

Dye extracted from *Costus woodsonii* leave as a natural sensitizer for dye-sensitized solar cell

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ABSTRACT

Current work employs dye extracted from leaves of *Costus woodsonii* as a new sensitizer for dye-sensitized solar cells (DSSCs). The leave was extracted in three different solvents namely ethanol, methanol, and acetone. Extraction of leaves was carried out by the freezing method. DSSCs with the configuration of TiO₂/dye/electrolyte/Pt were assembled. The dyes in DSSCs were *Costus woodsonii* leaves extracted in methanol, ethanol, and acetone. DSSC with methanol extract of leaves has an efficiency of 0.23 % and short-circuit current density (J_{sc}) of 0.63 mA cm⁻². DSSC sensitized with ethanol extract of leaves has an efficiency of 0.37 % and J_{sc} of 0.85 mA cm⁻². DSSC sensitized with acetone extract of leaves shows the highest efficiency of 0.48 % and J_{sc} of 1.35 mA cm⁻². The performance of the DSSCs in this work is compared with other natural dye-based DSSCs. The efficiency obtained in this work is better or at par with the works reported by other researchers.

Keywords: *Natural dye; Costus woodsonii; Leave; Dye-sensitized solar cells*

INTRODUCTION

Solar energy is the most abundant renewable energy available on earth [1,2]. Photovoltaic conversion using solar cells is the most convenient way to use solar energy. A wide range of solar cell technologies is being researched such as crystalline silicon cells [3,4], multifunction cells [5,6], thin-film cells [7,8], dye-sensitized solar cells (DSSCs) [9,10], and perovskite cells [11,12] to name a few.

The first DSSC was introduced by O'Regan and Grätzel in 1991 [13]. DSSCs are deemed as a potential candidate for the next-generation solar cell given their lower fabrication cost, design opportunity, and flexibility as well as a better performance at diffuse light [14-16].

A typical DSSC is composed of a dye-absorbed titanium dioxide (TiO_2) photoanode, an electrolyte with I/I_3^- redox couple, and a platinum (Pt) counter electrode. When DSSC is illuminated, the photo-excited dye sensitizer, D^* injects electrons to the conduction band of TiO_2 and becomes oxidized, D^+ . In the electrolyte, the iodide ion, I^- provides electron to the D^+ and becomes triiodide, I_3^- . The photo-excited electron of TiO_2 arrives at the Pt counter electrode via the external circuit. At the counter electrode, the I_3^- recombines with the electron and reduces to I^- . The I^- regenerates the D^+ by providing the electron back to the D^+ . The photo-electric processes in a DSSC can be expressed by the following equations [17,18].



DSSCs performance mainly depends on the dye as a sensitizer. Several organic dyes and inorganic metal complexes have been engineered and used as sensitizers. DSSCs sensitized with ruthenium-polypyridyl complexes have reported good efficiencies of 11 – 14 % [19-21]. However, the synthesis of these complexes is not only complicated but is also expensive. In addition, heavy metal in these complexes is harmful to the environment.

Natural pigments extracted from flowers, fruits, and leaves can be used in DSSCs. Natural dye-sensitized solar cells attracted a great deal of scientific interest because they are cheap, biodegradable, and environmentally friendly. A good sensitizer should have a maximum absorbance wavelength in the visible light spectrum. Many factors are governing the light absorbance by dyes and one of them is the dye extracting medium.

This paper reports the performance of DSSCs assembled using natural dye extracted from a leave of *Costus woodsonii*. The effect of different extraction solvents on the efficiencies of DSSCs is discussed. *Costus woodsonii* is known as *Setawar Halia Merah* by the locals. Fig. 1 shows the photograph of *Costus woodsonii*.



Figure 1: Photograph of *Costus woodsonii*.

EXPERIMENTAL

Extraction of Costus woodsonii leave

Extraction of *Costus woodsonii* leaves was carried out by the freezing method. First, the collected *Costus woodsonii* leaves were washed with distilled water and left to dry. Then, the leaves were crushed into fine flakes using a blender. 13 g of *Costus woodsonii* flakes were immersed in 40 mL of different solvents i.e. ethanol (Sigma-Aldrich, 95%), methanol (Baker, 100%), and acetone (System, 99.5%) and were kept in a freezer for 24 h. Finally, the resulting extracts were filtered to remove any solid residue.

Assembly of DSSCs and characterization

TiO₂ photoanodes were prepared by depositing two layers of TiO₂ on fluorine-doped tin oxide (FTO) glass. The first layer is composed of 0.5 g of P90 TiO₂ in 2 mL of nitric acid (pH = 1). The mixture was ground for 30 min before being spin-coated on FTO glass. The spin-coated FTO glass was sintered at 450 °C for about 30 min. The second layer is composed of 0.5 g of P25 TiO₂, 0.1 g of carbowax, and 2 drops of Triton X-100 in 2 mL of nitric acid (pH = 1). The mixture was ground for 30 min, doctor bladed on the P90 TiO₂-coated FTO glass, and then sintered at 450 °C for 30 min. After cooling down to room temperature, the double-layered TiO₂ photoanodes were

soaked in the dye solutions extracted from *Costus woodsonii* leaves for 24 h. The Pt counter electrodes were prepared by spin-coating a Pt solution (Solaronix) on FTO glass and sintered at 450 °C for 30 min.

