Effect of Sintering Temperature in Curcumin Dye-Sensitized Solar Cell using ITO Glass

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Abstract. The world’s energy needs are increasing as the human population increases. The fulfillment of fossil-based energy has reached optimal conditions and is predicted to decline in the future. One potential that can be developed to meet future energy needs is dye-sensitized solar cell (DSSC). DSSC is an efficient third generation that produces green energy at low production costs because no vacuum system or expensive equipment is required to manufacture. This study examines the structure of the DSSC using indium tin oxide (ITO) glass, and its working principles are described. The dye solution uses curcumin as the photosensitizer. From the results of this study, it is known that DSSC at a sintering temperature of 400°C has better results than DSSC with a sintering temperature of 350°C. The DSSC with turmeric (Curcuma longa) has an efficiency of 0.81%.

1. Introduction

The rapid industrial development resulted in the increasing need for energy to meet all the industrial world’s markets. However, over time, the amount of energy reserves is increasingly limited because energy use is still focused on fossil energy or non-renewable energy. The use of fossil energy has had many negative impacts, including the depletion of the ozone layer, global warming, and climate change.

The most abundant and widely used renewable energy source is solar energy. Indonesia, which is located on the equator, has a large enough intensity of solar radiation throughout the year, has great potential to apply solar energy as a renewable energy source. One of the uses of sunlight as renewable energy is to use solar cells to convert sunlight into electrical energy. Solar cells are divided into three types, the first is solar cells from single-crystal silicon and multijunction silicon, the second, thin-film solar cells, and the third are dye-sensitized solar cells or DSSC. Currently, solar cells that are widely used are solar cells made of crystalline silicon. However, crystalline silicon-based solar cells produce a by-product of silicon tetrachloride, which is very dangerous to humans. Based on these considerations, DSSC is an alternative to replace crystalline silicon-based solar cells.

According to history, Graetzel and co-workers [1] have pioneered the manufacture of dye-sensitive colloid TiO₂ films to make high-efficiency, low-cost solar cells in 1991. Remarkable development from non-silicon based solar cells where the overall light-to-electric energy conversion efficiency is approximately 12% during the day [2]. An extensive review of DSSC can be found in many references [3–6].
The utilization of energy from sunlight is considered as one of the effective solutions in producing green energy. The solar cell is the basic block of the solar array in which the absorption of light quanta of specific energy results in the generation of charge. Photo generational charges carry their energy to some external load where it is converted into other forms of energy desired.

The dye has a significant impact on the effectiveness of the DSSC. The more light that is absorbed, the better it will be in electricity production. But on the other hand, the anode’s role in DSSC performance is quite large because the anode is a component that separates positive and negative charges, which will later become electrical energy. A suitable anode is one that has a large band gap. The larger the anode surface area, the more light can be converted. The method that can increase the surface area without taking up a lot of space is the multi-layer method. Still, this method can be done by mixing nano and micro semiconductors to get a large surface area, and the maximum light can be scattered. The types of anodes used in DSSC include TiO$_2$, which is readily available, and the price is quite affordable.

DSSC is a tool to convert sunlight energy into electrical energy using a photosensitizer with a wide band gap semiconductor. Semiconductors are compounds that can conduct electrons, and semiconductors used in DSSC must have a wide band gap. The materials commonly used as semiconductors in DSSC are TiO$_2$, ZnO, Nb$_2$O$_5$, SnO$_2$, and CdO, which have a wide band gap of 3.2, 3.2, 3.4, 3.6, and 2.5 eV, respectively. This experiment uses TiO$_2$ as a semiconductor. TiO$_2$ was chosen because it is non-clinking, easy to obtain, cheap, and able to absorb UV and visible light to assist a suitable photosensitizer [6–8].

Natural or synthetic dyes can be used as dye sensitizers on DSSC cells. Ruthenium-based synthetic dyes can produce high efficiency in the DSSC experiment, but synthetic dyes have carcinogenic properties harmful to the environment. Therefore natural dyes are preferred because they are cheap and certainly safer for the environment. Dye sensitizers must have carboxyl and hydroxyl groups to bond with a suitable semiconductor that shows maximum absorbance from visible to infrared light regions and is not easily degraded. The primary function of electrolytes is to regenerate dye. The electrolyte transfers the positive charge towards the counter electrode, where the redox pair is cycled by electrons flowing back through the external circuit [10–12].

The electrolyte must have a low viscosity, negligible vapor pressure, and high dielectric properties. Three types of electrolytes are widely used: inorganic solvents I-/I$_3$-, inorganic ionic liquids, and solid electrolytes. In DSSC, electrolyte I-/I$_3$- is the most commonly used because iodine provides high efficiency for DSSC [10]. This experiment using a 5% Lugol solution. This solution has good thermal stability, non-volatility, and electrical conductivity [7].

