Mekanika: Majalah Ilmiah Mekanika

Nanofiber Semiconductor Experiment with Distance Variation Electrospinning Method to Improve the Efficiency of the DSSC

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Keywords:
DSSC
Electrospinning
Rotating collector
Distance

Abstract
Dye-Sensitized Solar Cell (DSSC) is a solar cell that uses dyes to transfer sunlight to electrical energy. DSSC construction uses a layered system (sandwich) that consists of a working electrode and an opposing electrode, both of which are placed on conducting glass and electrolytes to allow electron cycling. DSSC has a high price, so increasing efficiency is needed to use these solar cells more widely. This research aims to determine the effect of the distance between the tip and the rotating collector to increase the efficiency of the Dye-Sensitized Solar Cell (DSSC) and examine its impact on the morphology of the ZnO nanofiber. This experiment is carried out by varying the distance between the tip to the rotating collector, 4 cm, 6 cm, and 8 cm. This research indicates that at a distance of 8 cm, it produces a small, uniform, and stable ZnO nanofiber structure with V_{oc}, J_{sc}, FF, and DSSC efficiency values of 0.559 V, 9.809 mA/cm^2, 43.3%, and 2.3%. In addition, at a distance of 8 cm, it also produces the highest DSSC electrical efficiency from the other distances due to the absorbance of the dye and high electron excitation.

1 Introduction

Energy is the primary source of life in the world. The use of energy in society still depends on non-renewable fossil fuels such as petroleum, coal, and natural gas. This fossil fuel is not only limited in use but also can cause environmental pollution. To overcome this problem, another alternative fuel is needed. Therefore, researchers focused on clean and renewable energy sources, namely solar energy. Solar energy is a source of energy that produces heat and radiation. Solar cells are a tool that can convert solar radiation into electrical energy through a photovoltaic process [1,2].

Solar cells have been developed from generation to generation with different characters and different components, namely silicon-based solar cells, thin film-based solar cells (thin film), and DSSC. Silicon-based solar cells are made of silicon and have very high efficiency. The disadvantage of this solar cell is that it is expensive to produce. Thin film-based solar cells are a development of silicon solar cells, which have lower efficiency than silicon solar cells but are more economical. The price is lower than silicon solar cells [3]. Michael Gratzel first discovered the Dye-Sensitized Solar Cell (DSSC) solar cell in 1991.

https://dx.doi.org/10.20961/mekanika.v21i1.51479

Revised 27 May 2021; received in revised version 20 February 2022; Accepted 21 March 2022
Available Online 31 March 2022

2579-3144

Gratzel's research shows that DSSC has a relatively low price compared to the previous generation, simple fabrication, and environmentally friendly materials [4]. DSSC consists of five layers: Fluorine-doped Tin Oxide (FTO) glass, semiconductor, dye, electrolyte, and counter electrode [5]. The efficiency of the DSSC depends on the semiconductor that must have high electron mobility and a surface area to absorb the dye. Currently, DSSC has an efficiency of 15% [6]. Semiconductor materials that are often used in DSSC are TiO_2 and ZnO. Both have their advantages and disadvantages, including the advantages of ZnO, namely having a wide band gap of 3.37 eV [7] and the high electron mobility of TiO_2 [8]. At the same time, the drawback is the level of chemical stability which is relatively low. TiO_2 has advantages, namely high color adsorption ability and high chemical stability but the disadvantage of TiO_2 is that it has a low band gap of 3.2 eV [7]. To get optimal performance, the Double Layer method is used. This method is used to form a DSSC anode using several semiconductor layers to form a DSSC anode order to have good performance. The electrospinning method with a rotating collector makes nanofiber fibers with an easy working principle and can maintain the uniformity of the nanofiber produced. In principle, electrospinning utilizes the electrostatic force that arises from charged particles due to a high voltage between the tip of the tip and the rotating collector [9].

