Efficient TiO$_2$ nanoparticle-ruthenium sensitzers with high open-circuit voltage (Voc) for high-performance dye-sensitized solar cells

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Abstract. The study aims to characterize Ruthenium as a photosensitizer in Dye-Sensitized Solar Cells (DSSC). Samples are made in the structure of the working electrode pair Sandwich and the opponent electrode. Sample absorbance test using UV-Visible LAMBDA 25 spectrophotometer and test current and voltage characterization (I-V) using Keithley 2602A. The results of the study showed that the maximum absorbance in the high dye ruthenium appeared at the two peaks at 448 nm and 580 nm. While I-V curve measurements showed great efficiency that resulted in ruthenium dye with concentrations of 0.1, 0.5, and 1 in a row were 0, 12%, 0.186%, and 0.26%. These results show that higher concentrations of ruthenium dye can increase the value of the resulting efficiency.

1. Introduction
Solar cells based on current technological developments and manufacturing materials can be differentiated into the first three, solar cells made of single silicon, and multi-crystalline silicon. Secondly, thin-layer solar cells and the third organic solar cells (Dye-Sensitized Solar Cell) [1]. Conventional solar cells in the form of a p-n junction connection made from semiconductor materials such as silicon, are still expensive to develop due to the use of sophisticated technology. Until found by Gratzel i.e organic solar cells, DSSC as a solar cell with dye sensitizer from organic materials can be developed a low cost and cheap fabrication [2].

DSSC is different from the silicon-based commercial solar cells, in which the DSSC solar cells occur between the separation of the light absorption function and its transport carrier [3]. The advantage of DSSC compared to commercial solar cells based on silicon is cheap, making it easy, and has high efficiency even at a light intensity less [4]. DSSC is a photoelectrochemical solar cell so used electrolytes as a medium of transport payload. DSSC is divided into several parts consisting of TiO$_2$
Nanoparticles, an adsorption dye molecule on the TiO$_2$ surface, and a catalyst which are all deposited between two conductive glass [5]. Figure 1 shows DSSC structure.

![DSSC structure](image)

**Figure 1.** Dye-Sensitized Solar Cells (DSSC) structure [6]

DSSC working principle converts light energy to electrical in molecular scale in reaction form from electron transfer [7]. The first process starts with the excitation of electrons in the dye due to photon absorption. This is one of the roles of the nature of TiO$_2$. When photons of sunlight befall the working electrode at DSSC, the photon energy is absorbed by the dye attached to the TiO$_2$ surface. So dye gets the energy to be recorded. Dye was recorded as carrying energy and injected into the conduction tape at TiO$_2$. TiO$_2$ serves as an electron acceptor. The abandoned dye molecule is then in an oxidized state. Furthermore, electrons will be transferred through the outer circuit to the comparison electrode (an extrude containing carbon seams). Electrolytes (iodide and triiodide pairs) act as electron mediators so that they can produce cycle processes in cells. The Triode Ion captures electrons derived from an outer range with the help of a catalyzed carbon molecule. The electron is recorded to enter back into the cell and is assisted by the carbon so that it can react with the electrolyte which causes the addition of the iodide ion to the electron. Then an iodide ion in the electrolyte delivers an electron carrying energy toward the oxidized dye. Electrolytes provide a replacement electron for the oxidized dye molecule. So dye returns to its original state [8].

This study used ruthenium as a dye. Ruthenium is one of the chemical elements with atomic number 44. This element is in group 8 with the emblem of Ru. Ruthenium is a silvery-color transition metal, is hard, and has a melting point or high boiling point [9]. The most common compounds for this element are ruthenium trichloride. This compound is shaped in red solids and is widely used as a synthetic chemical [10]. The use of this compound is known in the form of ruthenium dioxide combined with lead and bismuth ruthenate as a thin-film resistor [11]. So that ruthenium is a good catalyst for improving solar cell efficiency [12]. Figure 2, It is an I-V DSSC curve that can produce voltage and current. The picture is shown the open-circuit voltage (VOC), short circuit current (Iis), maximum voltage, maximum current and fill factor. When the short circuit (Iis) condition, the cell will produce a short circuit current. When the open circuit condition there is no current flowing so that the tension will be maximum or called with open-circuit voltage. Fill factor is a measure of the quality of solar cell performance.
The Fill Factor (FF) is a quantitative measure of the quality of a solar cell, as well as the outer square size of the I-V curve, the Fill Factor can be obtained using the equation 1.

$$FF = \frac{V_{maks}I_{maks}}{V_{oc}I_{sc}}$$  \hspace{1cm} (1)

The maximum power generated solar cells can be obtained through equations 2.

$$P_{maks} = V_{oc}I_{sc}FF$$  \hspace{1cm} (2)

The resulting efficiency of solar cells can be obtained through equations 3.

$$\eta = \frac{P_{maks}}{P_{in}}$$  \hspace{1cm} (3)

Efficiency becomes the global measure of the quality of solar cells. Solar cell efficiency which is a quantitative comparison of the maximum cell-generated power ($P_{max}$) with the power of the Dating Light ($P_{light}$) can be determined by equation (3). The study aims to characterize Ruthenium as a photosensitizer in Dye-Sensitized Solar Cells (DSSC). Characterization is important to do, this aims to know the ability of dye to deliver electrons in solar cells. The higher the efficiency of the resulting cells, the ability to dye or constituent materials of solar cells can be said to be very good.

