Investigating the Influence of Selective Co-sensitization of Two N719 Dyes on the Micro-Energy Generation from Dye-sensitized Solar Cells

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Abstract

All of life’s processes require energy for their successful implementation. However, the amount of energy required for different process has varying indices. Thus, there is a keen focus on the study of energy generation from eco-friendly resources as represented in this study. Several outstanding attributes of dye-sensitized solar cells (DSCs) make them notable alternatives for inquiry from the wide repertoire of renewable energy resources. Foremost amongst these properties is ready availability, low cost, ease of fabrication, tunable optical properties, ability to operate under conditions of diffuse lighting and withstand extreme temperatures. Preliminary phytochemical investigation of B.spectabilis and L.arboreus leaves showed the presence of numerous metabolites available for charge transport. More intricate spectroscopic study of their microstructure with SEM revealed factors that contributed to the electrodynamics and output performance of the DSCs. FTIR spectroscopy identified active chromophores responsible for the characteristic redox of each DSC. Finally, the photovoltaic characterization of each DSC was compared with the co-sensitized DSC of the two dyes. The result is a geometric multiplication of their individual output. The short circuit current (Isc) values of the co-sensitized DSC was 94.7 % and 97.2 % less than the initial recorded respectively for B.spectabilis and L.arboreus DSCs. Maximum power output from the Co-sensitized DSC was over 500 times that from the individual DSCs. The significance of this result is that co-sensitization improved favourable interstitial boundary spaces which facilitated excellent interboundary relationship. Although this efficiency output is a miniscule compared with present efficiency output of monocrystalline silicon solar cells, the microstructural analysis in this work provides impetus for more research especially, in more co-sensitization of with other dyes, modelling. It is also recommended that, electron lifetime vital factor of consideration in future selection of dyes for co-sensitization.

1. Introduction

Research has shown that Co-sensitization produces an improvement in photovoltaic parameters in DSCs such as, short-circuit photocurrent where there is a complementary absorption of the two or more sensitizers [1]. This outcrop is accredited to amplifying the short circuit current, open circuit
voltage, and even the fill-factor of the solar cells [2]. Intracellularly, this translates into improvement in fermi level potential alignment and complementary absorption spectra of both dyes [3]. Consequently, open circuit voltage ($V_{oc}$) is improved because of better connectivity in microstructure, increasing charge transport and effective life time of electron [4]. The background for these encouraging development is traced to systematic dye desorption, absorption spectroscopy and intensity modulated photo voltage spectroscopy inquiries [5]. Several research attempts to elicit broader spectral response from dyes in the visible region have been made. This includes the use of ruthenium based C106 and organic D131 dye sensitizers, the result was a clear upgrading with reference to devices sensitized with either D131 or C106 [6]. At other times, dyes have been carefully chosen for co-sensitization because of differences in sizes of their molecule and complementary absorption properties [7]. The outcome was co-sensitization resulted in higher efficiency due to improved dye application and passivation at the photo anodic surface [8]. More examples featured co-sensitization of TiO$_2$ with porphyrin and an organic dye, the result of the co-sensitized devices was a substantial boost in the output efficiency of the DSCs [9]. Another co-sensitization technique involved a step-by-step application of one single dye solution followed by another single dye solution. The result showed higher output performance than when co-sensitization was carried out in a cocktail solution [10]. Research perspective also diversified into DSC devices based on a mixture of porphyrin dye co-sensitizers used in conjunction with quasi-solid-state gel electrolyte. There were remarkable improvements in power output conversion efficiencies by at least quadruple compared with devices sensitized with only the porphyrin dyes [11]. Generally, the open-circuit photo voltage observed usually falls within the range for the porphyrin dye and the lower voltage for the organic dye. This result is in consonance with their electron lifetimes [12]. Thus, this research investigates the effect of layered co-sensitization of two organic dyes separately from a cocktail co-sensitization of a photoanode with $B$.spectabilis and $L$.arboreus dyes from environmentally benign methods.