Photoanode of DSSC made of nanomaterial with different morphologies are nanofibers, nanowires, nanorods, nanobelts, nanotubes, nano spiral, nano rings [10], and nanoparticles [11]. Nanofiber has the advantage that nanofiber morphology can provide direct electron flow from photogeneration to the conductive substrate. The branching structure makes the morphology of the nanofiber has a high surface area. Nanofiber structure that can stick to the substrate and the dye will directly facilitate the mobility of electrons that have been excited. The direct deposition method is a coating technique on nanomaterials with an electrospinning process in which the precursor solution is sprayed directly onto the FTO glass. The benefit of this method is that the ZnO coating process on the DSSC assembly will be shorter and reduce nanofiber damage. Meanwhile, the attachment process to nanomaterials such as doctor blade, slip casting, and spin coating uses a similar technique by coating the nanomaterial from a paste form into a thin layer on FTO glass. The process before coating the nanomaterial paste is by making a solution first. Then the solution is converted into a nanomaterial that has been sintered [12]. This method still has some disadvantages, such as a more extended procedure and can damage the nanofibers.

In this study, the DSSC photoanode manufacturing process will be examined using distance variations in the electrospinning process with the direct deposition method on a rotating collector and a method of coating nanomaterials using ZnO material with an electrospinning process where the results of spraying ZnO solution will be captured directly by the FTO which has been coated with TiO_2 nanoparticles-moreover, glued to the rotating collector. Therefore, the direct deposition method using electrospinning with a rotating collector will shorten the DSSC fabrication process and hopefully reduce the damage to the nanofiber produced and produce a good performance.

2 Experimental Methods

2.1 Preparation of photoanode

This research uses semiconductor types of ZnO nanofiber and TiO_2 nanoparticles. To obtain the nanofiber morphology, an electrospinning process was carried out with a rotating collector so that semiconductors need to be added to precursor solutions which are polymers with good electrical conductivity. Preparation of precursors using 10 grams of Polyvinyl Alcohol (PVA) (Merck, MW = 72,000) mixed with 10 ml of distilled water (H_2O). To produce a homogenized solution, the stirring process was carried out for four hours at a solution temperature of 70 ℃. The $Zn(Ac)_2$ solution was synthesized using 2 grams of zinc acetate dihydrate ($(CH_3COO)_2Zn.2H_2O$, Merck) and 8 ml of H_2O, after which the homogeneity process was carried out by stirring for 1 hour, keeping the solution at 70 ℃. The homogenization process between the PVA and $Zn(Ac)_2$ solution was carried out in a 4:1 wt% at 70 ℃ for eight hours. Furthermore, the $Zn(Ac)_2$/PVA solution was left to stand at room temperature for 24 hours to remove the formed foam [13,14] so that a $Zn(Ac)_2$/PVA solution is produced, which is used to produce ZnO nanofiber fibres using an electrospinning machine with a rotating collector as shown in Figure 1.

