

Natural Pigments as Sensitizers for Dye Sensitized Solar Cells

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Abstract: The performance of dye sensitized solar cells (DSSCs), sensitized with natural pigments extracted from mango (*mangifera indica*), carica papaya, moringa oleifera leaves and bougainvillea flower was demonstrated. The photoactive electrodes of the various DSSCs were sensitized with aqueous extract of the natural pigments. The resulting photoelectrodes were successfully incorporated into the DSSCs. The photoelectrochemical performance of the DSSCs were evaluated under 100 mAc^m⁻² light intensity with open circuit voltage (V_{OC}) ranging from 0.36 to 0.49 V and short circuit current density (J_{SC}) ranging from 0.0134 to 0.1314 mAc^m⁻². From the photovoltaic performance of the extracts, the *Mangifera Indica* extract sensitized solar cell gave the best performance with J_{sc} of 0.1314 mAc^m⁻², V_{oc} of 0.49 V, a fill factor (FF) of 0.59, and an overall solar energy conversion efficiency (η) of 0.038%. The sensitization performance related to the interaction between the dye and TiO₂ surface is discussed.

Keywords: DSSCs, Natural Dye Extracts, Sensitization, TiO₂

1. Introduction

There are however concerns on maintaining the usage of fossil fuels as the main source of energy. Basically, energy from fossil fuels faces two problems, the first being the limitation of resources and the second their environmental impact [1]. For these two reasons, there has been an urge to develop sustainable energy solutions. The supply of clean sustainable energy is considered as one of the most important scientific and technical challenges facing humanity in the 21st century [2]

Among the different alternative power sources existing today, solar energy has the most potential [2]. Several new types of solar cells have been studied and developed. Among them, the dye sensitized solar cell (DSSC). The DSSC is a very attractive choice for utilizing the solar energy, due to its potentially low production cost. In contrast to conventional systems, where the semiconductor works as both the light absorber and charge carrier, the DSSC separates the two functions which facilitate the production of the device. Other advantages with DSSCs are flexibility, short energy payback

time and relatively high performance at diffuse light conditions [3].

The DSSC contains several different components: A conducting glass substrate, a mesoporous semiconductor film, a sensitizer, an electrolyte with a redox couple and a counter electrode as shown schematically in figure 1 [1]. The function of the sensitizer is to absorb the incident light, inject the excited electron into the semiconductor, and become regenerated by the redox couple in the electrolyte.

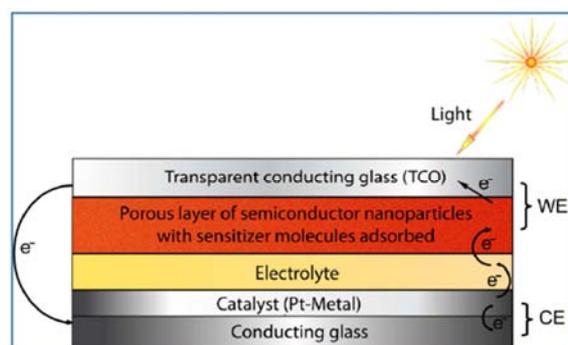


Figure 1. Schematic overview of the Dye sensitized Solar Cell (DSSC).

The use of natural dyes have been considered as potential candidates to enhance the light response of semiconductor in active layers of solar cells and have been demonstrated in several solar cell materials [4-17]

In this study, Four types of natural dyes were extracted from flowers and leaves such as *carica papaya*, *mangifera indica*, *moringa oleifera* leaves and *Bougainvillea spectabilis* flower. These extracted dyes were characterized by UV-vis absorption spectra. The photoelectrochemical properties of the DSSCs using these extracts as sensitizers were investigated. The results from the sensitization performance shows that, the DSSC sensitized with the extract of *mangifera Indica* outperformed the other DSSCs sensitized with other natural dyes in this research work.

2. Experiment

2.1. Extraction of Natural Dyes

50 g of the fresh leaves of (*Mangifera Indica*, *carica papaya*, and *moringa oleifera*), and flower of (*Bougainvillea spectabilis*) were collected each. The collected leaves of *Mangifera Indica*, *moringa oleifera*, *carica papaya* and the flower of *Bougainvillea spectabilis* were grinded to small particles using a blender with 100 ml deionized water each as extracting solvent. The solution was filtered to separate the solid from the pure liquid.

2.2. DSSCs Assembling

The FTO (solaronix) glass were first cleaned in detergent solution using an ultrasonic bath for 10 minutes, rinsed with deionized water and ethanol, and then dried. The photoanode was prepared by first depositing a blocking layer on the FTO glass, followed by the nanocrystalline TiO_2 (solaronix). The blocking layer was deposited from a 2.5wt% TiO_2 precursor and was applied to the FTO glass substrate by spin coating and subsequently sintered at 400°C for 30 mins. The $9\ \mu\text{m}$ thick nanocrystalline TiO_2 layer was deposited by screen printing. It was then sintered in air for 30 mins at 500°C . The sintered photoanodes was sensitized by immersion in the sensitizer solution at room temperature overnight. The photoanode and the screen printed platisol counter electrodes were assembled to form a DSSC by creating a gap of $50\ \mu\text{m}$ inbetween the two electrodes to be filled with 50 mmol of iodide/tri-iodide dissolve in acetonitrile.

