Effect of sintering on transparent TiO$_2$ 18NR-T type thin films as the working electrode for transparent solar cells

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Abstract. The working electrode based on semiconductor transparent TiO$_2$ type 18NR-T for transparent solar cells have been grown by screen printing method. This study aim is to determine the effect of sintering on TiO$_2$ thin films transparent as the working electrode of transparent solar cells. TiO$_2$ films will be sintered at temperature 450$^\circ$C, 500$^\circ$C, 550$^\circ$C and 600$^\circ$C. TiO$_2$ films optical properties were characterized using UV-Vis spectrophotometer, electrical properties were characterized using 4 point probemethods and the crystallization was characterized by X-Ray Diffraction (XRD). The lowest transmittance due to the treatment of annealing temperature variations is 550$^\circ$C because the 550$^\circ$C TiO$_2$ layer is more absorbing. The peaks resulted from the annealing temperature treatment show that the high temperature the more anatase peaks. Characterization using four-point probe showed that the highest conductivity of TiO$_2$ 18NR-T thin film was 2.42 x 10$^{-2}$ $\Omega$ m$^{-1}$ at annealing temperature 550$^\circ$C.

1. Introduction
Solar cells as a device to convert sunlight into electrical energy is always growing, in principle solar cells is an alternative technology that produces electrical energy by using free electrons produced by sunlight. This development is evidenced by the innovations that are divided into three generations. The first generation of silicon solar cells [1], the second thin layer solar cell [2] and the third generation of Dye-Sensitized Solar Cell (DSSC) [3-5]. One application of DSSC is a solar window, the main requirement is that windows are transparent and usually use transparent semiconductor material TiO$_2$ transparent 18NR-T. The transparent window used is a transparent conductor of transparent conducting oxide (TCO). This material has been widely used in optoelectronic applications and photovoltaics.

Titanium dioxide (TiO$_2$) is a versatile material in several applications whether in light absorption or transparency for the addition of electrical conductivity. Titanium dioxide has three distinct crystalline structures: rutile (tetragonal), anatase (tetragonal) [6,7] and brookite (orthorhombic) [8-11]. The type of crystal phase of TiO$_2$ frequently used in DSSC is the anatase phase, this is because the anatase phase has a high degree of photoactivity and large surface area. Factors affecting the photocatalytic activity of TiO$_2$ are phase structure, surface area, crystal size, particle shape and surface hydroxyl number [12-18]. With the addition of annealing temperatures, TiO$_2$ can transform into anatase and rutile forms [19]. Therefore, in this study focused on TiO$_2$ layer due to the treatment of variation of annealing temperature given. The heat treatment of the TiO$_2$ coating results can
produce anatase phase which is well used in DSSC, low temperature to produce anatase phase on TiO$_2$ ranging from 400°C - 600°C [20]. In this observation, the TiO$_2$ layer was deposited by screen printing method. TiO$_2$ layer is the result of fabrication of transparent TiO$_2$ paste type 18NR-T.

2. Experimental

The substrate used in the study is a glass preparation having a resistance specification of thickness 1.1 mm. The first substrate was washed using an ultrasonic cleaner with 4 stages that are using soap water, quads, acetone, and alcohol which each step done for 10 minutes. TiO$_2$ used is brand dyesol with type 18NR-T shaped paste yellow. Pasta TiO$_2$ 18NR-T weighed 1 gram and measured 1 ml of ethanol with a micropipette. The sample is stirred using a magnetic stirrer for 1 hour with a rotation speed of 300 rpm at room temperature.

The TiO$_2$ 18NR-T solution is deposited on a glass substrate using screen printing method, the screen used is the T-49 type which has 125 holes per inch. The type of screen affects the volume deposited on the glass substrate. Deposition of TiO$_2$ 18NR-T solution above the substrate measuring 2.5 cm x 2 cm, the deposition area of 1.5 cm x 1 cm. TiO$_2$ 18NR-T thin layer than in drying using the oven at 130°C for 10 minutes. The subsequently finished TiO$_2$ 18NR-T thin layer was heat treated with 4 temperature variations of 450°C, 500°C, 550°C and 600°C for 60 minutes. The heat treatment is carried out for 1 hour with atemperature rise of 15° per minute. Sintering is intended for crystallinity of TiO$_2$ 18NR-T thin films to form.