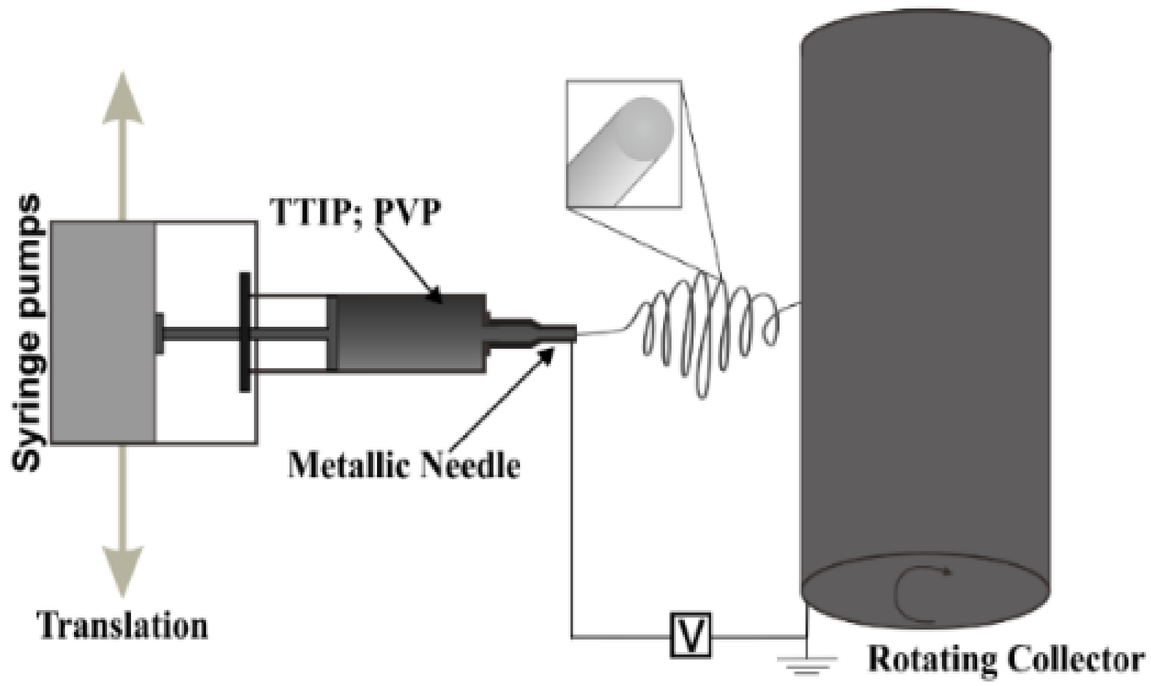


Figure 1. Schematic illustration of electrospinning with rotating collector [15]

The solution that has been synthesized is then put into 1 ml of the electrospinning solution pump injection. The central part of the electrospinning device consists of a high-voltage Direct Current (DC) source, a spinneret tube, and a small diameter needle with an inner diameter of 200 µm, which is connected to the positive 15 kV high voltage terminal to the plate on the rotating collector made of metal to which FTO glass has been deposited with TiO_2. Nanoparticles and connected to the negative terminal using the direct deposition method (Figure 1). The flow rate of the solution through the needle is 4 µL / minute because it can produce more uniform nanofiber fibers. The tip distance to the rotating collector uses a variation of 4, 6, 8 cm. the rotating speed at the collector is 45 rpm. The solution then attaches itself to the surface of the collector plate in the form of pulling strands called green fibers. The green fibers were then centered at a temperature of about 500 °C with one hour of holding to remove organic matter and form ZnO crystals [16]. The result of nanofiber deposition on FTO coated with TiO_2 nanoparticles can be used as a double layer photoanode.

2.2 DSSC fabrication and testing process

After the sintering process is carried out, the FTO is left to cool then soaked in sanitizer-N719 dye ([RuL2 (NCS) 2]: 2TBA (L = 2,2'-bipyridyl-4,4'-dicarboxylic acid; TBA = tetra- n-butylammonium)) from Dyesol for one day. The DSSC fabrication process combines the FTO with a counter electrode, including semiconductors and dye. Then, the electrolyte solution is placed between the FTO and the counter electrode using the injection method. The electrolyte used in this study was Iodide (I^{3-}) EL-HPE from Dyesol. In general, the performance of the DSSC can be characterized by several electrical parameters, including the Photocurrent-Voltage curve (*JV* curve), Open-Circuit Photovoltage (V_{oc}), and Short-Circuit Photocurrent Density (J_{sc}), Fill Factor (*FF*), and Efficiency (η). The measurement is carried out by shining the DSSC at the measured intensity (generally 100 mW/cm^2) and given a variation of the electric load from zero to infinity. Then the voltage and current are measured every time [18]. The results of the measurements are in the form of voltage and current values, which are plotted in a graph as in Figure 2.