The counter electrode is a crucial factor in DSSC. The counter electrode’s primary function is as a catalyst so that the electron transfer process and iodine/triiodide reduction are faster. Thus, the quicker the DSSC produces electricity. The materials used at the counter electrode are inert (not easy to react), such as platinum, gold, and carbon. In this research, carbon is used as a counter electrode because it is cheap, has high electronic conductivity, is corrosion resistant to triiodides, and has high reactivity for triiodide reduction.

The cell consists of four elements: a conductor electrode and a counter conductor electrode, a nano structured TiO$_2$ layer, a dye molecule, and an electrolyte. The transparent conductor electrode and the counter conductor electrode are coated with a thin conductive and transparent tin dioxide (SnO$_2$) layer. Nano crystalline TiO$_2$ is deposited on the conducting electrode (photoelectrode) to provide the necessary large surface area where the dye molecules are adsorbed. After absorption of sunlight, dye molecules are excited from HOMO (highest filled molecular orbital) to LUMO state (lowest unfilled molecular orbital). After the electrons are injected into the conduction band of the wide band gap semiconductor nano structured TiO$_2$ film, the dye molecules (photosensitizer) become oxidized. The injected electrons are transported between the TiO$_2$ nano particles and then extracted to the load, where the work is done sent as electrical...
energy [13]

To mediate the electrons between the TiO$_2$ photo electrode and the carbon-coated counter electrode-electrolyte containing redox I-/I$_3$-ions is used to fill the cell. Therefore, the oxidized dye molecule (photo sensitizer) is regenerated by accepting electrons from the redox mediator ion I, which will be oxidized to I$_3$- (tri-iodide ion). I$_3$- replaces the internally donated electron with that from an external load and is reduced to I- ion. Therefore, the generation of electric power at the DSSC does not cause permanent chemical changes or transformations.

Figure 1: Construction of a dye-sensitized solar cell consists of four parts: (1) The working electrode of film layer (TiO$_2$) covered by dye molecules that absorbs solar energy; (2) Indium tin oxide (ITO) layer is used to facilitate charge transfer from the electrode layer; (3) The counter electrode layer made of C; and (4) Iodide electrolyte it used to supply electrons to dye to replace the ones being extracted by TiO$_2$

2. Methodology

DSSC is assembled by sandwiching two ITO (indium tin oxide) glass plates, given an electrolyte solution. Light sources, semiconductors, photo sensitizers, electrolytes, and counter electrodes have a significant role in the manufacture of DSSC. Each layer of the DSSC cells has its activity. The ITO glass used is transparent because sunlight can enter the cell [8].

The working electrode is made by depositing the TiO$_2$ solution on top of the ITO conductive transparent glass using the doctor blade method. The method was used in the deposition of the TiO$_2$ suspension, which was applied uniformly to the electrode plates that had been sterilized (rinsed with ethanol). The TiO$_2$ film is allowed to dry and then annealed at about 450°C (in a well-ventilated zone) for about 15 minutes to form a large surface area and porous TiO$_2$ film. The film should be allowed to cool slowly to room temperature. Necessary to relieve thermal stress and avoid cracking of the peeled glass or TiO$_2$ film. The investigation of the formation of the nanocrystalline TiO$_2$ film was confirmed by scanning electron micrograph of SEM. The TiO$_2$ nanocrystalline layer was stained with dye for approximately one day, then washed with distilled water and ethanol to ensure no water in the film after the residual dye was removed. The counter electrode is coated with graphite (sooth), which acts as a catalyst in the dye’s redox reaction. Both the photo and the counter electrodes are clamped together, and electrolyte drops are applied to fill the connected cells. The electrolyte used consists of an organic solvent containing a redox pair (usually an iodide/triiodide [I-/I$_3$-] pair). Measurement of open-circuit voltage and short circuit current is carried out using a solar simulator. UV and IR cutoff filters but no AR coating on the photoelectrode were used. Then, the TiO$_2$ layer was burned at 350° and 400°C for 2 hours and immersed in a turmeric dye solution. Furthermore, the counter
electrode circuit by depositing the carbon suspension on the ITO glass. The union of the DSSC solar cells is done by combining the working electrode with the counter electrode and filling the electrolyte (5% Lugol) into the two electrodes’ cavity through the holes that have been made on the counter electrode [14].

