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Analysis of Tyndall effect on output performance of *P. macrophylla Benth.* dye-sensitized solar cells

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Abstract

The study demonstrates the impact that maximum light-scattering effect has on negligible amount of *P. macrophylla B.* dye. It investigated the influence of particle size on intensity via the exponential factor of the intensity of Rayleigh scattering. The study adopted two approaches of experimental and theoretical investigations, while two sets of dye sensitive solar cells (DSCs) were employed. One set of DSCs (crude) had an organic light scattering layer attached while the second (hexane) set was without the light scattering layer. The outcome of the experiment revealed a significant increase in photovoltaic performance of DSCs which had an improvised scattering layer. The short circuit current (I_{sc}) of *P. macrophylla B.* crude was 64.7% higher than that of the hexane DSCs, the open circuit voltage (V_{oc}) of the crude DSC was more than 50% greater than the hexane DSCs. Although, hexane DSCs had a better fill factor (ff), the output performance of the crude DSCs was thrice that recorded by hexane DSCs. The implication of this study is that, theoretical models can be used for simulating optimal angles of incident in DSCs which can be maximized for higher output in further studies.

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1. Introduction

The effect of penetration and scattering of light in dye-sensitized solar cell (DSC) plays a vital role in its photovoltaic performance [1]. Past research efforts delved into the influence of a bilayer structure on normal and light-scattering layer (LSLs) patterns in DSC [2]. They reported that photovoltaic performance of the LSL in the DSC is upgraded with light reflected from the film which consists of the LSL. This was attributed to increases in the reabsorbing capacity of the dye [3]. The LSL was placed at the back of the DSC to reflect light, in order to achieve a relatively inexpensive, but highly efficient DSC [4]. The correlation between concentration and conversion efficiency of dye was investigated to take full advantage of the light-scattering effect by means of a minimal amount of adsorbed dye [5]. Generally, dye-sensitized solar cells (DSCs) consist of a nanocrystalline TiO₂ as an anode. The novelty was the incorporation of an independent, elastic light scattering sheath made of minute Al₂O₃ particles mixed with a little quantity of ionic polymer binder. Its output performance was compared to DSCs composed of nanocrystalline sub micrometer TiO₂ bi-layer acting as an anode [6]. The observation showed that the cell efficiency of the first DSC system was greater than that of the second DSC. This result indicated that the boost in light absorption from a DSC with light-scattering layer relative to that gotten from a regular DSC was realized through the combination of a large surface area of nanocrystalline TiO₂ and autonomous light scattering film. Equally noteworthy is the record of higher resistance from the independent light scattering film as recorded by an electrochemical impedance analysis. Importantly however, the cell performance was not extremely affected by the extra resistance. Conversely, when the autonomous scattering film was coupled with flexible type of DSCs, the result showed higher power conversion efficiency and improved long-term stability than the ordinary DSC [7]. This present study eases the conversation between regular DSCs and DSCs with a light scattering barrier using oil bean dye-sensitized solar cells as basis for the research.

2. Materials and Method

150 grams of oil bean leaf was harvested and air dried until it assumed constant weight. Subsequently, it was milled and spread out to remove the moisture in it and to cool down to room temperature. It was then soaked in thermoluminescent tanks for two weeks in methanol to extract the *P.macrophylla B.* dye. This mixture was separated to recover the dye solution which was put as feedstock inside a rotary evaporator to obtain the pure *P.macrophylla B.* dye. The prepared dye was divided into two sections of 1g each for further use. The light scattering layer was obtained by mixing sub-micrometer sized aqueous ethyl acetate with the second portion of the *P.macrophylla B.* The uniform blend was used as a coat on a thin sheath and attached to the counter electrode. Subsequent preparation of the electrodes followed standard methods described by Abodunrin et al. 2015 [8]. The counter electrode was coupled with the photoanode afterwards with binder clips on either side. The procedure was completed with two drops of aqueous electrolyte inserted in-between the slides. A liquid film barrier was used to seclude the electrolyte from leaking.