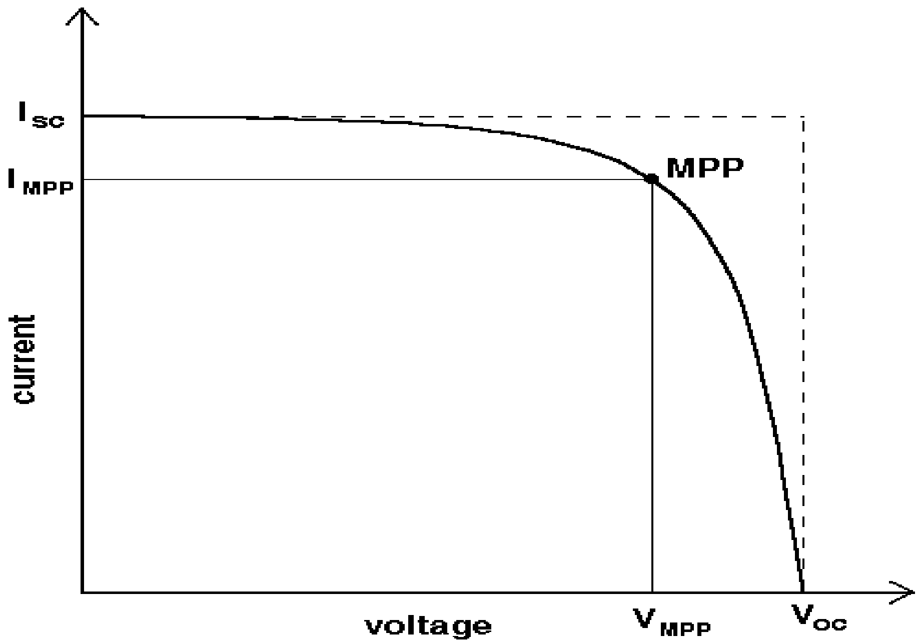


Figure 2. Current – voltage curve (I–V curve) on DSSC [17]

From the voltage-current curve (Figure 2), it can be seen that the Fill Factor (*FF*) value, that the fill factor is a parameter that determines the efficiency of the DSSC. Graphically, the fill factor is the ratio between the maximum power (*PMPP*) to the multiplication of short-circuit current (I_{sc}) and open-circuit voltage (V_{oc}). To find out the fill factor (*FF*) value, you can use Equation 1 [17].

$$FF = \frac{V_{MPP}\ x\ I_{MPP}}{I_{SC}\ x\ V_{OC}} \tag{1}$$

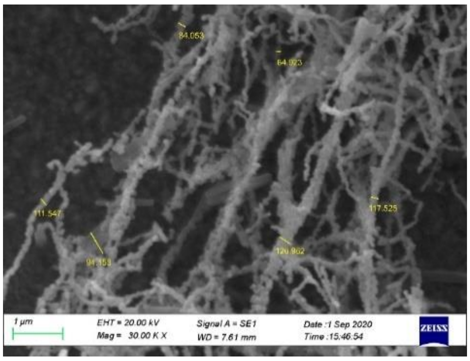
The efficiency of the DSSC (Equation 2) solar cell is the ratio between the maximum power (P_{MPP}) to the power emitted by light in the active region of the solar cell (P_{light}). Which was (P_{light}) is the multiplication of sunlight intensity (I_{rad}) to the active area of the solar cell (A) [18].

$$\eta = \frac{P_{MPP}}{P_{light}} = \frac{P_{MPP}}{I\ x\ A} = \frac{I_{SC}\ x\ V_{OC}\ x\ FF}{I\ x\ A} \tag{2}$$

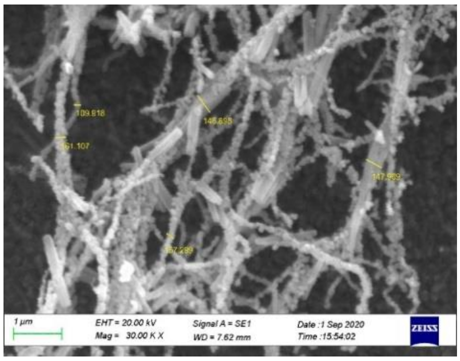
3 Results and Discussion

3.1 DSSC nanofiber morphology test

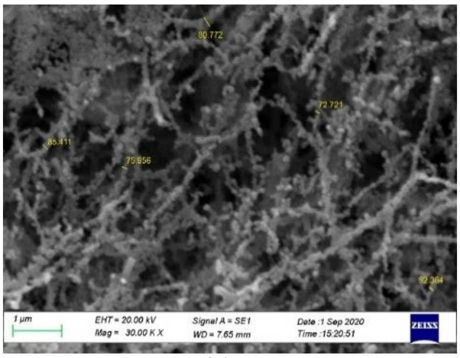
Figure 3 shows the results of the Scanning Electron Microscopy (SEM) ZnO nanofiber test by using the shorter tip distance to the rotating collector, which will result in an irregular morphology of the nanofiber, has a large diameter and has branches like dendrites on nerves. This situation occurs due to poor solvent evaporation, which causes irregular beading and build-up of nanofiber, as shown in Figure 3 (a). The shorter the tip distance to the rotating collector, the less solvent evaporation process, so that the solvent adhering to the Fluorine-doped Tin Oxide (FTO) glass is less than perfect. This is consistent with previous research, which states that the distance between the tip and the rotating collector has sufficient evaporation time for the nanofiber to fully adhere to the FTO glass, resulting in a thinner and uniform nanofiber. Meanwhile, with the decreasing distance between the tip and the rotating collector, the resulting nanofiber is irregular, the nanofiber becomes branched, and there are lumps in the resulting nanofiber.