Characterization is performed to determine the result of a thin layer formed after sintering. A given sintering temperature difference may affect the formation of a rutile crystal or anatase TiO$_2$, characterization using XRD will show the anatase and rutile peaks formed. TiO$_2$ 18NR-T thin layer will also be directed by UV-VIS to determine the value of absorbance, transmittance and bandgap energy.TiO$_2$ 18NR-T thin electrical properties were characterized by Four Point Probe.

3. Result and Discussion

TiO$_2$ 18NR-T thin layer has been deposited by screen printing method. Figure 1 shows the results of X-Ray Diffraction TiO$_2$ 18NR-T thin film with annealing temperature treatment of 450°C, 500°C, 550°C and 600°C.

![Figure 1. X-Ray Diffraction Pattern TiO$_2$ 18NR-T with annealing temperature variation.](image)

The variation of annealing temperature provided affects the formation of the number of diffraction peaks. Based on matching with ICDD 21-1272 database, the peaks formed are TiO$_2$ anatase phases.
Higher annealing temperatures result in the formation of more anatase phase peaks, proving that the formation of the best anatase phases at 550°C. TiO$_2$ semiconductors in photovoltaic applications, the most stable phase used is anatase phase. This is because the anatase surface area is wider so that in the absorbing process the anatase phase is larger absorbs.

In Figure 2 showed the transmittance value of the deposited TiO$_2$ 18NR-T layer with annealing temperature variation. The resulting value supports the absorbance value obtained, where the transmittance results with increasing temperature increase the value of transmittance is decreased. This value proves that low transmittance indicates more absorbing material.

![Figure 2. TiO2 18NR-T transmittance curve with annealing temperature variation](image)

Figure 3 shows the current-voltage (I-V) characteristics of TiO$_2$ 18NR-T thin film using a four-point probe methods. Characterization is done by varying the current value so as to obtain the voltage...
value of TiO$_2$ 18NR-T thin layer. Annealing temperature variations result in a higher resistance value, which means that the TiO$_2$ 18NR-T thin film conductivity value is greater. The conductivity can be obtained by first calculating the value of TiO$_2$ 18NR-T thin film resistivity with equation 1:

$$\rho = 2\pi s \frac{V}{I}$$  \hspace{1cm} (1)

Where $s$ is the distance between the probes used in the measurement. Equation of conductivity value:

$$\sigma = \frac{1}{\rho}$$  \hspace{1cm} (2)

The conductivity value of TiO$_2$ 18NR-T thin film due to annealing effect can be seen in Table 1.

| Annealing Temperature (°C) | Conductivity x $10^2$ (Ωm)$^{-1}$ |
|---------------------------|-----------------------------------|
| 450                       | 1.51                              |
| 500                       | 1.87                              |
| 550                       | 2.42                              |
| 600                       | 2.15                              |

The TiO$_2$18NR-T thin film with an annealing temperature of 450°C has a conductivity value that is $(1.51 \times 10^2 \Omega \text{m}^{-1})$. The Conductivity value at annealing temperature 450°C-550°C increased. While at annealing temperature 600°C the conductivity value of TiO$_2$ 18NR-T thin film decreased by $(2.15 \times 10^2 \Omega \text{m}^{-1})$. It can be concluded that TiO$_2$ 18NR-T thin film with an annealing temperature of 550°C has good electrical properties.

4. Conclusion

The structure and optical properties of the TiO$_2$ 18NR-T layer have been exposed to the substrate using screen printing method with annealing temperature variation treatment. Characterization using XRD showed anatase phase growth in the presence of peak intensity at each of the annealing temperature treatments. Anatase phase grows more at 550°C. UV-Vis characterization results show different transmittance values due to the temperature difference, transmittance results with increasing temperature increase the value of transmittance is decreased. this may be caused by crystallinity due to annealing temperature. This is supported by the conductivity of TiO$_2$ 18NR-T thin film characterized by Four Point Probe, TiO$_2$ 18NR-T thin film with an annealing temperature of 550°C has good electrical properties.

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