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Effect of screen printing type on transparent TiO_2 layer as the working electrode of dye sensitized solar cell (DSSC) for solar windows applications

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Abstract The working electrode based on semiconductor TiO_2 DSSC has been fabricated by screen printing method. This study aim is to determine the effect of the screen type on TiO_2 layer as the working electrode of DSSC. Screen used for deposition of TiO_2 has the types of; T-49, T-55 and T-61. TiO_2 layer was sintered at temperature of 500ºC. DSSC structure was composed of semiconductor TiO_2 adsorbed dye, an electrolyte solution and a platinum counter electrode. TiO_2 layer thickness was characterized by Scanning Electron Microscopy (SEM), while the absorbance was characterized using UV-Vis spectrophotometer and the electrical properties of DSSC were characterized by Keithley I-V measurement. TiO_2 layer fabricated by screen T-49 had the biggest thickness that was 3.2 ± 0.3 μm and the highest UV-Vis absorbance wave at the peak wavelength of 315 nm with the absorbance value was 1.7. The I-V characterization showed that the sample fabricated by screen T-49 obtained the greatest efficiency that was 1.0 x 10^{-1} %

1. Introduction

Solar cell is device which is capable of converting solar energy into electrical energy. The development of solar cell has reached three generation in the world, among them are solar cell made from bulk silicon semiconductor [1], a thin film solar cell [2], and solar cell based on dye-sensitized [3-5]. Dye-sensitized solar cell (DSSC) structures consist of semiconductor layers, dye, an electrolyte solution and a catalyst. Semiconductor layer coated dye acts as the cathode. The catalyst is grown on glass substrates luorine doped in Oxide (FTO) serves as the anode. Dye functions as a light-sensitive substance (photosensitizer). Electrolyte solution performs as substitute of excited electrons from the dye. Catalyst does as the counter electrode [5-6].

Solar window is one of DSSC applications. Solar windows can be installed in the windows of a building. The presence of solar windows is expected to be able to support government programs in electricity savings. Solar windows require large size to be applied in the windows of the building. The suitable method for the fabrication of DSSC in a large scale is screen printing method [7]. The other advantages of screen printing method are investment in equipment that is relative inexpensive and simple fabrication process. The effectiveness of the screen printing method is determined by many factors. Hole size (mesh) and pressure on the screen [8] are important factor in DSSC fabricated by screen printing method. Those factors become the determinant of the amount of TiO_2 particles that can be deposited on substrate. The more deposited particles make TiO_2 layer getting thicker, so that the more dye absorbed. This study is focused on obtaining the effect of screen printing type on each type of TiO_2 pasta to the TiO_2 layer as the working electrode of DSSC. There are three screen types in the screen printing method; those are T-49, T-55 and T-61. Each screen mode represents the number and the mesh diameter of the screen. This research is expected to be able to provide a scientific contribution in the development of DSSC using screen printing methods, as well as application of DSSC as the pioneer of solar windows in Indonesia.

Solar windows require transparent materials in order to be able to pass sunlight into the room. The use of transparent materials is expected to be able to make the absorbed photons in the DSSC become more maximal. The absorbed photons cause electrons excited from the dye molecules. TiO_2 layer is fabricated from transparent TiO_2 pasta with type of 18NRT.

2. Materials and Method

FTO glass substrate (Merck Dyesol) with resistance of 7 Ω/sq was cleaned using ultrasonic cleaner. This study used TiO_2 pasta of 18NR-T which is transparent. TiO_2 coating process on substrate was conducted by screen printing method. Coating of TiO_2 pasta was done by two times in order to obtain two layers of TiO_2 (double layer) without fissure [9]. Types of screen used were; T-49, T-55 and T-61. The code numbers on the screen type indicated the number of mesh/cm. Mesh on the screen became determinant of the amount of TiO_2 particles which can be deposited on the substrate. Screen of T-49 had 49 mesh/cm while T-55 and T-61 had 5 and 61 mesh/cm, respectively.

