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CHARACTERISTICS OF DYE-SENSITIZED SOLAR CELLS USING MUCUNA FLAGELLIPES AND ZEAMAIZE COMB NATURAL DYES

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Abstract

Dye-sensitized solar cell fabrication procedure has been employed using natural dye extracts from Mucuna flagellipes and Zeamaize comb as natural sensitizer of TiO_2 films. The dye yielding materials were dried to invariant weight in the laboratory and the dye extracted using simple laboratory technique. Photovoltages and photocurrents of 0.11 and 0.25 mV, 6.44 and 5.34 mA were obtained for Mucuna flagellipes and Zeamaize comb dye extracts, respectively. Similarly, overall solar energy conversion efficiencies and fill factors of these cells obtained under Am1.5 irradiation were 0.33 and 0.47, 0.43 and 0.32 for Mucuna flagellipes and Zeamaize comb dye extracts, respectively. Among the natural dye sensitizers studied, the Zeamaize comb gave the best

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photosensitizing effect which can be used as an environmental friendly low cost alternative solar power conversion system.

1. Introduction

The use of dye molecules as light harvester in a solar cell (Dye-sensitized solar cell: DSSC) for future clean energy has been most attractive and successful when the dye is chemoadsorbed on a porous network of interconnected nanometer-sized crystallites of a wide band gap semiconductor [1]. The best studied example is the Ruthenium-bipyridyl dyes which shows a high conversion efficiency of about $11 - 12\%$. However, this Ru-polypyridyl complexes contain heavy rare metal, which is undesirable from point of view of the environmental aspect [2]. Furthermore, the process to synthesize the complexes is complicated and costly. Therefore, natural dyes can be adopted as alternative for the same purpose with an acceptable efficient metal-to-ligand charge transfer [3]. The advantages of natural dyes include their readily availability, low cost [4] and their simple extraction into cheap organic solvents which can be applied without further purification.

In nature, both the different parts of the shoot and root systems of plant show various colours from red to purple and contain various natural dye which can be extracted by simple laboratory procedures.

Natural dye extracts containing anthocyanins [5, 6] and carotenoids [7] have shown different sensitizing performances. The carbonyl and hydroxyl groups present in the anthocyanin molecule bound to the surface of the porous TiO_2 film, this makes electron transfer from the anthocyanin molecule to the conduction band of the TiO_2 effective [8, 9].

In this study, DSSCs were prepared using Natural dye extracted from Mucuna flagellipes and Zeamaize flowers as sensitizer, as these plants are relatively abundant in tropical rain forest countries and rich in anthocyanin [10].

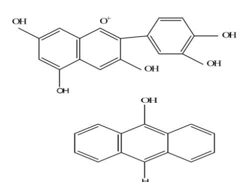

Figure 1. (a) Cyanidin from Zeamaize comb pinkish-red colour (b) Anthranol from Mucuna flagellipes brownish-yellow colour.

2. Experimental

2.1. DSSC preparations

Petals of flower/comb harvested from the dye-yielding plants were dried in the laboratory until the weight becomes invariant. It is then crushed into tiny bits and extracted into a mixture of ethanol (fluka, $96\%(v/v)$) and water in the ratio 4:1, keeping them overnight. Then residual parts were removed by filtration and filtrate was washed with hexane several times to remove any oil and chlorophyll present. It is then hydrolysed with few drops of conc. HCL so that the extracts became deep pinkish-red and brownish-yellow in colour $(pH < 1.5)$ in Zeamaize comb and Mucuna flagellipes extacts, respectively. These extracts were directly used as dye solution in the preparation of the DSSCs.

TiO_2-paste purchased from solaronix (nanoxide -T, colloidal anatase particles size $\sim 13nm$, $\sim 120m^2/g$ (SA) was coated by Doctor blade method on $1.0\,cm^2$ active area of pre-cleaned fluorine doped Tin-oxide (FTO) conducting glasses (Nippon glass sheet $10\text{ - }12\,\Omega sq^{-1}$). Finally, the glass sheet was sintered at $450°C$ for 30 minutes to melt together the TiO_2 nanocrystals and to ensure its good mechanical cohesion on the glass surface.

