Sensitization of TiO_2 Thin Film with Different Dye for Solar Cell Application

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***Abstract*—Titanium Dioxide (TiO2) solution having different concentration were synthesized and deposited on glass substrate by using sol-gel and spin coating method. The effects of structural and electrical properties in Dye-Sensitized Solar Cell (DSSC) application is studied. Recently, TiO2 was studied because it has a major role in the enhancement of electrical properties in DSSC. The starting materials are ethanol, titanium isopropoxide (TTIP), glacial acetic acid (GAA), Triton X-100 and distilled water. The effects of different molarity of TiO2 solution is studied. The solution is then deposited on the substrates by spin coating method to form a transparent TiO2 thin film. The TiO2 thin film is fabricated for DSSC application. The performance of the thin film is characterized by scanning electron microscope (SEM) for structural properties while I-V measurements to analyze the electrical properties of the thin film. It was notified that 0.25 M film has more porous structure. By integrating different dyes with TiO2 thin films it was notified that the turn-on voltage increases from 0.2V to 1.2 for TiO2 and for turmeric, respectively.**

***Index Terms*—DSSC; TiO2; Thin Film.**

I. Introduction

Renewable energy such as solar energy is a hot topic and very effective solution due to limitations of fossil fuels, emission of greenhouse gases and pollutions problems [1]. There are alternative energy resources which can be explored and fully utilized. The renewable energy has many advantages such as high availability, less polluting and no fuel cost or fuel supply problems [2-3]. Based on previous research, Titanium Dioxide (TiO_2) are relatively low cost, simple manufacturing and results in high performance of dye-sensitized solar cells [1]. TiO_2 is a semiconductor material that has three polymorphisms which are rutile, anatase and brookite. The rutile structure is the most stable phase compared to anatase and brookite. TiO_2 is very suitable chemical for DSSC application because the TiO_2 anatase phase has a wider band gap of 3.2 eV compared to rutile phase of 3.0 eV [3-10].

There are many methods to deposit titanium dioxide thin film such as spin coating, sputtering, Chemical Vapor Deposition (CVD) and spray pyrolysis [1-4]. One of the most suitable technology to deposit TiO_2 is sol-gel method. The advantages of this technique are the good homogeneity of coated films and low processing temperature [4-9].

To develop DSSC, there are two types of dye; inorganics and organics dye. An inorganic dye such as ruthenium (Ru) which is based counter electrode has been widely used and it gives better efficiency which is up to 10% and high durability [1]. However, these advantages are offset because the material is very expensive and difficult to synthesize. This sensitizer is one of Nobel materials which is very expensive and limited resources [5-7]. In addition, it can cause illness because it is highly toxic. Therefore, nowadays, organic dyes have been utilized in obtaining good efficiency. In this work, the performance of DSSC with different natural dye (pandan, dragon fruit, and turmeric) is investigated. The uniformity of TiO_2 with different molarity is observed and I-V characteristics measurement is performed.

II. Materials And Methods

A. *Synthesis of Titanium Dioxide (TiO_2) by Sol-Gel Method*

TiO_2 solution is prepared by mixing ethanol or ethyl alcohol (C_2H_6O), Glacial Acetic Acid (GAA), titanium isopropoxide (TTIP), distilled water and Triton X-100 in a Schott Bottle Blue Cap. The solution is continuously stirred for two hours at 60^{O}C with 600 rpm. The heating process is very important to break the carbon chain while continuous stirring is to avoid from agglomeration [10]. In this method, TTIP is used as a precursor, ethanol as a solvent, GAA as a stabilizer or chelating agent while Triton X-100 act as a surfactant to avoid precipitation [11-13]. Besides that, Triton X-100 is very important in order to increase the conductivity of the thin films. The experiment is repeated with varies concentration of 0.15 M, 0.20 M and 0.25 M.

B. *Preparation of Glass Substrates*

Glass substrates were cut in the dimension of 2.5 cm x 2.5 cm. Then, the glass substrates were cleaned by using acetone and distilled water in ultrasonic bath for 10 minutes each to remove any contaminant on the glass surface. The substrates were dried using blower [10]. For ITO glass substrates, they were cleaned by using acetone and isopropanol in ultrasonic bath for 10 minutes each.

C. *TiO_2 Thin Film Deposition*

The spin coater is set at speed 3000 rpm for 30 seconds. By using micropipette, the TiO_2 solution will be dropped at the center of the ITO glass substrate. Then, the glass will be heated on the hot plate at a temperature of 100ºC for 5 minutes. In order to get a uniform thin film, this process is repeated for five times. The samples were annealed at 450ºC for 6 hrs.