The preparation of gel-like electrolytes for the DSSCs is similar to the work reported in [22]. 0.05 g of iodine chips (I₂) were added to a poly(vinylidene fluoride-co-hexafluoropropylene) (PVdF-HFP)/ propylene carbonate (PC)/ 1,2-dimethoxyethane (DME)/ 1-methyl-3-propylimidazolium iodide (MPII) electrolyte. The amounts of PVdF-HFP and MPII were fixed at 0.2 g and 1.0 M, respectively. The PC:DME was fixed at v:v = 7:3. The mixture was stirred until homogeneous until a gel-like electrolyte was obtained. A small amount of electrolyte was sandwiched between the TiO₂ photoanode and Pt counter electrode for DSSCs assembly. A total of three DSSCs were assembled i.e. cells A, B, and C. The dyes in cells A, B, and C are *Costus woodsonii* leaves extracted in methanol, ethanol, and acetone, respectively. The current-voltage (*J-V*) characteristics of the DSSCs were measured under the illumination of 100 mW m⁻² Xenon light from an Oriel Newport LCS-100 solar simulator.

RESULTS AND DISCUSSION

Figure 2 presents the *J-V* curves for the DSSCs. Their performance parameters such as the open-circuit voltage (*V*_{oc}) and the short-circuit current density (*J*_{sc}) were measured. The fill factor (*ff*) and conversion efficiency (*η*) of DSSCs were calculated using the following equations [1]. Performance parameters are summarized in Table 1.

$$ff = \frac{J_{\max} V_{\max}}{J_{sc} V_{oc}} \quad (5)$$

$$\eta = \frac{J_{sc} V_{oc} ff}{P_{in}} \quad (6)$$

The *J*_{max} and *V*_{max} are the current density and voltage at the maximum power output point, respectively. The incident light power is *P*_{in}.

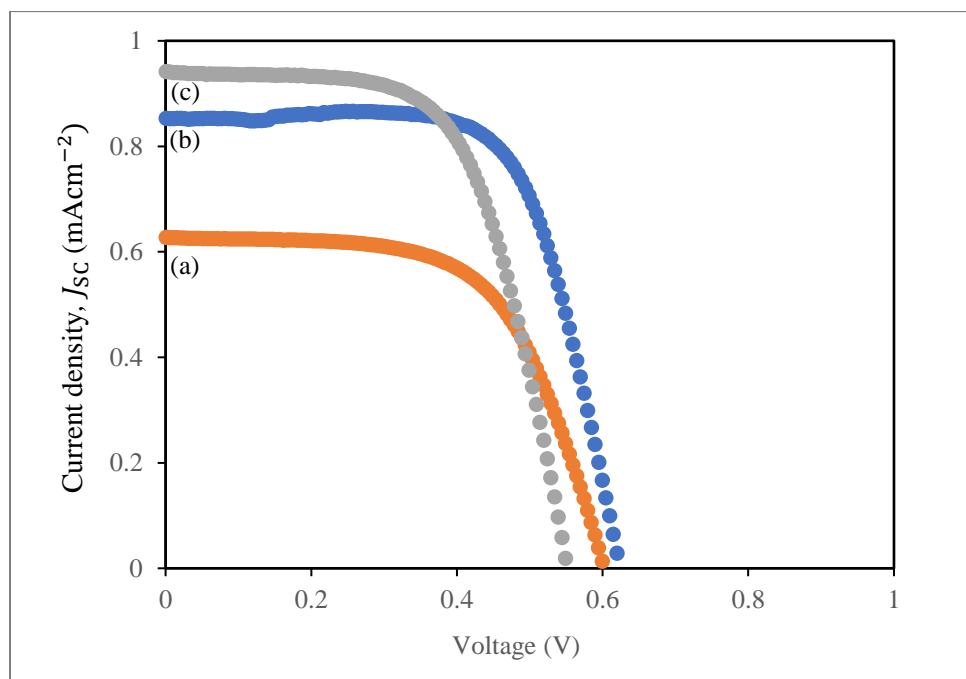


Figure 2: *J-V* curves of (a) cell A, (b) cell B, and (c) cell C.

Table 1: Performance parameters for cells A, B, and C.