(a)



(b)



(c)

Figure 3. SEM test results for ZnO nanofiber with variations in tip distance to the rotating collector: (a) 4 cm, (b) 6 cm, and (c) 8 cm with a flow rate of 4 μL/minute

3.2 DSSC performance

The voltage-current curve shows the performance of Dye-Sensitized Solar Cells (DSSC) solar cells at a tip to collector rotating distance of 4.6 and 8 cm. It is known that the voltage-current curve on the DSSC is shown in Figure 4. Some of the DSSC performance parameters include Short-Circuit photocurrent density (J_{sc}) of 5 mA/cm, Open-Circuit photovoltage (V_{oc}) of 0.658 V, Fill Factor (*FF*) of 0.29%, and efficiency of 0.98% for the tip distance to the rotating collector of 8 cm which can produce the highest current. However, the efficiency values at the tip to collector rotating distances of 4 cm and 6 cm are shown in Table 1. The results of this study indicate that the J_{sc} value affects the resulting efficiency value. The more the J_{sc} value increases, the DSSC efficiency value will also increase.

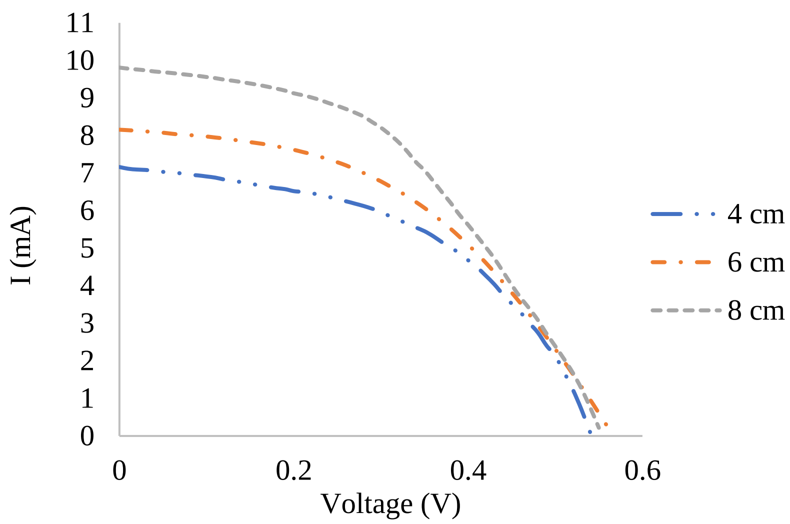


Figure 4. Current – Voltage curve (*I* – *V* curve) on DSSC

Table 1. The performance of DSSC

Distance (cm)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	η (%)
4	0.544	7.1	48	1.91
6	0.566	8.1	45.8	2.11
8	0.559	9.8	43.3	2.37

4 Conclusions

The ZnO nanofiber fabrication process in making photoanodes with nanofiber fibers in DSSC was carried out using an electrospinning machine with the use of variations in the distance between the tip to the rotating collector in the electrospinning process using the direct deposition method. The addition of the distance in the electrospinning process will produce nanofiber fibers with a small and uniform diameter and size to improve the performance of DSSC because the distribution of electrons becomes more even. Vice versa, the larger the size and diameter of the resulting nanofiber fibers, the lower the performance of the DSSC. DSSC performance is also influenced by the value of J_{sc}. The higher the value of J_{sc}, the higher the efficiency of DSSC. In this study, the highest efficiency of the DSSC was 2.37, which was achieved at a distance of 8 cm. The V_{oc}, J_{sc}, and FF values were 0.559 V, 9.8 mA/cm^2, and 43.3%.

5 Acknowledgement

This work was partially supported by a PDUPT grant from the Ministry of Research, Technology, and Higher Education, the Republic of Indonesia, with contract number 112/UN27.21/HK/2020 for FY 2020.

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