2. Materials and Method

2.1. Preparation of dye extract
Stochiometric quantities of $B$.spectabilis and $L$.arboreus leaves determined with Ohaus electronic balance was given as 500.0 g each. The two samples were air dried at conditions of 1.5 air mass. When the leaf samples assumed constant weight, they were blended to a coarse texture and spread out to eliminate moisture. The dry coarse blend of the two samples was then soaked in separate thin layer chromatography tanks to extract the dye. This resulting methanolic mixture was separated after two weeks using sterile filters into a mother liquor and chaff. The mother liquor was further separated by a rotary evaporator into methanol and the dye extract of $B$.spectabilis and $L$.arboreus respectively according to standard laboratory procedure [13].

2.2. Micro-spectroscopy of dyes
The dye specimen was prepared by dissolving 1 g in 100 methanol, 10 ml was put into the cuvette. This ratio was observed in both the SEM and FTIR. The equipment was calibrated before the reading was obtained. This is a necessary procedure to ensure accuracy.

2.3. Fabrication of DSCs
The doctor blade method of application of TiO$_2$ photo anode was used. High temperature sintering at 450$^\circ$C and 1h 30 min. was used to affix the TiO$_2$ paste to indium doped tin oxide (ITO) conducting slides with resistivity of 10 ohms per meter squared. The counter electrode was prepared by coating a second pair of ITO glass in epitaxial layers over a naked Bunsen flame in a simulated vacuum enclave. The dye extract was grown onto the photo anode by inserting it inside a 200 ml beaker containing 1 g dye dissolved in 10 ml of methanol. The initial process was $B$.spectabilis layer coat. It was allowed to dry for some hours before the second $L$.arboreus layer coat was applied to the same photo anode [14]. The photo anode was coupled with the counter electrode with binder clips, two drops of electrolyte (1
g dissolved in 100 ml of dissolved water) from a 21 G X 1.5 hypodermic needle was administered in-between the two slides. This set up was then connected in parallel with a variable load and a digital multimeter. The first reading was from only the B. spectabilis DSC, a second set of readings was collected from L.arboreus DSC before the final data from the co-sensitized dual layer.

3. Results and Discussion

3.1. Phytochemical Screening: The result of the qualitative phytochemistry is presented in Table 1.

Table 1: Metabolites present in dye extract

| Sample Name | Flavonoid | CHO | Saponin | Alkaloid | Tannin | Terpenoid | Phenol | Cardiac Glycoside | Quinone | Steroid |
|-------------|-----------|-----|---------|----------|--------|-----------|--------|-------------------|---------|---------|
| L.arboreus  | +         | -   | +       | +        | -      | +         | +      | -                 | -       | -       |
| B. spectabilis | +     | +   | +       | -        | +      | +         | +      | -                 | +       | +       |

The function of the flavonoid is illustrated in Figure 1; it provides ligands for the attachment of other chromophores. This characteristic is particularly desirable in complex molecules such as, organic compounds, it facilitates charge transport. The significance of this is the provision of a skeletal frame from which numerous linkages occurs with the other metabolites, resulting in a very bulky structure.

Figure 1: Illustration of the Flavonoid structure with several ligands

Key: The red dot represents O (Enol)

3.2. UV/VIS Spectroscopy: This technique provides the information on the wavelength of maximum absorbance of the dye extract. B. spectabilis and L.arboreus exhibit a near ruthenium characteristic absorption. Ruthenium dye records some of the best photovoltaic performance till date. The challenge is that, ruthenium is very scarce and thus, expensive. This same characteristic in low cost organic dyes is therefore of keen scientific interest. Very few dyes are able to absorb near ultraviolet range, about 330 nm as exhibited by B. spectabilis and L.arboreus dye extracts. Figure 2 is also characterized by oxide emissions before the UV/VIS assumes a steady form. This would further articulate with the flavonoid’s oxygen atom.
3.3. FTIR Spectroscopy

