Dye sensitized solar cell (DSSC) with natural dyes extracted from Jatropha leaves and purple Chrysanthemum flowers as sensitizer

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Abstract. DSSC (Dye-Sensitized Solar Cell) prototype has been investigated using Jatropha leaves and purple Chrysanthemum flowers as natural dyes. DSSC consists of working electrode and counter electrode. A working electrode composed of semiconductor nanoparticles TiO$_2$ that has been coated with dye molecules. Dye molecules serve as light photon catchers, while semiconductor nanoparticles TiO$_2$ function to absorb and forward photons into electrons. In the electrode counter given catalyst carbon, serves to accelerate the reaction kinetics of triiodide reduction process on transparent conductive oxide (TCO). DSSC using TiO$_2$ as a semiconductor material and natural dyes as sensitizer from Jatropha leaves and purple Chrysanthemum flowers are successful produced. The physical properties of the working electrode have been determined by using XRD and the chemical properties of the TiO$_2$ powder and dye powder using FTIR and dye solution using UV-Vis. The resulted fabrications are also examined its I-V characteristics. The best performance is generated by mixed dye 1.91 x 10$^{-3}$ % compared than those DSSC for dye extracted from Jatropha leaves or purple Chrysanthemum. The characterization results show that the higher of the absorption wavelength of the DSSC efficiency is high.

1. Introduction

Dye-Sensitized Solar Cells (DSSC) was invented in 1991 and now become attractive attention for researcher in the world due to inexpensive devices for converting sunlight into electricity [1,2]. Wide band gap oxide semiconductor materials as photoanode for DSSC which is accepted electrons from the photo excited dye/sensitizer [3]. The absorption spectrum of the dye to the surface of titanium dioxide (TiO$_2$) is important parameters in determining the efficiency of the cell [4].

Previously, DSSC employs ruthenium poly-pyridyl complexes as the effective sensitzers. However, ruthenium is a heavy metal, which is undesirable from point of view of the environmental aspects and costly [5]. Another method is replacing it by using natural dyes pigments due to the extraction is easy, cost efficiency, environment friendly, non-toxicity, availability, and biodegradability [3]. Natural dyes are playing a key role in harvesting sunlight and transferring solar energy into electrical energy [6].

In recent years, several researches have been reported several part of plants as natural dyes. They used natural dyes extracted from the trees, flowers, fruits, and vegetables as sensitzizers for fabrication of Dye Sensitized Solar Cell (DSSC) [7]. Peihui Luo et al. achieved conversion of visible light into electricity of dyes of C. indica L., S. splendens and S. nigrum L with the efficiency of the cells...
sensitized up to (0.29%), (0.26%), and (0.31%), respectively [5]. Afterward, Rajita Ramanarayanan et al. extracted dye from red amaranth leaves showed a better efficiency (0.53 %) [3].

In this paper, DSSCs were prepared with natural dyes extracted from Jatropha and Chrysanthemum (purple). These extracted dyes were characterized by X-Ray diffractometer to analyze the structure of a material, UV-Vis Spectrophotometer to observe on the absorption spectra and FT-IR spectral analysis to determine the functional group in the natural dye.

2. Experimental

2.1. Preparation of sensitizers using natural dyes/Natural Dyes preparation as Sensitizers of DSSC

Jatropha leaves and purple Chrysanthemum were cut about 2 cm x 2 cm, washed with distilled water and dried in an oven at 40 °C before being crushed into fine powder by using a mortar. Concisely, the powders are dissolved using ethanol, acid citrate, and distilled water 5: 1: 4 (10 grams of powder, 10 ml of ethanol, 2 ml of acid citrate, and 8 ml of distilled water) and stir uses a magnetic stirrer in temperature of 60 °C for 30 minutes. Then, the solution stored in the bottle for 24 hours at room temperature without light. The extract was then filtrated using filter paper (Whatman No. 42) to remove solid residues resulting dye solution was used as a sensitizer in the DSSC. Then, 7 g of TiO2 nano-powder is added in 15 ml of Ethanol. The paste was stirred it uses magnetic stirrer for 30 minutes. Powder Potassium Iodide (KI) of 0.8 grams mixed with 10 ml of polyethylene glycol (PEG). The solution was added with iodine (I2) and stored in the bottle. Furthermore, the scotch tape is applied on four sides of conducting ITO glass to control the thickness of the TiO2 film. The scotch tape controlled the thickness and the area of the TiO2 film. TiO2 paste was immediately spread as evenly possible onto the 2 cm × 2 cm area of the conductive glass by using a dropper pipette and spin by using a spin coating at 1000 rpm for 60 seconds. The TiO2 films have cooled for 15 minutes at room temperatures. After that, the TiO2 was immersed into dye for 2 hours for “sensitized” process. The electrolyte solution was dripped into the film. Then, the scotch tape was removed from the film. For counter electrode, graphite is applies on the conducting surface of another ITO glass. The two electrodes were clipped together using two binder clips to prevent the electrolyte from leaking.