The TiO_2 electrodes of thickness $8.2\,mm$ prepared were immersed (face-up) in the natural dye sensitizer solution for 10-16 hours to adsorb the dye onto the TiO_2 porous thick-film adequately, i.e., this turned the TiO_2 thick-film from white to lightly red and yellow colours, respectively, the other impurities/excess dye were washed away with anhydrous ethanol and dried in moisture free air.

DSSC of $1\,cm^2$ active area were assembled by filling a liquid electrolyte $(0.5M\ KI + 0.05M\ I_2$ in solvent of ethylene glycol + acetonitrite with a volume ratio of $4{:}1)$ between the TiO_2 photoanode and planium counter electrode (prepared by spraying method).

The two electrodes were clipped together and a cyanoacrylate adhesive was used as sealant to prevent the electrolyte from leaking.

2.2. Characterization and measurements

UV-visible absorption measurements of the extracted pigments in acidified ethanol/water solution were carried out with a dual wavelength double beam spectrophotometer (model UV - 300). Current-voltage (*I-V*) characteristics of DSSCs were examined with a standard solar radiation of $1000\,\mathrm{Wm}^{-2}$ (overhead Veeco-viewpoint solar simulator), a four point Keithley multimeter coupled with a Lab-tracer software was used for data acquisition at room temperature.

The power conversion efficiency (η) was calculated according to the equation:

$$\eta = \mathrm{FF} \times J_{sc} \times V_{oc} / I, \tag{1}$$

where J_{sc} is the short-circuit voltage (volts), I is the intensity of the incident light $(\mathrm{W/m^2})$, V_{oc} is the open circuit voltage (volts) , FF is the fill factor defined as

$$\mathrm{FF} = J_m V_m / J_{sc} V_{oc}, \tag{2}$$

where J_m and V_m are the optimum photocurrent and voltage that can be extracted from the maximum power point of the *I-V* characteristics [4, 8, 9].

3. Results and Discussion

Figure 2 shows the Optical absorption spectra of Mucuna flagellipes and Zeamaize comb extracts as well as their mixture (1:1 by volume). The absorption peak of Mucuna flagellipes was found to be 0.110 a.u. and that of Zeamaize comb is 0.108 a.u. The difference in the absorption characteristics is due to the different type of anthocyanins and colours of the extracts, i.e., the optical absorption strength of Anthranol from Mucuna flagellipes is larger than that of Cyanidin from Zeamaize comb.

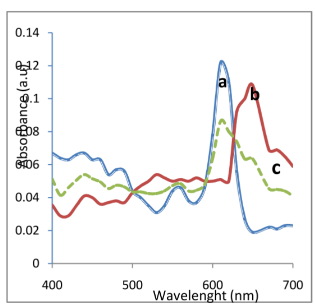

Figure 2. Absorption spectra of (a) Anthranol from Mucuna flagellipes (b) Cyanidin from Zeamaize comb (c) mixed extracts from Zeamaize comb and Mucuna flagellipes (1:1 volume).

However, the combination of both extracts as depicted in Figure 2(c) did not affect the absorption peaks, the curve merely corresponds to the average absorption nature of both extracts. The observed absorption peak of $0.08\,\text{a.u.}$ of the mixed extract occurred at $620\,\text{nm}$, while those of Anthranol from Mucuna flagellipses and Cyanidin from Zeamaize comb occurred at 610 and $620\,\text{nm}$, respectively. The difference absorption peaks wavelength is due to the different colours of the extracts. As shown in Figure 2, the mixed extract exhibits a broader absorption spectrum compared with the extract from Mucuna flagellipes and Zeamaize comb.

