The influence of increased carbon content on the number of electrons in dye-sensitized solar cell (DSSC)

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Abstract. Dye-Sensitized Solar Cell (DSSC) is a solar cell that uses sensitive dye toward visible light to convert light into electricity. The sensitive dye that are commonly used are chlorophyll which contains many elements of carbon. The carbon element in chlorophyll contains electrons which can generate an electric current in the DSSC. This research has proven that increasing the carbon content of dye can increase the number of electrons generated in the DSSC. The method used in this study was to vary the dye content of TiO2, namely dye concentrations of 25%, 50%, 75% and 100%. The results showed that increasing the dye content would increase the carbon content and the number of electrons generated by the DSSC, namely that the 100% dye content had a carbon content of 1.414% and the number of electrons was $0.22 \times 10^{19}$.

Keywords: dye, carbon, electron

1. Introduction

Renewable alternative energy that has the potential to be developed in Indonesia is energy that comes from sunlight. This is because Indonesia's territory, which is located on the equator, makes the potential for solar energy in Indonesia quite large, because according to calculations, Indonesia's territory will always be exposed to the sun for more than 10 hours a day and also due to the intensity of irradiation that is almost evenly distributed in all regions of Indonesia. The content of solar energy in Indonesia's territory if used as a power plant is equivalent to 4.8 kWh/m²/day or around 112000 GW, but that is used to generate new electricity around 14000 kW or 0.000012% [1]. The very minimal use of solar energy is caused by various problems in its development.

Constraints in the utilization of solar energy are caused by varying amount sunlight on earth from one region to another. Tropical climates like Indonesia have great sun exposure throughout the year, however this exposure is often blocked by clouds. If it’s rainy or cloudy, very little energy is produced by solar cells. In cold climates near the poles they have very little sun exposure, and experience winters with very long nights, while in summer it is the opposite. Another obstacle to the development of solar power is that sunlight is only available during the day, so that in order to be utilized at night, solar energy generated by solar cells must be stored in batteries. While the technical constraints for the use of solar cells are, to achieve 30% efficiency of solar cells requires...
expensive single crystalline silicon in solar cell panels. To produce a large amount of power required solar panels in large quantities due to low efficiency so that high costs are needed [2].

Silicon solar cells have a narrow absorption spectrum area which is another technical obstacle. Purple and ultraviolet light spectrum is the main area of light absorption in silicon solar cells. This portion constitutes 7% of the entire spectrum of sunlight in addition to 47% visible light and 46% infrared. So that about 93% of the sunlight spectrum area cannot be utilized by silicon solar cells [2]. The problem of pollution is the next obstacle to the use of solar cells, this is because solar panels are toxic. Even though its use does not cause pollution, in the process of making solar cells there is waste or pollution to the environment due to the use of toxic materials such as polysilicon in the process of making solar cells. The gas that creates the greenhouse effect, nitrogen tetrafluoride is also used in the manufacture of solar panels. This gas is 17000 times stronger than carbon dioxide. This is what causes damage to the environment [3].

To solve the problems found in silicon solar cells, a Dye-Sensitized Solar Cell (DSSC) was developed, a solar cell that uses dye to convert sunlight into electricity by O’ Regan and Gratzel in 1991[4]. DSSC is a solar panel device whose process resembles the principle photosynthesis in plants is a photo electrochemical system in which a wide-gap semiconductor is adsorbed by a dye which functions to absorb photons of sunlight to be converted to electrical energy by the process of transporting electrons in its structure [5-6].

The DSSC structure is composed of nano-sized semiconductors immersed in a dye solution which is useful for absorbing photons of light (dyes used are synthetic dyes such as ruthenium or organic dyes), conducting glass, counter electrodes and electrolytes, DSSC is also known as Gratzel cells or Dye-Sensitized Solar Cell (DSSC). DSSC has several advantages that is easy to set up, cheap, not harmful to the environment and light thin film structure compatible with automated manufacturing [7].