3. Results and Discussion

DSSC solar cell performance testing is carried out using a multimeter plugged into both sides of the DSSC cell to find out how much current and voltage are generated. For light sources are used directly from sunlight during the day with 100 mW/cm$^2$. From the test, several data were generated, i.e., the amount of current, voltage, and light intensity used to find the efficiency of the DSSC. In this study, using temperatures of 350$^\circ$C and 400$^\circ$C were used. The following Table 1 is the data obtained from testing with the unit as follow: voltage in mV, current in mA, power in mW, light intensity in (mW/cm$^2$), efficiency is for DSSC in %.

| Temperature | Voltage | Current | Power | Light intensity | Efficiency |
|-------------|---------|---------|-------|----------------|------------|
| 350         | 42.5    | 0.038   | 0.269 | 100            | 0.27       |
| 350         | 40      | 0.02    | 0.133 | 100            | 0.13       |
| 350         | 117     | 0.04    | 0.780 | 100            | 0.78       |
| 350         | 78      | 0.02    | 0.260 | 100            | 0.26       |
| 350         | 23      | 0.04    | 0.153 | 100            | 0.15       |
| 350         | 155.6   | 0.07    | 1.815 | 100            | 1.82       |
| 350         | 65.2    | 0.07    | 0.761 | 100            | 0.76       |
| 350         | 54      | 0.12    | 1.080 | 100            | 1.08       |
| 350         | 104.6   | 0.04    | 0.697 | 100            | 0.70       |
| 350         | 83.4    | 0.07    | 0.973 | 100            | 0.97       |
| 350         | 149.9   | 0.11    | 2.748 | 100            | 2.75       |
| 350         | 60.3    | 0.055   | 0.553 | 100            | 0.55       |

Based on the results of the SEM test above, it can be seen that the gaps in the 350C sample look tighter, and the 400C models have more gaps and have varied gap sizes where the gap serves to absorb the dye, which dye will absorb light later. The more the gap, the better the absorbance of the dye will be, and the light absorption will be better. Therefore, the SEM test can ascertain that the 400C sample is better in absorbance of dye and light. Particle size is calculated based on the following equation:

$$D = \frac{0.92\lambda}{\text{FWHM} \cos \theta}$$

where: D = average particle size (nm), $\lambda$ = wave number (for Cu is 0.15408), FWHM = full width-half maximum (rad), and $\theta$ = the crest angle used (rad). From the calculations, the resulting crystal size in the 350$^\circ$ and (b) 400$^\circ$C is 1.2104nm and 0.9411 nm, respectively. The diffractogram of the XRD test can be described as shown in Table 2.

Before being used as a photosensitizer, the turmeric dye extract was characterized using FTIR testing. This characterization was carried out to determine the presence of functional groups in turmeric extract. Wave number spectrum testing is carried out using a wavelength of 400-500 cm$^{-1}$. The results of FTIR spectra interpretation are put in Table 3. The infrared spectra show that the extracted curcumin contains functional groups such as -OH shown by the sharp absorption in the 3418.97 cm-1 regions, supported by the appearance of absorption
1019.42 cm\(^{-1}\) waves for C-O-C bonds. The absorption of the aromatic -C = C double bond is shown by the sharp absorption at wave number 1637.64 cm\(^{-1}\), which is also supported by the appearance of absorption on wave 572.88 cyclohexane group, and for the 705.01 absorption wave is a bent -C-H bond. Based on the FTIR spectrum results, it can be concluded that the compound extracted is curcumin.

**Table 3: FTIR test for curcumin dye**

| No | Spectra (cm\(^{-1}\)) | Reference range (cm\(^{-1}\)) | Pattern | Functional groups          |
|----|-----------------------|-------------------------------|---------|-----------------------------|
| 1  | 3418.97               | 3500-3000                     | Sharp   | -OH                         |
| 2  | 1637.64               | 1650-1450                     | Sharp   | -C=C aromatic               |
| 3  | 1019.42               | 1230-1000                     | Sharp   | C-O-C alcohol               |
| 4  | 705.01                | 900-690                       | Normal  | C-H crumpled                |

**4. Conclusion**

Much research has been done in the DSSC field with natural dyes. Natural dyes as a photosensitizer are more desirable because they are environmentally friendly, non-toxic, easy...
to obtain, and economical in cost. In this study, we used turmeric dye as a photosensitizer in DSSC. From the results of this study, it is known that semiconductors at a sintering temperature of 400°C have better results than DSSC with a sintering temperature of 350°C. And when compared with several other dyes, the highest efficiency was obtained by Javanese jute dye (kenaf hibiscus), which was 2.87%. In contrast, DSSC with turmeric dye (Curcuma longa) had an enormous efficiency, namely 2.74%. From the results that have been obtained, DSSC using natural dyes has excellent potential and is also promising. However, researchers’ problems in developing DSSCs are still the organic properties of the materials used, such as heat resistance, durability, and purification methods to obtain intact color pigments. DSSC will continue to be in the development stage to achieve this. Researchers are expected to conduct further research to develop this natural photosensitizer so that the performance of DSSC can be increased.

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