D. *Preparation of Dye Solution*

There are three types of dyes prepared. Firstly, 100 g of *pandan* leaves is prepared to extract chlorophyll. The pandan leaves are cut into small pieces and crush by using mortar. The leaves are immersed in 100 ml of ethanol and left the solution at room temperature for one week. Secondly, turmeric dye solution is prepared from 100 g of turmeric powder immersed in 100 ml of ethanol to extract curcumin dye. Third, anthocyanin dye is extracted from 100 g of purple cabbage which is dissolved in 100 ml of ethanol. The solution has to be placed at a dark place which does not expose to sunlight. After two weeks, the solution is filtered by using filter paper. The solid residues were filtered out. As prepared, the clear solutions are used. The extracted dyes were properly stored in a dark place and used as sensitizers in DSSC.

E. Preparation of Electrodes for Dye-Sensitized Solar Cell (DSSC)

The anode and cathode electrodes are prepared for fabrication of DSSC. For anode electrode, the TiO_2 coated ITO glass substrate was immersed in the dye solution. After 24 hours, the substrate is removed from the solution. Then, the substrate is rinsed off with distilled water. For the cathode electrode, the substrate is coated with graphite. Both of the substrates is combined together with a binder clip as shown in Figure 1. A few drops of electrolyte which are Potassium Iodide (KI) were injected between the electrodes to prevent the substrates from drying out and provide ions that will carry the current through the solution.

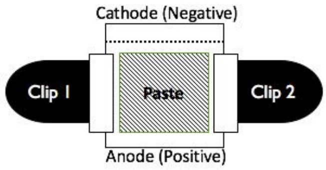
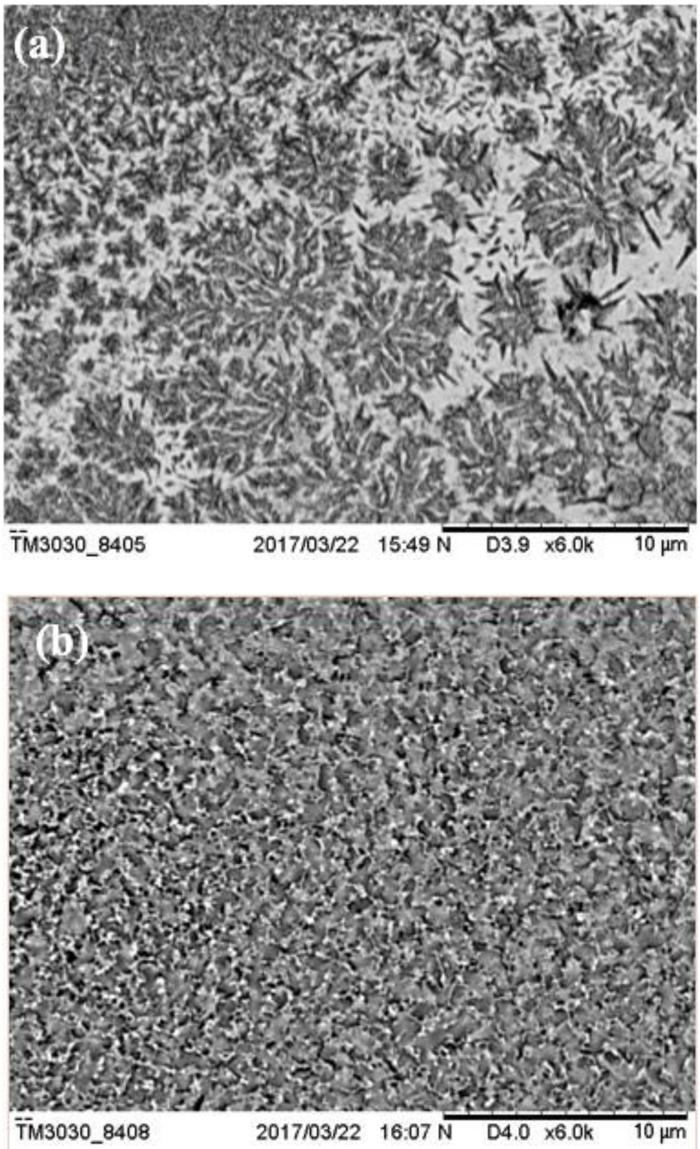


Figure 1: Top view with a binder clip on both side.

F. Characterization of TiO2

The structural properties of TiO_2 thin films were observed by using Scanning Electron Microscope (SEM). Electrical properties of TiO_2 thin films were measured using KEITHLEY 2450 source meter.