2.2. Characterization and measurements

In this research, the characterizations were used X-Ray Diffraction (XRD), Fourier Transform Infra-Red (FTIR), and Uv-Vis Spectrophotometer. a XRD measurement was used to determine the crystal structure and phase of TiO2. The crystal size has been calculated using Scherrer’s formula [9]:

\[ D = \frac{k\lambda}{\beta \cos \theta} \]  

where, D is the grain size, K is a constant taken to be 0.94, k (1.54 Å) is the wavelength of the X-ray radiation, \( \beta \) is the full width at half maximum and \( \theta \) is the angle of diffraction. FTIR is used to determine the functional groups of TiO2 and dye and Uv-Vis Spectrophotometer is used to determine the dye absorbance spectrum. The performance of solar cells can be seen through current measurements and voltage variations. The voltage measurement circuit in the solar cell construction is carried out using an unhindered circuit and with resistance (100 kΩ, 200 kΩ, 300 kΩ, 390 kΩ, 470 kΩ, 680 kΩ, and 820 kΩ) and a digital multimeter. Measurements are performed outdoors using sunlight as a light source. As for the resulting currents is calculated using Ohm’s law approach, namely:

\[ I = \frac{V}{R} \]  

The point on I-V curve yielding maximum current and voltage was called maximum power point (Max). The maximum power of solar cell was stated by [10]:

\[ P_{\text{max}} = \frac{V_{\text{max}}I_{\text{max}}}{A} \]  


Calculates the efficiency of the DSSC was calculating from the data given by the equation:

\[ \eta = \frac{P_{\text{max}}}{I} \times 100\% \] (4)

3. Result and discussion

3.1. XRD Characterization

Figure 1 (a) shows the XRD spectra of TiO\(_2\). The figure shows the peaks of the TiO\(_2\) characteristics that form the anatase phase at an angle of 25.9948 °; 37.6237 °; 38.4764 °; 39.2470 °; 48.7037 °; 54.5413 °; 55.7067 °; 63.3199 ° with the highest intensity at the angle 25.9948° which is clearly indicated phase of anatase as reported in Ref [11]. The maximum grain size is found to be 57.90 nm. The peaks of anatase are indicated by “A”. Figure 1 (b) shows the XRD spectra of dye extracted from Jatropha leaves which have been deposition with TiO\(_2\). Figure 1 (c) shows the XRD spectra of dye extracted from purple Chrysanthemum flowers which has been deposition with TiO\(_2\).

Figure 1. (a) Spectrum XRD (a) pure TiO\(_2\), (b) TiO\(_2\)–Jatropha leaves, (c) TiO\(_2\)–purple Chrysanthemum, and (d) TiO\(_2\)–mixed dye.

Figure 1 (a) and (b) show that the absorption of dye on the TiO\(_2\) molecule. The peak intensity of TiO\(_2\) increased after the absorption of dye in TiO2 layer. As shown in table 1:
### Table 1. Intensity from XRD spectra for all peaks of TiO$_2$ and with dyes.

| 2θ  | TiO$_2$ | TiO$_2$ - Jatropha leaves | TiO$_2$ - purple Chrysanthemum |
|-----|---------|---------------------------|--------------------------------|
| 25,99 | 1812 (011) | 3710 | 1824 |
| 37,62 | 95 (013) | 212 | 3185 |
| 38,48 | 338 (004) | 759 | 293 |
| 39,25 | 81 (112) | 220 | 1021 |
| 48,70 | 433 (020) | 628 | 303 |
| 54,54 | 283 (015) | 658 | 1004 |
| 55,71 | 262 (121) | 642 | 882 |
| 63,32 | 239 (024) | 591 | 854 |

#### 3.2. FTIR Characterization

Figure 2 (a) shows the FTIR spectrum of TiO$_2$ by using the optimal solvent (ethanol). The figure shows that spectrum range of 500 - 4000 cm$^{-1}$. The O-H group appears as the broadest peak at the wavelength of 3419.9 cm$^{-1}$. At the wave number 2926.01 cm$^{-1}$ shows the C-H bond of the aromatic ring. The wave number 1645.28 cm$^{-1}$ shows the C = C bond of the alkene compound and at the wave number 1514.12 cm$^{-1}$ shows the C = C bond of the aromatic ring compound. In the TiO$_2$ spectrum, there is also an O-Ti-O bond at 500 cm$^{-1}$ - 680 cm$^{-1}$.