Cell	Extraction medium	J_{sc} (mAcm^{-2})	V_{oc} (V)	ff (%)	η (%)
A	methanol	0.63	0.60	0.61	0.23
B	ethanol	0.85	0.63	0.69	0.37
C	acetone	1.35	0.57	0.62	0.48

Cell A with methanol extract of leaves has an efficiency of 0.23 % and short-circuit current density (J_{sc}) of 0.63 mA cm^{-2} . Cell B sensitized with ethanol extract of leaves has an efficiency of 0.37 % and J_{sc} of 0.85 mA cm^{-2} . Cell C sensitized with acetone extract of leaves shows the highest efficiency of 0.48 % and J_{sc} of 1.35 mA cm^{-2} . The light absorption capability of the dye governs the efficiency of DSSCs. The light absorption capability is correlated to the concentration of dye in an extraction solvent [23-26]. The nature of extraction solvent affects the extraction yield and therefore concentration of extracted dye [27]. This is because different chemical compounds in plants have different solubility in different solvents. Studies on the effect of extraction solvent on the yield of dye extraction are underway and the results will be reported in the nearest future.

Table 2 compares the performance of the DSSCs in this work with other natural dye-based DSSCs. The highest efficiency obtained in this work is better or at par with the works reported by other researchers.

Table 2: Performance of various natural dye-based DSSCs.

Dye	J_{sc} (mA/cm ²)	V_{oc} (mV)	ff	η (%)	Ref.
<i>Costus woodsonii</i>	1.347	569	0.623	0.477	this study
Chlorophylls					
Spinach	0.467	550	0.51	0.13	[28]
Ipomoea	0.914	540	0.56	0.28	[28]
Pomegranate leaf	2.05	560	0.52	0.59	[29]
<i>Alternanthera dentata</i> leaves	0.4	540	0.67	0.13	[30]
Barley grass	-	690	0.60	0.18	[31]
Carotenoids					
Achiote shrub (Bixin)	1.1	570	0.59	0.37	[32]
Achiote shrub (Norbixin)	0.38	530	0.64	0.13	[32]
Crocetin	2.84	430	0.46	0.56	[33]
Crocin	0.45	580	0.60	0.16	[33]
<i>Kerria japonica</i>	0.5597	583	0.677	0.22	[34]
Flavonoids					
<i>Jathopa curcas</i> Linn	0.69	54	0.87	0.12	[35]
<i>Cosmos sulphureus</i>	1.041	447	0.61	0.54	[36]
Plants					
<i>Amaranthusdubius</i>	-	338	0.449	0.134	[37]
<i>Curcuma longa</i>	-	499	0.481	0.378	[37]
Fruits					
Blueberry	1.0	590	0.61	0.26	[38]
<i>Nephelium lappaceum</i>	1.17	453	0.48	1.37	[39]
<i>Melastoma malabathricum</i> L	1.506	430	0.43	0.046	[40]
<i>Malus domestica.</i>	0.24	240	0.38	0	[41]
Orange peel	-	760	0.49	0.25	[42]

Seeds					
Thuja	0.81	490	0.38	0.15	[42]
Chelidoniumma	0.345	490	0.37	0.062	[39]
Llexpuraguariensis	0.7	570	0.33	0.13	[39]
Quercus (Oak)	1.77	530	0.40	0.38	[39]
Lactuca sativa	2.5	590	0.21	0.31	[39]
Rapa	0.55	540	0.40	0.12	[39]
Corchorus olitorius	1.8	635	0.43	0.49	[39]
Apium graveolens	0.512	463	0.484	0.115	[42]
Flowers					
Begonia	0.63	537	72.2	0.24	[39]
Rhododendron	1.61	585	60.9	0.58	[43]
Marigold	0.51	542	83.1	0.23	[43]
Yellow rose	0.74	609	57.1	0.26	[43]
Petunia	0.85	616	60.5	0.32	[43]
Violet	1.02	498	64.5	0.33	[43]
Chinese rose	0.90	483	61.9	0.27	[43]
Rose	0.97	595	65.9	0.38	[43]
Lily	0.51	498	66.7	0.17	[43]
Rosella	1.63	404	0.57	0.37	[24]
Blue pea	0.37	372	0.33	0.05	[24]
<i>Cassia surattensis</i>	0.13	475	0.74	0.046	[44]
<i>Cassia tora</i>	0.06	292	0.72	0.013	[44]
<i>Cassia alata</i>	0.16	800	0.95	0.122	[44]
<i>Cassia occidentalis</i>	0.20	833	0.90	0.150	[44]
Algae					
<i>U. pinnatifida</i>	0.379	0.559	0.44	0.178	[45]
<i>Sargassum wightii</i>	0.20	330	0.46	0.07	[46]

CONCLUSION

Conversion of light to electricity was successfully achieved by dye extracted from *Costus woodsonii* leaves. DSSCs sensitized with acetone extract of *Costus woodsonii* shows the highest efficiency of 0.48 %. Encouraging results were obtained and works will be continued to improve the sensitizing ability of dye extracted from *Costus woodsonii* leaves.

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