The nanoparticle layer that is often used is Titanium dioxide or TiO₂ [8]. The large bandgap energy (Eg) value of 3.20 eV, good chemical stability, non-toxic properties, environmental compatibility and low price are the advantages of TiO₂ semiconductor material [9-11]. The anatase structure of TiO₂ can be used as electrodes in solar cells, lithium batteries and electrochromic devices [12].

The most basic problem in Dye-Sensitized Solar Cell (DSSC) is that the efficiency is still low compared to silicon solar cells [13]. The highest DSSC efficiency currently reaches 11%, still lower than silicon solar cells which have an efficiency of about 20% [14]. The low efficiency of DSSC is due to the high recombination process of free electrons in the electron transfer process with oxidized dye and electrolytes [15]. One of the reasons for the high rate of recombination is the limited diffusion of electrons in the TiO₂ layer. The low diffusion of electrons will result in electrons being trapped at the boundary between TiO₂ particles [16]. Furthermore, the trapped electrons are trapped. at the grain boundaries this results in a higher chance of recombination, because the low electron diffusion occurs because of the less than optimal contact between the particles [17].

Various attempts have been made to improve the efficiency of the DSSC. Modifications to the semiconductor layer to increase efficiency have been carried out by Zainal Arifin engineering the photoanode layer using the double layer concept [18], Javed by making a heterojunction photoanode layer ZnO / TiO₂ [19] and Sujjinapram making a composite layer of SnO₂-ZnO [20]. Dye engineering can also increase efficiency, as Hara did with the use of mercurochrome sensitizers [15], Zeng made a conjugation between ethylenedioxythiophene and thienosilole in organic photosensitizers [21], and Supriyanto modified natural organic dye using Celosia Argentums and Lagerstromia sp [22].

Increasing the efficiency can be done by increasing the number of electrons flowing through the semiconductor. The number of electrons can be increased by increasing the element content,
especially carbon, which is the source of electrons in the dye. Therefore, this study aims to determine the effect of increasing carbon content on the number of electrons generated from DSSC.

2. Research methods
This study used experimental methods to determine the effect of increasing carbon content on the number of electrons generated by DSSC. In the Transparent Conduction Oxide (TCO) with dimensions of 1.5 x 1.5 cm$^2$ in the conductive section using scotch tape an area of 1 x 1 cm$^2$ is formed to deposit TiO$_2$. The thickness of the TiO$_2$ paste is adjusted based on the thickness of the scotch tape.

The doctor blade technique is used to position TiO$_2$ on the prepared area in the conductive glass. TiO$_2$ paste is flattened using a stirring rod. Furthermore, the layer is allowed to dry for 15 minutes and sintered / burned at 4500C for 30 minutes in the furnace. Conductive glass that has been deposited with TiO$_2$ paste and has been sintered for 24 hours is immersed in a dye solution containing chlorophyll until the TiO$_2$ layer on the conductive glass turns green, indicating that the TiO$_2$ surface has been adsorbed by chlorophyll. The content of chlorophyll dye used to soak TiO$_2$ varied in percentage, namely 25%, 50%, 75% and 100%. Variation in the percentage of dye content was carried out to determine the elemental content of carbon produced by the dye and its effect on the number of electrons.

The electrolyte solution is then dropped on the TiO$_2$ layer and dye. The counter-electrode which has been given a carbon catalyst is then placed on top of the TiO$_2$/dye/electrolyte layer resembling a sandwich structure with the two ends of the electrode leaving an area of 0.5 cm which functions as an electrical contact. So that the two electrodes of the conductor glass are tightly connected and securely clamped using clips. Furthermore, Energy Dispersive X-ray Spectroscopy (EDS) testing and measurement of electric current on solar cells were carried out.