![Figure 2. Spectrum FTIR (a) Pure TiO$_2$ (b) TiO$_2$ - Jatropha leaves (c) TiO$_2$ - purple Chrysanthemum](image)

Figure 2 (b) shows that the FTIR spectrum of by Jatropha leaves using the optimal solvent (ethanol, citric acid, and aquades). The O-H group appears as the broadest peak at the wavelength of 3421.72 cm$^{-1}$ which is also supported by the sharp peak at the wave number 1737.86 cm$^{-1}$ for the bonding of C=O. The absorbance peak at 2920.23 cm$^{-1}$ shown C-H$_3$ vibration and 2852.72 cm$^{-1}$ indicates the
presence of C-H$_3$ vibration. The absorption of C = C aromatic double bonds is shown at 1651.07 cm$^{-1}$ and for the C-O-C bonding absorption at the wave number 779.24 cm$^{-1}$, which is indicated the existence of chlorophyll.

Figure 2 (c) shows that the FTIR spectrum of purple chrysanthemum by using the optimal solvent (ethanol, citric acid, and aquades). The O-H group appears as the broadest peak at the wave number of 3412.08 cm$^{-1}$ which is also supported by the peak absorption at the wave number of 2924.09 cm$^{-1}$ for the C-H$_3$ at the wave number 2854.65 shown C-H$_2$ and at the wave number 1737.86 cm$^{-1}$ shown C=O double bond of alcohol. The absorption peak for C-N bond is shown at the wave number from 1441.61 cm$^{-1}$ which is indicated that the existence of anthocyanin.

3.3. UV-Vis Characterization

Figure 3 (a) shows UV-Vis spectrum of dye extracted from, purple Chrysanthemum, and Jatropha leaves mixed with purple Chrysanthemum leaves used UV-Visible Spectrophotometer 300-800 nm. Figure 3 (a) shows the UV-Vis absorption spectra of dyes extracted from Jatropha leaves. Figure 3 (b) shows the UV-Vis absorption spectra of dyes extracted from Purple Chrysanthemum. Figure 3 (c) shows the UV-Vis absorption spectra of dyes extracted from Purple Chrysanthemum.

![Figure 3](image)

**Figure 3.** Spectrum UV-Vis of (a) Jatropha leaves, (b) purple Chrysanthemum, (c) Jatropha mixed with purple Chrysanthemum

3.4. Performance of DSSC

The DSSC prototype has been tested using a digital multimeter by placing a positive pole on the working electrode and the negative pole of the counter electrode to determine the resulting voltage. The resulting current is calculated using Ohm's law approach on equation (3). By varying, the value of resistance will be obtained the value of current and voltage generated from the solar cell is shown in table 2.
Table 2. The measurement results of DSSC

| Dye                          | i (mW/cm²) | V (mV)  | I (mA)      | P (mW/cm²) | η (%) |
|------------------------------|------------|---------|-------------|------------|-------|
| **Jatropha leaves**          | 55.3       | 3.5     | 3.5 x 10⁻⁶ | 3.06 x 10⁻⁶| 5.53 x 10⁻⁶|
| **Purple Chrysanthemum**     | 51.35      | 3.3     | 4.02 x 10⁻⁶| 3.32 x 10⁻⁷| 6.46 x 10⁻⁷|
| **Jatropha leaves + Purple Chrysanthemum** | 66.36 | 22.5    | 22.5 x 10⁻⁴| 1.26 x 10⁻⁴| 1.91 x 10⁻³|

After measured the current, then will be calculated the value Pₘ (Maximum power generated by voltage and current) for determine of the efficiency. Based on Table 3.2 can be seen that Pₘ produced of Jatropha leaves 3.06 x 10⁻⁶ mW / cm², purple chrysanthemum 4.02 x 10⁻⁶ mW / cm², and Jatropha leaves mixed with purple Chrysanthemum 3.32 x 10⁻⁷ mW / cm².

DSSC conversion efficiency used equation (4) to determining efficiency by used dye extracted from Jatropha leaves is 5.53 x 10⁻⁶ %, purple Chrysanthemum is 6.46 x 10⁻⁷% and for mixed 1.91 x 10⁻³ %. From the analysis efficiency of DSSC based on the dye extracted from Jatropha leaves mixed with purple Chrysanthemum is higher than dye extracted from only Jatropha leaves or purple Chrysanthemum. DSSC is performed outdoors using sunlight as a light source. DSSC successfully convert solar energy into electrical energy based on current and voltage values generated.

The efficiency of DSSC is influenced by the absorbance of dye and semiconductor materials. Dye absorbance is directly proportional to the coefficient of absorption. The higher absorption coefficient is indicated the higher the electron-hole rate. In addition, the efficiency of DSSC is also influenced by the type of semiconductor, light source, conductivity, and phase and semiconductor structure.

4. Conclusion

Fabrication of DSSC used natural dyes Jatropha Leaves and Purple Chrysanthemum have been investigated. The dye gives the absorbance at wavelength 400-500 nm. It indicated that the dyes absorb visible light and have been found to be suitable for the use as sensitizer in solar cells. The best performance is generated by mixed dye 1.91 x 10⁻³ % compared than those DSSC for dye extracted from Jatropha leaves is 5.53 x 10⁻⁶ % or purple Chrysanthemum 6.46 x 10⁻⁷%.

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