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Optical sensor based on dye-sensitized solar cell with tobacco chlorophyll

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Abstract

Modified optical sensor based on dye-sensittized solar cell has been successfully fabricated to measure the number of light energy. The electric parameters as the sensor output were achieved from the light illuminance as the sensor input. The measured parameter from optical sensor according to the voltage and current output have been characterized to obtain the sensor performance. In this research, the modified sensor is customized from dye-sensitized solar cell with extracted tobacco chlorophyll dye as the photo-catalysator, photo-electrode of titanium dioxide and Iodine solution for redox reaction. The thick layer deposition with selected material is conducted using spin coating method of 1000 rpm. Based on the absorbance measurement, it shows that tobacco dye has the characteristics of visible light absorption in the wavelength of visible light spectra. The analytical result shows that the sensor has the wide linear characteristic in certain light illuminance and the increasing light intensity produces higher electrical parameter output both current and voltage. This sensor has potential prospect to be used as a light sensor and to be competitive fabrication cost.

Keywords*: modified optical sensor, sensor design, spin coating method, tobacco dye*

1. Introduction

The measurement of light intensity is playing an important role regarding to the process of conversion between the light energy to electricity. In this measurement, optical or light sensors are used to sense the physical phenomenons. Currently, applications of the optical sensor have been widely used in the field of energy savings [1, 2], image sensor [3, 4], light monitoring [5, 6], biochemical [7, 8], biomedical [9] and other applications [10-12]. A few number of research in the sensor technology, especially in optical sensor that is shows from a little domestic/local sensor production sold commercially. Today, a renewable energy is being encouraged specially the use of solar cell. Solar cell is a device that converts the energy of light directly into electricity by photovoltaic. Development of the optical sensor based on photo-electrochemical was obtained with the introduction of fractal thin film dye-sensitized solar cells previously [13]. Many studies are realized on the dye used for sensitizing DSSC since it is the principal source of the photo-generated current by the cell. However, the price of this dye stays even higher. Nevertheless, the natural dye becomes more real concurrent to an artificial one, as the efficiency of cell sensitized with this dye remains low [14]. The principle and the research optical sensor from the development of DSSC using TiO_2 as the active layer with variation dye has been characterized in the previous research [15, 16]. The TiO_2 not only has attractive oxide semiconductor for DSSC, but also suitable for sensor applications [17, 18]. The basic principle of DSSC is shown in Figure 1.

Tobacco based cigarette factories in Indonesia have been widely developed. The data show that the number of death in Indonesia increasing and the most reason of the death is smoking. Regarding to that problem become the dilemma of the government due to there are options that to be chosen i.e safe tobacco farmers or the health of smokers. To attend that problem, the change of point of view is needed. The use of tobacco for electronic component material is important and become the one of the solution to divert tobacco function as cigarette. If tobacco is applied to electronic material, it also uses a renewable energy and organic

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material. This research investigates the optical sensor based on tobacco dye. At the moment, so many researches work in sensor but the size of the sensors are big and use non-renewable materials. The size of sensor is influence to the use of sensor and energy harvesting.

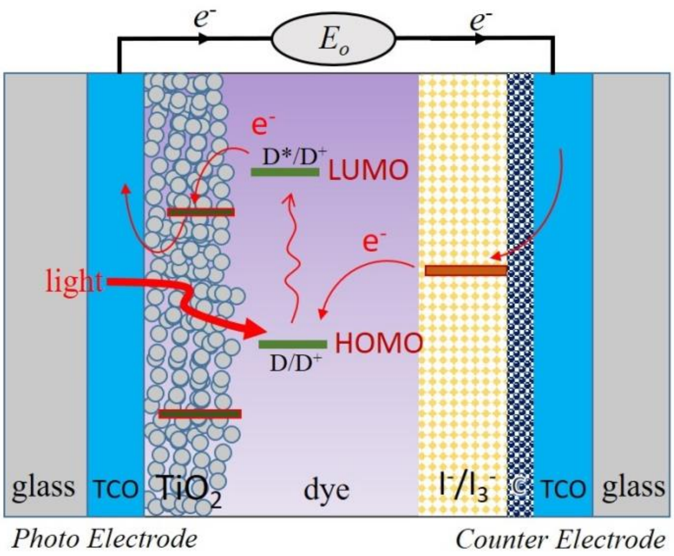

Figure 1. DSSC basic principle for sensor application

The principle of the optical sensor based on dye and TiO_2 refers to DSSC is shown in Figure 1. While the photons from the light source hit the DSSC, the energy of photons will be absorbed by the dye (D) that attaches to TiO_2 particles. Then the electron from the dye will receive energy, and the electrons will be exited condition while dyeing molecules electron in the excited condition (D*) as shown in (1).