In *L. arboreus* dye as shown in Figure 3 (a), at wavelength peak 777.34 cm\(^{-1}\), chloroalkanes present a weak appearance, wavelengths 1047.3 and 1076.32 cm\(^{-1}\) show C-H bonds bending and presenting a medium appearance. At 1384.94 cm\(^{-1}\), C-O bonds present a strong appearance. Wavelength peaks 1631.83 and 1701.06 cm\(^{-1}\) show C=O in strong appearance and stretching. Then at 1961.67, 2362.88, 2426.53, and 2733.22 cm\(^{-1}\) peaks, the C-H aliphatic presents a broad appearance. At 2556.67 and 2926.04 cm\(^{-1}\) peaks, aliphatic C-H bond presents a strong appearance. At 3416.05 cm\(^{-1}\), O-H bonds show a broad appearance. This explains why the flavonoid structure is so bulky, it comprises a long carbon chain with branch offs, contributed by the functional groups present in the dye extracts.
3.4. SEM Microscopy

![SEM Microscopy Image](image)

Figure 4: SEM Microstructure of: (a) *L. arboreus* and (b) *B. spectabilis*

The microstructure of *L. arboreus* dye consists of cylindrical grains of varying sizes as shown in Figure 4 (a). *B. spectabilis* dye is a complex labyrinth as illustrated in Figure 4 (b). The consequence of the double layered co-sensitization, is akin to alignment of *L. arboreus* grain structure to fit inside the void spaces in the matrix of *B. spectabilis*. This in effect enhances higher electron mobility as recombination is impeded.

4. Photovoltaic Characterization of *L. arboreus*, *B. spectabilis* and co-sensitized DSCs

The photovoltaic performance of the co-sensitized DSC outclasses the individual DSCs in $I_{sc}$ and $P_{max}$. Although *B. spectabilis* gives a comparatively good output relative to previous researches in DSCs, it records the highest efficiency, this could be due to better interboundary kinematics. This is buttressed by the high quality of the DSC illustrated by the exceptional fill factor. The highest fill factor is notably the co-sensitized DSC, this could largely be as a result of the enhancement of the two dyes different grains enmeshing to produce a more compact framework. The enhanced current is an affirmation as shown in Table 2. Interestingly, the co-sensitized DSC is less in efficiency to *B. spectabilis* DSC. This could be as a result of the fermi energy required for the transition of electrons from the valence band to the conduction band. The significance of this is that, the co-sensitized DSC may require more energy thus, the reaction is less favorable and not encouraged.

Table 2: Photovoltaic Parameters of *L. arboreus*, *B. spectabilis* and co-sensitized DSCs

| Parameter        | *L. arboreus* DSC | *B. spectabilis* DSC | Co-sensitized DSC |
|------------------|-------------------|----------------------|-------------------|
| $I_{sc}$ (mA)    | 0.083             | 3.0                  | 5.3               |
| $V_{oc}$ (mV)    | 14.6              | 250                  | 249               |
| $P_{max} \times 10^{-6}$ (W) | 1.057           | 693                  | 1237.5            |
| $F/F$            | 0.87              | 0.92                 | 0.94              |
| $\eta$ (%)       | 0.33 X 10^{-2}    | 2.2                  | 0.39              |
5. Conclusion and Recommendation

Co-sensitization of L.arboreus and B.spectabilis dyes amplified the energy output from DSC by 1,200. The short circuit current was a tangential increase which was higher in the open circuit value. This is clearly depicted in Figures 6 and 7. Due to the relatively high efficiency of monocrystalline silicon cells, co-sensitization is not applied. It therefore is imperative to discover if future researches could employ co-sensitization of silicon panels. Future research inquiry into cocktails of electrolyte could be a comparative study to this research. Applications in plastic, ceramic devices would also facilitate more flexible DSCs in future.
Figure 6: Analysis of photovoltaic output from DSCs

Figure 7: Comparison of Relative Output performance of DSCs

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