Table 1. Photoelectrochemical parameters obtained with the natural dye-sensitized solar cells under standard solar radiation of $1000\,\text{W}/\text{m}^2$

	I_{sc} (mA)	V_{oc} (mV)	FF	η
Mucuna flagellipes	6.44	0.11	0.47	0.33
Zeamaize comb	5.34	0.25	0.32	0.43
Mucuna flagellipes : Zeamaize (1:1 Vol.)	5.81	0.16	0.39	0.36

The device performances of the solar cells based on extracts (a) and (b), and their mixture (c) under AM 1.5 illumination are summarized in Table 1. Intriguingly, the short-circuit J_{sc}, open circuit voltage V_{oc}, and efficiencies η for the solar cell based on Anthranol from Mucuna flagellipes are dramatically lower compared to that based on Cyanidin from Zeamaize comb.

4. Conclusion

The conversion efficiency of the solar cell fabricated using the mixture of Mucuna flagellipes and Zeamaize comb is about 0.36 which is almost the average of the efficiencies of the two extracts in DSSC. The cost of performance (Defined by [conversion efficiency]/[cost of dye]) of the Zeamaize comb dye-sensitized solar cell which is the best in this study is several times larger than that of the Ruthenium complex-dye-sensitized solar cell. Although, the efficiencies obtained with these natural dyes are still below the current requirements for large scale practical application, the obtained results are encouraging in that, the wide availability of simple Laboratory dye extraction techniques and the low cost of natural dye make natural dye-sensitized solar cells promising.

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References

[1] B. O'Regan and M. Grätzel, A low cost, high efficiency solar cell based on dye-sensitized colloidal TiO_2 films, Nature 353 (1991), 737-740.

[2] Shoji Furukawa, Hiroshi Iino, Tomohisa Iwamoto, Koudai Kukita and Shoji Yamauchi, Characteristics of dye-sensitized solar cells using natural dye, Thin Solid Films 518 (2009), 526-529.

[3] Sancun Hao, Jihuai Wu, Yunfang Huang and Jianming Lin, Natural dyes as photosensitizers for DSSC, Solar Energy 80 (2006), 209-214.

[4] M. K. Nazeeruddin, A. Kay, I. Rodico, R. Humphry-Baker, E. Mueller, P. Liska, N. Vlachopoulos and M. Grätzel, Conversion of light to electricity by cis-X2bis (2,2'-bipyridyl-4,4'-dicarboxylate)ruthenium(II) charge transfer sensitizers $(X = Cl^-, Br^-, CN^-$ and $SCN^-)$ on nanocrystalline titanium dioxide electrodes, J. Am. Chem. Soc. 115 (1993), 6382-6390.

[5] N. J. Cherepy, G. P. Smestad, M. Grätzel and G. J. Zhang, Ultrafast electron injection: Implications for a photoelectrochemical cell utilizing an anthocyanin dye-sensitized TiO_2 nanocrystalline electrode, J. Phys. Chem. B 101 (1997), 9342-9351.

[6] G. Calogero and G. Di Marco, Red Sicilian orange and purple eggplant fruits as natural dye from calafate and jabotica, Solar Energy Materials and Solar Cells 92 (2008), 1341-1346.

[7] F. G. Gao, A. J. Bard and L. D. Kispert, Photocurrent generated on a carotenoid-sensitized TiO_2 nanocrystalline mesoporous electrode, J. Photochem. Photobiol. A: Chemistry 130 (2000), 49-56.

[8] G. P. Smestad, Education and Solar conversion: Demonstrating electron transfer, Solar Energy Materials and Solar Cells 55 (1998), 157-178.

[9] J. M. R. C. Fernando and G. K. R. Senadeera, Natural anthocyanins as photosensitizers for dye-sensitized solar devices, Current Science 95(5) (2008), 663-666.

[10] P. Bridle and C. F. Timberlake, Anthocyanins as natural food colours - selected aspects, Food Chem. 58 (1997), 103-109.