2.3. Characterization and Measurement

The current-voltage ($J-V$) characteristics of the cells were recorded under an irradiance of $100\ \text{mw}/\text{cm}^2$ (AM1.5) simulated illumination (Keithley 2400 source meter from a Newport A solar simulator). The film morphology of the TiO_2 was obtained by scanning electron microscope (Phenom Pro X model, Eindhoven de Netherlands). The absorption spectra of the dye were recorded on Ava-spec-2048 spectrophotometer in the region of 350–1000 nm. The effective irradiated area of each cell was $1.75\ \text{cm}^2$.

3. Results and Discussion

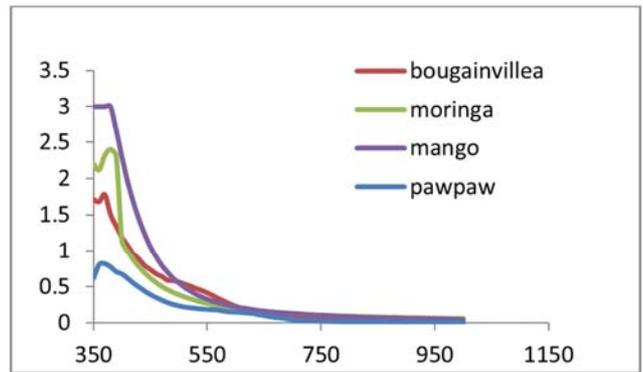


Figure 2. Absortion spectra of bougainvillea flower, moringa oleifera leaves, mangifera indica leaves and carica papaya leaves extract.

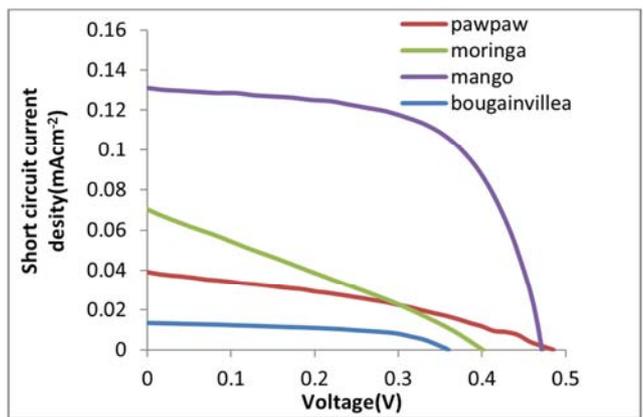


Figure 3. Photocurrent density-voltage ($J-V$) curve under $100\ \text{mW}/\text{cm}^2$ light intensity.

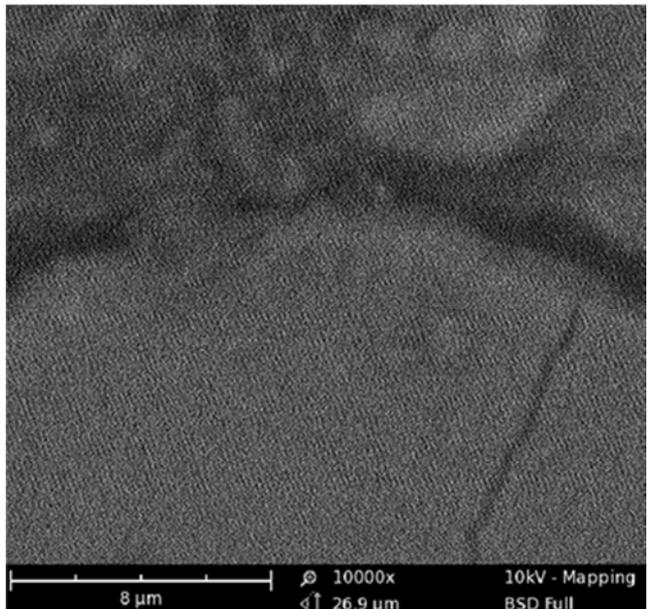


Figure 4. The Scanning electron microscope surface morphology of TiO_2 sample.