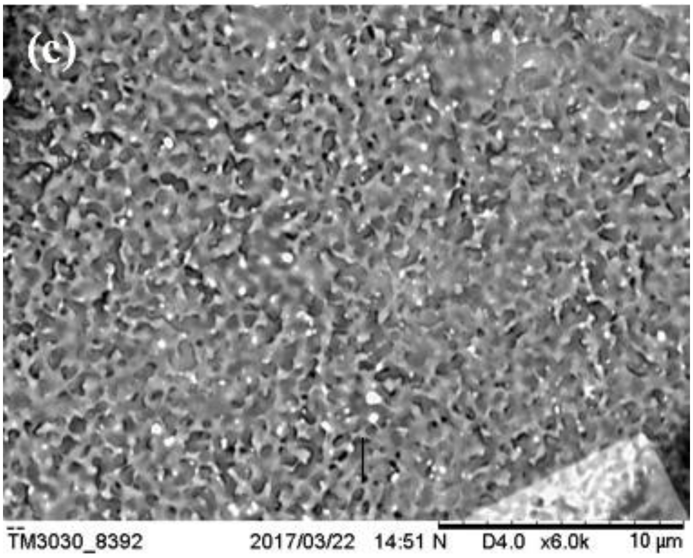


Figure 2: Different concentration shows different interspacing between the particles; SEM characterization for TiO_2 (a) 0.15M, (b) 0.20M, (c) 0.25M

III. Results And Discussion

A. Structural Properties

Figure 2 shows the micrographs obtained via Scanning Electron Microscope (SEM) for different concentrations of TiO_2 which were annealed at 450^oC. The samples in Figure 2 were taken with a magnification of 6000X. The interspacing (porosity) between the particles increases as the concentration increase. For solar cell application, if the structure is more porous, it has a higher capacity to absorb sunlight [14]. From Figure 2, 0.25 M has high porosity compared to other concentration. Therefore, this shows that the porosity of the structure increase with the concentration of TiO_2. Based on SEM images, in the current work 0.25 M film is selected for electrical characterization.

B. Electrical Properties

A thin film of TiO_2 is successfully deposited onto the ITO coated glass substrate. Figure. 3 shows the current-voltage (I-V) characteristic curves of TiO_2 thin films sensitized with different dyes. It was notified that all the sensitizing dyes displayed rectifier diode behavior. Figure 3 revealed that by sensitizing the film with different dyes there is a change in the current-to-voltage characteristics.

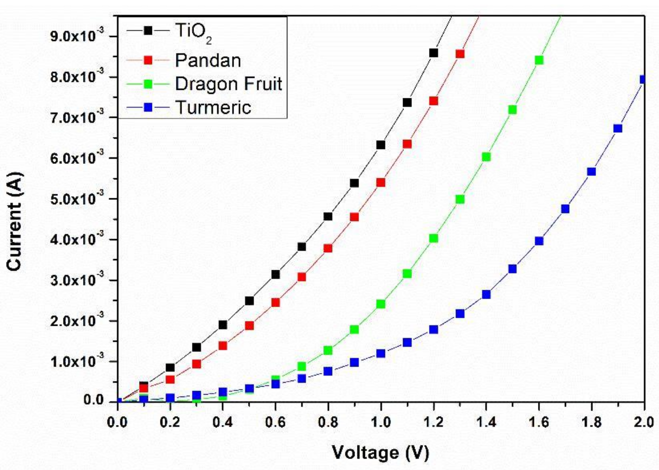


Figure 3: I-V Characteristics for 0.25 M of TiO_2 with different dyes

In order to determine the turn-on voltage, most of the researchers use a tunneling model of the Fowler-Nordheim theory [15]. By using that model, the tunneling current, *I* can be calculated by using the following equation:

$$I = F^2 exp\left(\frac{-b}{F}\right) \quad (1)$$

where *F* is the external electric field and *b* is a barrier shape dependent parameter. It was found that the turn-on voltage of the device withTiO_2 thin film was 0.2 V, while the turn-on voltage for Pandan, Dragon fruit and turmeric dye is 0.4 V, 0.7 V and 1.2 V, respectively. As expected, the device with TiO_2 has a lower turn-on voltage as the buffer layers have an effect to improve the attribution of holes, leading to more balanced electrons and holes within the recombination zone [16]. In the current study, it is not possible to come out with a final decision that which turn on voltage is good. Further work is going on in order to study the impact of turn-on voltage on the efficiency of as deposited films in order to decide the effeteness of a good DSSC.

IV. Conclusion

TiO_2 thin films having different concentration were deposited on glass substrates by sol-gel and spin coating method. It shows that the increasing the molarity affects the structural properties of TiO_2. Turmeric, pandan and dragon fruit dye were used as sensitizers in DSSC. In the fabrication of DSSC, the thin film must have high porosity to result in high conductivity. By considering the 0.25M thin film, it was notified that different dyes revealed in a change of turn in voltage. Further investigations are required in order to study the impact of that turn on the voltage on the performance of DSSC.

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