$$D+light \rightarrow D^* \quad (1)$$

The excited electrons from dye molecules will be injected to a conduction band of TiO_2 and the dye molecules in state oxidation (D^+) as shown in (2). Then the electron will be transferred to reference electrode.

$$D^*+TiO_2 \rightarrow e^- (TiO_2)+D^+ \quad (2)$$

Redox electron usually in the form of iodide and triiodide (I^-/I_3) that act as electron mediator then generate cycle in a cell. Tri-iodide from electrolyte will catch electrons that come from the outer circuit with the help of series carbon molecules as a catalyst. The excited electrons will return to the cell and react with electrolyte into the oxidized dye. An (3) shows the electrolyte which provide replacement electrons for the oxidation dye.

$$D^++e^- (electrolyte) \rightarrow electrolyte+D \quad (3)$$

The standard structure of the sensor is using two TCO glass as the substrate the place of establishment of the photo-electrode and counter electrode. The principle and the research optical sensor from the development of DSSC using TiO_2 as the active layer with variation dye has been characterized in the previous research [19]. This research is designed and analyzed the fabrication of the sensor with the dye chlorophyll tobacco extraction with low temperature processing associated with sensor performance [20]. According to the previous microfabrication method [21, 22], this sensor is also designed using simple technique. To enhances and builds the improvement in sensor research, this works on design an optical sensor uses tobacco dye for alternative solution, economic and it easy to fabricate. The aims of this research are to analize the performance of optical sensor in form variation and the effectivity of dye absorption as electron transport medium refer to the measurement method [23-27].

2. Research Method

The experimental procedure to fabricate and measure the optical sensor based on DSSC is shows in Figure 2. In this research, the designs of Transparent Conductive Oxide (TCO) have the same shape of square but different size and the same treatment is conducted to all designs. The different sensor areas are indicated with *area 1* and *area 2* of 1x1 cm^2 and 2x2 cm^2, respectively.

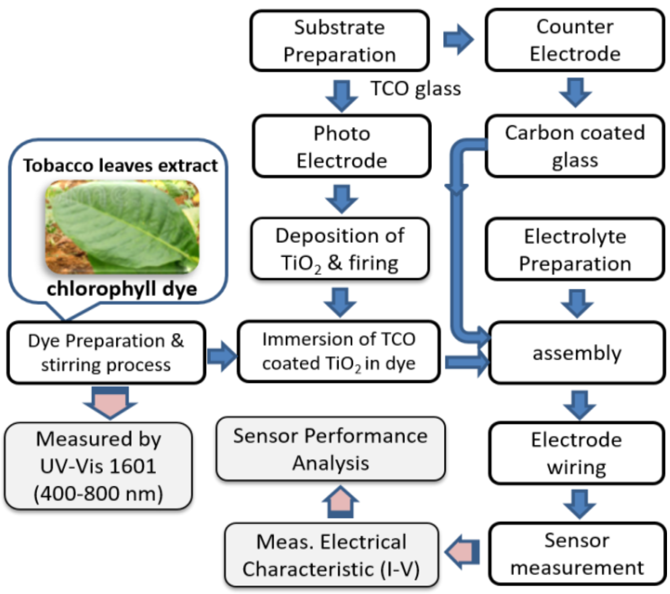

Figure 2. Experimental procedure

The materials that are used in this design included TiO_2 powder, Polyvinyl Alcohol (PVA) and aquades. TiO_2 paste uses for deposition into TCO glass. TiO2 powder mixed with 1.5 grams PVA that has been added 13.5 ml aquades. All the material is stired use magnetic stirrer in 80˚C during 30 minutes until the solution become thicken and homogen. This solution is called binder solution. Continually, the binder solution is mixed with 0.5 gram TiO2 powder. The spin coating method is chosen in this process where TiO2 paste is coated into TCO. Spin coating is a method coating desposition in order to distribute the liquid using high speed rotation (1000 rpm). Firing process using electrical furnace, the temperature is sets to 200oC for 30 minutes. It aims to obtain the perfect attachment between TiO2 and TCO glass. TiO2 layer is soaking into tobacco dye for 30 minutes. In here, the chlorophyll absorption is happened on the surface of TIO2. In this research, the carbonization process is done by heating the conductive side of glass TCO on a candle flame during 1 minute until the conductive side of TCO glass is covered by carbon. The electrolit is given to the TiO2 by dripping the electrolit solution using pipette around 5 drops or 0.25 ml. The electrolit is used for medium of electron transport from carbon to the dye. The TCO photoelectrode glass is attached to the TCO counter electrode in layer form and clamped using clip that aims to be more denses and not shifting.