Figure 3 shows the photocurrent density–voltage ($J-V$) curves of the DSSCs with different sensitizers. Based on the

curves in Figure 3, the fill factor (FF) and solar cell efficiency (η) were determined using equations (1) and (2) respectively.

$$FF = \frac{P_{\max}}{P_{in}} = \frac{J_{\max} \times V_{\max}}{J_{SC} \times V_{OC}} \quad (1)$$

$$\eta = \frac{FF \times J_{SC} \times V_{OC}}{P_{IRRADIANCE}} \cdot 100\% \quad (2)$$

Where V_{\max} = maximum voltage (V); J_{\max} = maximum current density (mA/cm²); J_{SC} = short circuit current density (mA/cm²); V_{OC} = open circuit voltage (V) and $P_{IRRADIANCE}$ = light intensity (mW/cm²)

Figure 2 shows the representative UV-vis absorption spectra for aqueous extract of *bougainvillea* flower, *moringa oleifera*, *carica papaya* and *mangifera indica* leaves. The extract of *bougainvillea spectabilis* exhibits an absorption peak of 370 nm. This absorption is attributed to the presence of indicaxanthin, and betacyanin pigment. The extracts of *Mangifera indica*, *Moringa oleifera* and *Carica papaya* leaves (Figure 2), shows absorption peaks at 360 nm, 400 nm and 360 nm. The chemical adsorption of these dyes is accepted to occur because of the formation of bond with the surface of nanostructured TiO₂ [7].

Photovoltaic test of DSSCs using these natural dyes as sensitizers are summarized in Table 1. The performance of the natural dyes as sensitizers in DSSCs were evaluated by short circuit current density (J_{SC}), open circuit voltage (V_{OC}), fill factor (FF), and energy conversion efficiency (η).

Table 1. Photovoltaic performance of DSSC with different sensitizer under 100mWcm⁻².

Samples	J_{SC} (mAcm ⁻²)	V_{OC} (V)	FF	η (%)
Bougainvillea	0.0134	0.360	0.514	0.0025
M. Indica	0.1314	0.490	0.595	0.0380
Carica papaya	0.0401	0.490	0.350	0.0068
Moringa	0.0682	0.402	0.286	0.0078

From the effective area of 1.75 cm², the efficiency of the DSSC sensitized by the *mangifera Indica*, was significantly higher than the DSSC sensitized by other natural dyes in this studies. It gives a J_{SC} of 0.0134 mAcm⁻², V_{OC} of 0.49 V, FF of 0.595 yielding an efficiency of 0.038%. This better performance is attributed to the higher intensity and broader range of the light absorption of the extract on TiO₂ and the higher interaction between TiO₂ and the pigment which lead to better electronic coupling and electron transfer [10]. The *mangifera Indica* extract, has a good and broader absorption in the visible spectrum which is expected to show a good rectification of J-V curve that is responsible for good current density and power efficiency [11].

It was once demonstrated that DSSCs based on anodes containing *Bougainvillea spectabilis*, *mangifera indica*, and *carica papaya* extracts showed photoelectrochemical performances of (J_{SC} = 0.088 mAcm⁻², V_{OC} = 0.20 V, FF =

0.374 and η = 0.0066%) [18], (J_{SC} = 0.114 mAcm⁻², V_{OC} = 0.433 V, FF = 0.570 and η = 0.049%) [7]. and (J_{SC} = 0.094 mAcm⁻², V_{OC} = 0.43 V, FF = 0.544 and η = 0.022%) [10]. When compared to our results with *Bougainvillea* extract sensitized DSSC, it is in agreement with Yirga et al [18], which recorded an improvement of 56.25% in efficiency. This improvement is attributed to the differences in phytoconstituents in different part of the plant. Also, when compared to Eli et al [10], their results was higher than our own result with 29%, which is also attributed to the differences in phytoconstituents in different part of the plant which results to aggregated dyes or non-injecting dyes at the surface of the TiO₂ that leads to small solar to electricity conversion efficiency. When the result of Kimpa et al [19]; (J_{SC} = 0.649 mAcm⁻², V_{OC} = 0.503 V, FF = 0.605 and η = 0.2%) was compared to our results, it outperformed our own result which is due to the dye extracting solvent (ethanol in their research and water in our studies) which indicates that the interaction between the TiO₂ film and the hydroxyl functions should bring a stronger electron transfer reaction.

4. Conclusions

The performance of dye sensitized solar cells with four natural dyes from leaves and flower was demonstrated. The dyes contained chlorophyll, indicaxanthin, and betacyanin pigments. The DSSCs fabricated using the extracted dyes show the V_{OC} varying from 0.36 to 0.49 V and the J_{SC} ranged from 0.0134 to 0.1314 mAcm⁻². Among the four dyes investigated, the extract obtained from *mangifera Indica* showed the best sensitization effect. Since the natural dye extracts, are generally, a mixture of several pigment, therefore the possible reason for the observed differences in sensitization action of the dyes is their varied abilities towards adsorption onto the semiconductor surface. The poor performance noticed in other natural pigment in this study is due to nonelectron injection or the steric hindrance preventing the dye molecule from effectively arraying on the semiconductor film which leads to weaker binding between the dye and the TiO₂.

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