 3.2 EIS Measurements



**Figure 4:** (a) Nyquist plot for  $\text{FTO}/\text{TiO}_2/\text{Electrolyte}/\text{Pt}$  and  $\text{FTO}/\text{AA}$  coated  $\text{TiO}_2/\text{Electrolyte}/\text{Pt}$  and (b) Typical equivalent circuit for photovoltaic cells

Nyquist plots photovoltaic cells of  $\text{TiO}_2$  film and  $\text{TiO}_2$  film coated with ascorbic acid is shown in figure 3(a). It is obvious that the impedance of the thin film decreased after absorbing ascorbic acid on the  $\text{TiO}_2$  film. Series resistance ( $R_s$ ) and charge transfer resistance ( $R_{ct}$ ) tabulated in the table 2 for  $\text{FTO}/\text{TiO}_2/\text{Electrolyte}/\text{Pt}$  and  $\text{FTO}/\text{AA}$  coated  $\text{TiO}_2/\text{Electrolyte}/\text{Pt}$ . The resulting equivalent circuit is shown in figure 3 (b).

**Table 2:** Simulated results of series resistance ( $R_s$ ) and charge transfer resistance of the ( $R_{ct}$ ) for  $\text{FTO}/\text{TiO}_2/\text{Electrolyte}/\text{Pt}$  and  $\text{FTO}/\text{AA}$  coated  $\text{TiO}_2/\text{Electrolyte}/\text{Pt}$

Photoanode	$R_s$ ( $\Omega$ )	$R_{ct}$ ( $\text{k}\Omega$ )
$\text{FTO}/\text{TiO}_2$	34.1	24
$\text{FTO}/\text{AA}$ coated $\text{TiO}_2$	77.7	13.7

#### 4. CONCLUSION

The TiO<sub>2</sub> film coated with 0.14 mol dm<sup>-3</sup> of L- ascorbic acid for one hour gave 1.98 mA of highest short circuit current and 0.29 % of highest photovoltaic efficiency. Modification of TiO<sub>2</sub> films with ascorbic acid was involved to enhance the photovoltaic characteristic of the photovoltaic cells. The charge transfer resistance of TiO<sub>2</sub>/ Electrolyte/Pt can be reduced by introducing ascorbic acid on the TiO<sub>2</sub> film of photovoltaic cell as confirmed by EIS measurements. Further studies need to be carried out to identify the donor energy state attributed to surface modification of TiO<sub>2</sub> by AA by spectroscopic methods that result for the red shift in the band gap of TiO<sub>2</sub>.

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