3. Results and Analysis

3.1. Absorbance Spectra

The tobacco dye performs the absorbance of the visible light at 400-700 nm wavelength. The absorbance spectra measurement is shown in Figure 3. The level of tobacco dye absorption shows that tobacco dye has the characteristics of visible light absorption in the maximum peak of 4 (a.u) at a wavelength of 400-550 nm and 600-700 nm with minimum absorbance occurs at a wavelength of 700-800 nm.

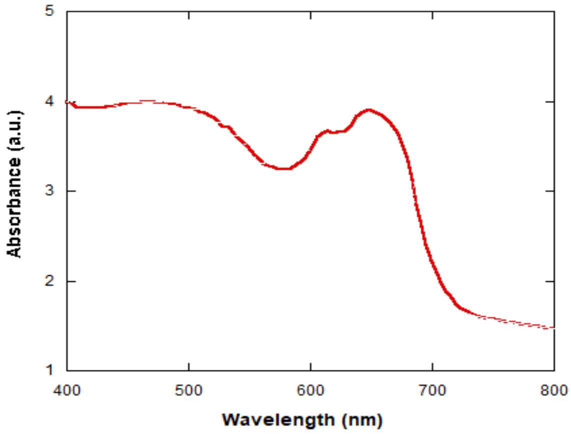

Figure 3. Light absorbance spectra measurement

3.2. The Voltage Measurement

3.2.1. The Influence of Sensor Area to the Output Voltage

Output voltage measurement based on the data of median value using five times measurement is shown in Figure 4. The graph shows determination coefficient value (R^2) of each regression result or transfer function is nearly 1. It means the voltage variable can be explained by illumination variable. As regression equation of 1 cm^2 design sensor shows the number of R^2=0.97291, means 97% of variation output voltage can be explained by the illumination variation (3% is explained by another variable). Another variable is probably in order to effect by temperature, tools performance and the materials.

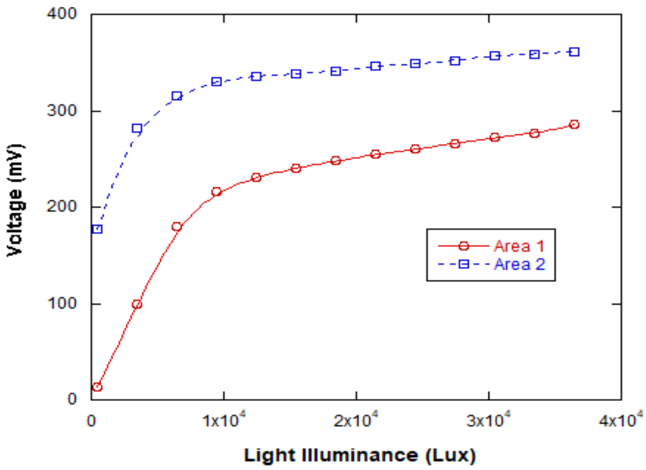

Figure 4. The relationship between area of sensor design and output voltage

3.2.2. The Impact of Sensor Area to the Current

Based on the data of median value using five times measurement is shown in Figure 5. Based on the result, it shows that determination coefficient value (R^2) of each regression result or transfer function is nearly 1. It means the current variable can be explained by illumination variables. This design can be concluded the increasing illumination, then the sensor output current goes up as well both on area 1 and area 2 of the sensor.

3.2.3. The Influence of Radiation Temperature to Output Voltage Variation

The temperature dependence to the output voltage both of area 1 and area 2 is shown in Figure 6. The Graph of temperature radiation to the output voltage in variation design can be noted that the temperature of radiation is increase due to the duration of time radiation. The temperature has been increased at 34 °C, this resulted the output voltage also increased. However, the temperature above 34 °C did not give significant increasly to the output voltage. It because the temperature increasly rise that affect to the tobacco dye structure is damage. It also possible that it works beyond exceeds the limit light absorption and high temperature exposure has been done so the quality of subtrate TCO is decrease.