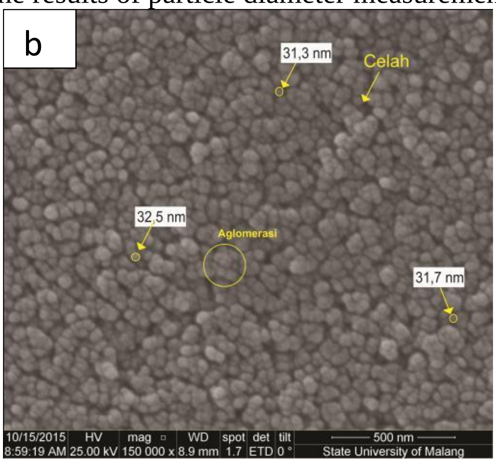
Active cell area of TiO2 was 1 cm^2. TiO_2 layers deposited on substrate was sintered at temperature of 500^oC for 10 minutes. The coloring process was done by immersing the substrate coated TiO_2 into Ruthenium dye N719 for 24 h. The counter electrode was fabricated using FTO glass substrate coated catalyst solution of Counter Electrode Solution/ CELS (Merck Dyesol).

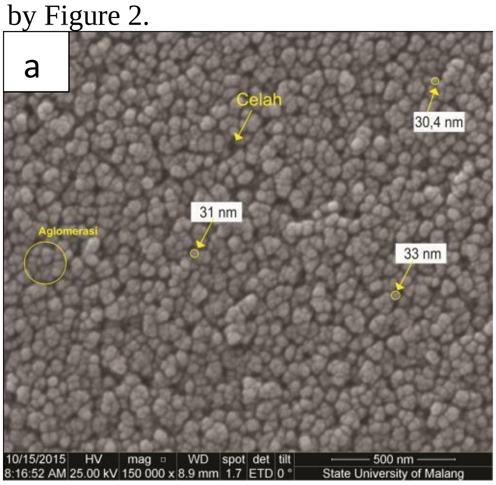
Catalyst deposition process was carried out by droplet method; the catalyst solution was dripped onto the substrate using a syringe. After that, the counter electrode was sintered at temperature of 420^oC for 10 minutes. DSSC sandwich structure was composed of dye sensitized TiO_2 working electrode and the counter electrode. The space between the electrodes was injected by electrolyte solution which served as electron recharge through redox reaction. The morphology and the thickness of the deposited TiO_2 layer were characterized by Scanning Electron Microscopy (SEM), while the absorbance was characterized by UV-Vis Spectrophotometer Lambda 25. The electrical properties of DSSC were characterized by using I-V Keithley Measurement.

3. Results and Discussion

Characterization using SEM was conducted to recognize the morphology and the thickness of TIO_2 layers fabricated with different screen. The morphology results of TiO_2 layer are shown by Figure 1.

The shapes of TiO_2 particles are spherical, and formed agglomerations in some parts. Looked there are slits on the surface of TiO_2 layer. Those cracks are useful to adsorb dye molecules[16]. TiO_2 particle size was measured by doing a manual comparison to the scale shown on the results of the SEM image. The results of particle diameter measurement are presented by Figure 2.





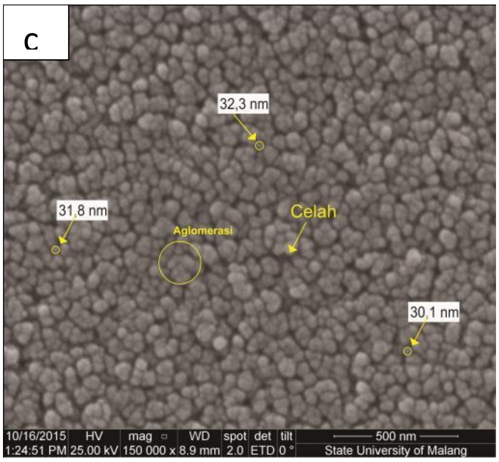


Figure 1. The morphology of TiO_2 layer fabricated by using screen (a) T-49 (b) T-55 (c) T-61

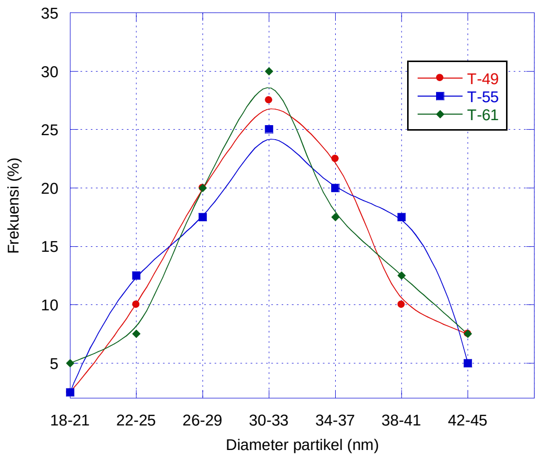


Figure 2. The result of TiO_2 particles size distribution imaged by SEM

Diameter of TiO_2 particles fabricated by screen T-49, T-55 and T-61is nearly same, that is in range of 30-33 nm. Based on this study, the types of screen do not affect the change in diameter of TiO_2 particles. This is due to the size of the particle diameter and TiO_2 crystals can change if they are given different heat treatment [10-11].