2. Method

The TiO$_2$ used in this study is Titanium (IV) nanoparticles with a size of 21 nm. TiO$_2$ as much as 0.5 gr is dissolved in 2 ml of absolute ethanol stirred for 30 minutes using a vortex styrer. TiO$_2$ is superimposed on the Fluorine Tin Oxide (FTO) conductive glass with the depositor of 2 cm x 1.5cm to use the spin coating method. The deposition layer of TiO$_2$ is heated at 500°C for 60 minutes above the hot plate. This study used ruthenium dye which was dissolved using Isopropanol where previous research uses ethanol solvent. After stirring then it is allowed to sit for 24 hours at room temperature. The DSSC construction used is a sandwich system. The working electrode in the form of FTO conductive glass that has been coated with TiO$_2$, which has been soaked with the ruthenium dye. The opponent's electrode is FTO conductive glass that has been coated with thin coating Pt (Hexachloroplatinic (IV) acid 10%). Electrolytes are made from I$_2$/KI which is dissolved in PEG which is then transmitted between the opponent electrode and the working electrode is given a barrier keyboard protector so that no short circuit occurs. The working electrode and the opponent's electrode that has been transmitted by the electrolyte are then stacked and pinned using the Clipboard. The DSSC Sandwich was then characterized by its current and voltage.
3. Results and discussion

Research on using ruthenium dye dissolved in isopropanol while previous research using ethanol solvent. Then tested absorbance using Spectrophotometer UV Visible Shimadzhu 1601 PC and current-voltage measurements use I-V meter/Elkahfi 100 from I-V meter to determine the value of electrolyte and dye conductivity. Ruthenium Absorbansi measured using UV-Vis Spectroscopy at a wavelength range of 350-800 nm. Figure 3 shows a graphic absorption of Ruthenium with a variety of concentrations of 0.1%, 0.5%, and 1%.

![Figure 3. Chart absorbance](image)

Ruthenium's absorption in the study has an absorption peak at a wavelength range of 300-600 nm (Figure 3). The same results were obtained at the research of M. Gratzel (2003) [13], A. Khatibi et al 2015 [14], and Eiji et al. 2013 [15], thus Ruthenium can absorb light on the wavelength range of

![Figure 4. Chart conductivity](image)
visible light (visible). Current-Voltage (I-V) carnitine is a method of knowing the performance of the Dye-Sensitized Solar Cells which is how much DSSC capability can convert light into electrical energy the I-V measurements are done in dark and light conditions namely under the illumination of the halogen lamp with an intensity of 1991 W/m². The conductivity values of DSSC can be seen in Figure 4.

Based on the results of the "I-V Dye" Ruthenium characterization, it obtained the I-V curve in dark and bright conditions (Fig. 4). The current value of Ruthenium dye is increased linearly when the voltage value increases. As the amount of Ruthenium dye concentration increases, more Ruthenium dye molecules will produce free electrons [16]. This is a free electron that will produce a flow of charge, so it will generate currents [17]. These characteristics appear in both dark and light conditions. Image 4 shows that the ruthenium dye can produce good electrical current [18].

DSSC Performance Testing a variation of Ruthenium dye concentration was performed to see the effect of concentration on the performance produced by DSSC. This test is done on the condition of using platinum as an opponent electrode. The efficiency produced by DSSC using Ruthenium with treatment on TiO₂ is presented in table 1. DSSC generates efficiency.

Table 1. DSSC generated efficiency

| Concentration (%) | Imax (Ampere) | Vmax (Volt) | Isc (Ampere) | Voc (Volt) | Fill Factor | Efficiency (%) |
|-------------------|---------------|-------------|--------------|------------|-------------|----------------|
| 0.1               | $0.7 \times 10^{-3}$ | 0.18        | $7.8 \times 10^{-3}$ | 0.33       | $1.2 \times 10^{-8}$ | 0.12           |
| 0.5               | $1.1 \times 10^{-3}$ | 0.23        | $2.1 \times 10^{-3}$ | 0.40       | $1.8 \times 10^{-8}$ | 0.186          |
| 1                 | $4.6 \times 10^{-4}$ | 0.29        | $9 \times 10^{-4}$ | 0.58       | $2.1 \times 10^{-7}$ | 0.26           |

Table 1 presents the efficiency of each DSSC with different concentration variations at the time of the same lighting intensity of 1991 W/m². From table 1 can be seen that DSSC which produces the best performance is DSSC which uses Ruthenium dye with 1% concentration and generate an efficiency of 0.26%. This indicates that increasing dye concentration can affect the efficiency of DSSC.

4. Conclusion
Measurement and analysis of the absorption spectral of Ruthenium dye have been performed with varying concentrations. The results showed that Ruthenium dye had a spectrum of absorption in wavelengths between 300 – 600 nm, thereby Ruthenium was able to absorb light at a wavelength range of visible light (visible). The higher the concentration then the higher the efficiency is generated. This makes ruthenium materials need to be investigated as a DSSC sensitizer material. An increase in ruthenium dye concentration can affect the performance of DSSC.

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