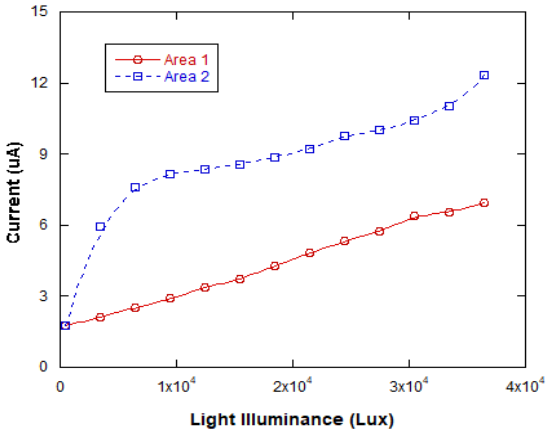

Figure 5. The relationship between area of sensor design and output current

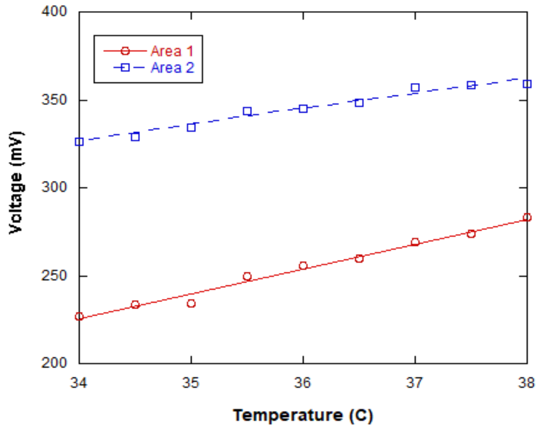

Figure 6. The relationship between area and temperature

3.3. Sensitivity Analysis

The sensitivity analysis based on output voltage with five times measurement is shown in Table 1 and Table 2. The highest sensitivity of the sensor was achieved by 0.9817 and 0.9729, respectively.

Tabel 1. Sensitivity Analysis of Sensor with area 1

Sensor Design	Voltage meas. -n	Equation	R^2
Area 1	1	y = 67.713ln(x) – 434.15	0.9544
	2	y = 67.305ln(x) – 421.94	0.9636
	3	y = 65.053ln(x) – 394.52	0.9734
	4	y = 64.787ln(x) – 387.67	0.9705
	5	y = 64.834ln(x) – 382.18	0.9817

Tabel 2. Sensitivity Analysis of Sensor with area 2

Sensor Design	Voltage meas. -n	Equation	R^2
Area 2	1	y = 40.956ln(x) – 55.355	0.9478
	2	y = 39.212ln(x) – 41.479	0.9413
	3	y = 42.109ln(x) – 72.107	0.9729
	4	y = 39.267ln(x) – 46.587	0.9591
	5	y = 43.555ln(x) – 88.569	0.9682

3.4. Uncertainty Analysis

The uncertainty analysis is shown in Table 3 and Table 4. The highest relative uncertainty value is square sensor design with the smallest surface area of TiO_2 in area 1 of 1.307%, and the smallest uncertainty value is an optical sensor that has the largest surface area of TiO2 in area 2 design that is 1.307%. This optical sensor design that has the best level of accuracy is an optical sensor with area 2 design. Due to the smaller the relative uncertainty level of a measuring instrument, the higher the level of accuracy is achieved.

Table 3. Uncertainty Analysis of Sensor with Area 1

LI (Lux)	$\underline{x}$ (mV)	σ^2	σ	ε	ε_m (%)
500	12.86	6.073	2.464	1.102	8.570
3500	99.38	22.577	4.752	2.125	2.138
6500	179.36	25.658	5.065	2.265	1.263
9500	215.6	14.244	3.774	1.688	0.783
12500	231	11.722	3.424	1.531	0.663
15500	240.66	8.489	2.914	1.303	0.541
18500	247.74	8.203	2.864	1.281	0.517
21500	254.74	5.977	2.445	1.093	0.429
24500	260.24	4.187	2.046	0.915	0.352
27500	266.24	6.753	2.599	1.162	0.437
30500	272.2	6.304	2.511	1.123	0.413
33500	277.06	8.141	2.853	1.276	0.461
36500	285.34	7.569	2.751	1.230	0.431
Average Relative Uncertainty (Area 1)					**1.307**

Table 4. Uncertainty Analysis of Sensor with Area 2

LI (Lux)	$\underline{x}$ (mV)	σ^2	σ	ε	ε_m (%)
500	177.000	46.915	6.849	3.063	1.731
3500	282.020	49.267	7.019	3.139	1.113
6500	314.960	39.413	6.278	2.808	0.891
9500	330.580	22.912	4.787	2.141	0.648
12500	335.960	26.998	5.196	2.324	0.692
15500	338.140	21.818	4.671	2.089	0.618
18500	341.200	15.290	3.910	1.749	0.513
21500	346.520	16.112	4.014	1.795	0.518
24500	348.780	21.292	4.614	2.064	0.592
27500	352.380	3.747	1.936	0.866	0.246
30500	357.460	6.843	2.616	1.170	0.327
33500	359.080	14.507	3.809	1.703	0.474
36500	361.480	11.947	3.456	1.546	0.428
Average Relative Uncertainty of Area 2					**0.676**

4. Conclusion

According to the design and measurement of the optical sensor based on customized DSSC material, it can be concluded this sensor has electrical parameter including output voltage and current. The sensor was measured with different light illuminance and different temperature as well. Increasing light intensity produces higher electrical parameter output both current and voltage. This sensor has potential prospect to be used as light sensor and to be competitive cost for fabrication.

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