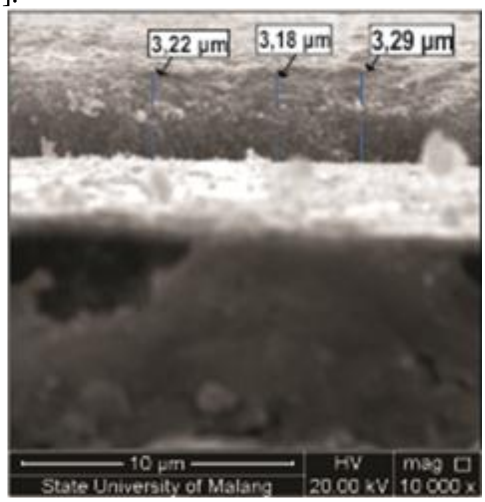


Figure 3. The result of SEM cross-section layer deposited by using *screen* T-49

The thickness of TiO_2 layer is shown by Figure 3. It is different for each variation of the screen type. The largest thickness is resulted by TiO_2 layer fabricated using screen T-49. TiO_2 layer deposited by screen T-49 has thickness of (3.2 ± 0.3) µm, while the screen T-55 and T-61 produce thickness of (2.8 ± 0.2) and (1.6 ± 0.2) µm, respectively. The thickness of TiO_2 layer is influenced by the number of mesh on the screen.

The more number of mesh on the screen causing the distance between the mesh becomes closer and the diameter of mesh becomes smaller so that the less of volume of TiO_2 pasta is distributed on the substrate. It causing the TiO_2 layer becomes thinner; otherwise if the more of volume of TiO_2 pasta is distributed, the layer of TiO_2 becomes thicker.

Absorbance of TiO_2 layer before and after immersion in dye was characterized using UV-Vis Lambda Spectrophotometer 25 shown by Figure 4. It is conducted by the absorbance spectrum with wavelengths of 300-700 nm.

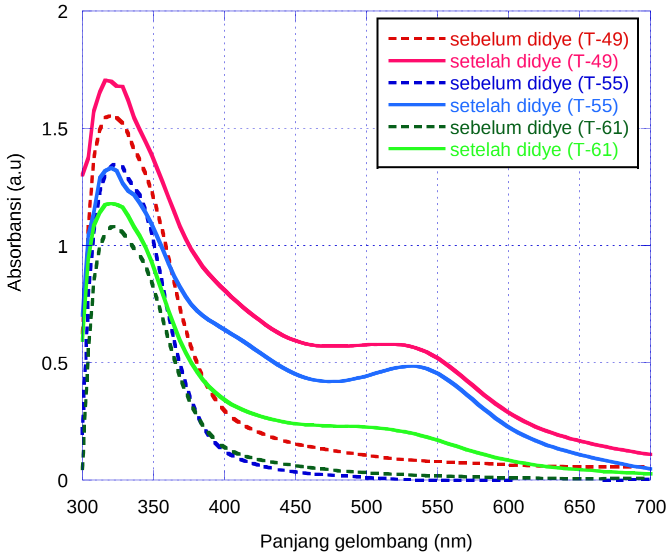


Figure 4. The absorbance curve of TiO_2 layers

Based on the UV-Vis characterization, there is an increasing rate of absorbance after TiO_2 layer soaked in dye. It is due to dye molecules attach to the TiO_2 particles, so it can be concluded that aging dye increases the absorbance of TiO_2 layer. The results of UV-Vis characterization show the absorbance peak of each material. The highest peak of photons absorbance of material TiO_2 is in the wavelength of 200 nm-410 nm [12]. The highest peak of photon absorbance of Ruthenium dye N719 appears in the visible wave range of 500 nm-550 nm [13]. The highest absorbance value is resulted from the TiO_2 layer deposited by screen-type T-49. The highest peak of TiO_2 layer is in wavelength of 315 nm with the absorbance value is 1.7. According to beer lambert law [15], this is due to the TiO_2 layer deposited by screen-type T-49 has the greatest thickness.