3. Results and discussion
Characterization of the DSSC layer using Energy Dispersive X-ray Spectroscopy (EDS) aims to analyze the elemental composition of the sample surface. Table 1 shows the composition and variation of dye content, namely 25%, 50%, 75% and 100% in DSSC.

| Element     | 25%  | 50%  | 75%  | 100% |
|-------------|------|------|------|------|
| Carbon      | 0.627| 0.838| 0.965| 1.414|
| Oxygen      | 37.417| 38.654| 40.226| 41.559|
| Sodium      | 0.573| 0.526| 0.481| 0.429|
| Chlorine    | 0.443| 0.398| 0.366| 0.325|
| Titanium    | 48.771| 48.774| 48.762| 48.751|
| Tin         | 12.169| 10.810| 9.200| 7.522|

From the results of the EDS test, it was found that the elements content and composition of the DSSC layer were shown in Table 1. In Table 1 for DSSC with a dye content of 25% containing Ti and O elements, respectively 48.771% and 37.417%. The presence of the elements Ti and O indicates the presence of TiO$_2$ molecules. While the presence of element C of 0.627% is an element in
chlorophyll dye. The presence of Na, Cl and Sn elements is an element found in Transparent Conductive Oxide glass.

From Table 1, it can be seen that the increase in the dye content in the DSSC shows an increase in the carbon element content in the DSSC with the highest percentage at 100% dye content, namely 1.414%. In the TiO$_2$ nanopore structure, the carbon element in the dye functions as a source of electrons which will be excited when subjected to external energy [4]. These excited electrons will flow through the TiO$_2$ conduction region causing an electric current to be generated by the DSSC. The more carbon, the greater the number of electrons produced, thus increasing the electric current from the DSSC.

The hexagonal layer formed by carbon molecules, namely three electrons, is used to make covalent bonds with the nearest neighboring C atom, so that there are free electrons that can move on the surface of the layer. The ability to conduct electric current by carbon is due to the presence of these free electrons. The uniqueness of carbon’s electronic structure allows carbon to form various bonds so that carbon can be found in various forms. Carbon has a nucleus arrangement surrounded by six electrons with the innermost shell tightly bonded to two electrons and the valence shell occupied by four electrons.

The 2s subshell and 2p subshell each occupied by two valence electrons are the ground state minimum energy carbon. With a small excitation to be able to move an electron from the 2s subshell to the 2p subshell is a special property of carbon. Causes a half full state of the four orbitals so that a strong covalent bond can be formed from this favorable carbon state. The four orbitals on carbon that are half full provide the ability for electrons on carbon to move freely and make carbon atoms can cause high electrical conductivity [23].

The high electrical conductivity of carbon is due to the fact that carbon is the electron source of the dye. The presence of unpaired valence electrons on carbon causes the electrons on carbon to be easily released or excited when exposed to a small energy. Dye containing chlorophyll have the ability to absorb photon energy from light and utilize this light energy to release electrons contained in carbon. So that by increasing the carbon content of the dye, the more electrons are contained in the dye [13].

Current measurement aims to determine the electric current generated from each DSSC. Measurement of electric current and number of electrons with variations in the percentage of dye content in TiO$_2$, namely 25%, 50%, 75% and 100% as shown in Table 2.

| Content of Dye | 25% | 50% | 75% | 100% |
|---------------|-----|-----|-----|------|
| Electric Current (mA) | 0.147 | 0.216 | 0.288 | 0.353 |
| Number of Electrons | 0.09x10$^{19}$ | 0.14x10$^{19}$ | 0.18x10$^{19}$ | 0.22x10$^{19}$ |

Table 2 shows that the increasing dye content in the DSSC results in an increase in electric current and the number of electrons produced. The highest number of electrons was in the dye content of 100% and the electric current was 0.353 mA, namely 0.22x10$^{19}$ electrons. The electrons produced come from the element carbon in the dye. The electrons in the element carbon are excited as a result of the absorption of the photon energy by the dye. Increasing the dye content of the DSSC causes more electrons to be excited and flow through the TiO$_2$ conduction region, thereby increasing the electric current generated by the DSSC.
4. Conclusion
This research concludes that by increasing the dye content in the DSSC will increase the content of carbon elements and the number of electrons produced by DSSC. The increase in electrons is because carbon is the source of electrons from the dye which will be excited when it is exposed to light energy which is absorbed by chlorophyll and will generate an electric current in the DSSC. The highest number of electrons in the dye content is 100% and the current is 0.353 mA, which is 0.22x10^19 electrons.

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