Current and voltage DSSC were characterized using I-V Keithley measurement presented by Figure 5. The light source used was a xenon lamp with intensity of 1000 W/m^2. DSSC active cell area is 1.10^{-4} m^2.

I-V curve and datasheet obtained from the characterization can be used to calculate the efficiency of DSSC. The highest efficiency is obtained using screen-type T-49 that is 1.0 x 10^{-1}%. It is occurred because the number of TiO_2 particles deposited using screen T-49 is more than the number of TiO_2 particles deposited using screen T-55 and T-61. The number of TiO_2 molecules is determined by the thickness of TiO2 layer deposited on the FTO glass substrate. The more TiO_2 molecules are deposited on the substrate, the more dye molecules are absorbed. Therefore, when the photons hit the surface of the DSSC, the more electrons are excited from band HOMO (dye) to band LUMO (TiO2 semiconductor) [14]. The number of generated electrons causes the more currents flowing to the external circuit. DSSC efficiency will increase as the increase electric currents flowing in the solar cell system.

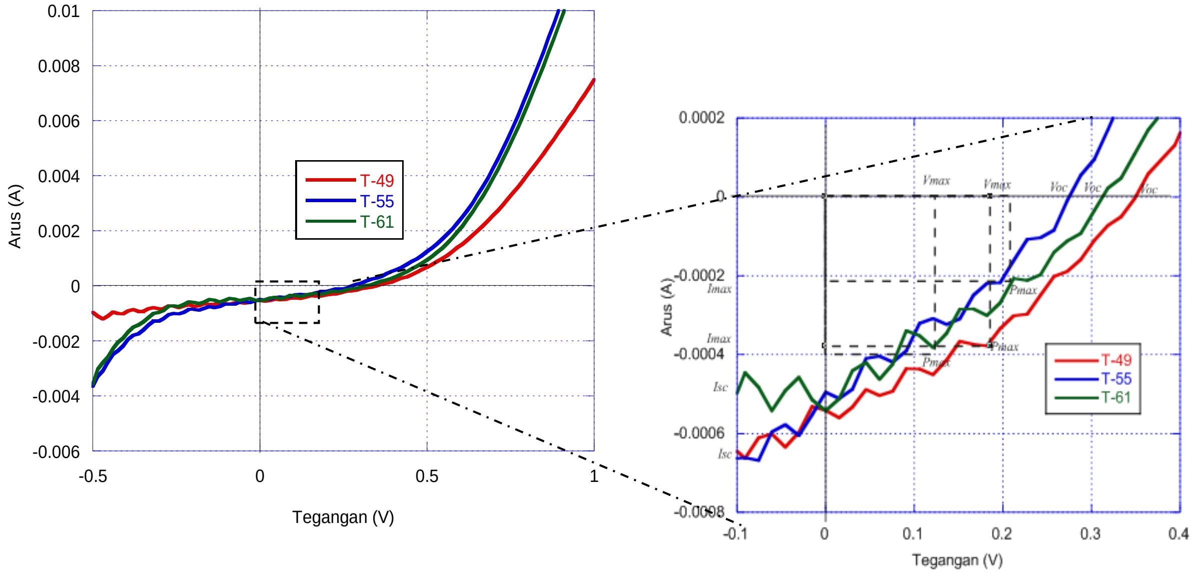


Figure 5. The characteristic curve of DSSC Currents-Voltages (I-V)

4. Conclusion

Based on this study, the screen type affects the thickness of TiO_2 layers, but it does not affect the morphology of the TiO_2 layer. The highest thickness is obtained using screen T-49. The thickness of TiO_2 layer is (3.2 ± 0.3) μm. The result of UV-Vis characterization shows that the thickness of TiO_2 layers affects the absorbance. The highest peak of TiO_2 layer is in wavelength of 315 nm with the absorbance is 1.7. The highest efficiency is obtained from DSSC which its working electrode is deposited by screen T-49. The highest DSSC efficiency is 1.0 x 10^{-1}%.

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