3. Results and Discussion

3.1. Ultraviolet Visible (UV/VIS) Spectroscopy

According to Beer Lambert's law, the absorbance of *P.macrophylla B* is equal $A = -\log(T\%) = \epsilon cl$ where ϵ is the molar absorptivity coefficient ($L \text{ mol}^{-1} \text{ cm}^{-1}$), c is the concentration of the solution (mol dm^{-3}). The significance of the ultraviolet visible spectroscopy is that the LSL affects the transmittance of incident light on the DSC. Thus, Figure 1(a) devoid of the LSL, the transmittance is less than that obtained in Figure 1 (b) with a LSL in consonance with Beer Lambert's law within the same wavelength spectrum. In addition, the TiO₂ nanoparticles having sizes akin to visible light's wavelength (Rayleigh) scatter the incident light by the aqueous ethyl acetate particles naturally embedded inside the dye and a light scattering layer at the bottom of the counter electrode. This lengthened the path of the incident ray. Thus, the application of the LSL provided a larger precise surface area for charge transport. This

consequently improved the short circuit current as shown in Figure 2(b). It is pertinent to note that the roughness factor of *P.macrophylla B.* increased due to the aqueous ethyl acetate particles. This is higher than that observed in Figure 2(a) devoid of LSL. This outcome agrees with the results of Zhang and other researchers, effective light scattering improved the optical absorption in DSC and ultimately the efficiency [9].

3.2. Fourier Transform Infrared (FTIR) Spectroscopy

The active chromophores involved in charge transport are identified in the FTIR spectrograph shown in Figure 3. Four functional groups were identified in *P.macrophylla B.* devoid of a LSL as shown in Table 1. Arenes elongated the alkyl structure of *P.macrophylla B.* and heightened the performance of the DSC by absolutely protecting the surface of TiO₂ from the iodide electrolyte and in so doing decreases the trickle of dark current. The Esters and carboxylic derivatives instigate the electrophilic substitution of displacing hydrogen in the typical redox reactions that characterize DSCs. The alcohols dissolved the redox mediators and additives which helped in charge dissociation, separation and transfer in the mechanism for both the LSL dye-sensitized solar cell and the DSC devoid of LSL.

3.3. Photovoltaic Characterization

The current-voltage characteristic of *P.macrophylla B.* is shown in Figure 3. In Figure 3 (a), where the LSL is absent, I_{sc} is 60% lesser than that of Figure 3(b) which has the LSL. This is due to the LSL trapping photons of energy which creates a more conducive environment for charge transport. The open circuit voltage also increases by approximately 36% due to the LSL. The significance is that recombination is inhibited but effective charge transport that translates to positive work been done in the circuit has been enhanced. This is buttressed and summarized in Figure 4.

Table 1. FTIR of *P.macrophylla B.*

Peak (cm) ⁻¹	Functional Group Present	Assignment
426.28	S-S	Disulphide bonds stretching.
673.18, 731.05 and 835.21	Arenes	Strong to medium intensity depicted by bending of C-H bonds and puckering of the ring structure.
1041.6, 1078.24, 1163.11, 1240.27	Esters	P=O bond in phosphine oxide and phosphate presenting a strong appearance.
1377.22, 1458.23, 1535.39, 1618.33, 1664.62, 1712.85, 1735.99, 2727.44, 2852.81, 2926.11 and 2956.97	Carboxylic acid and derivatives	Strong C=O bonds presenting two bands.
3392.9	Alcohol	Strong O-H bonds giving a sharp appearance.

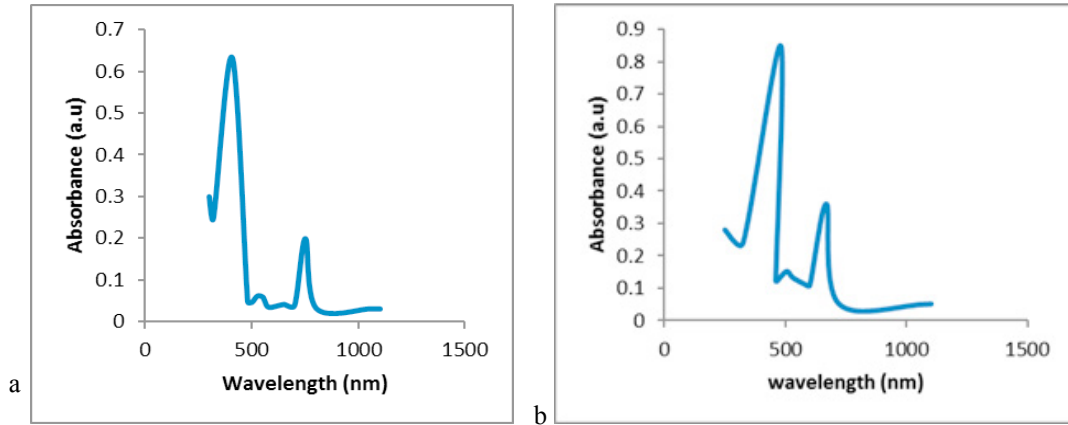


Figure 1. UV/VIS of *P. macrophylla* B. dye (a) without LSL; (b) with LSL.

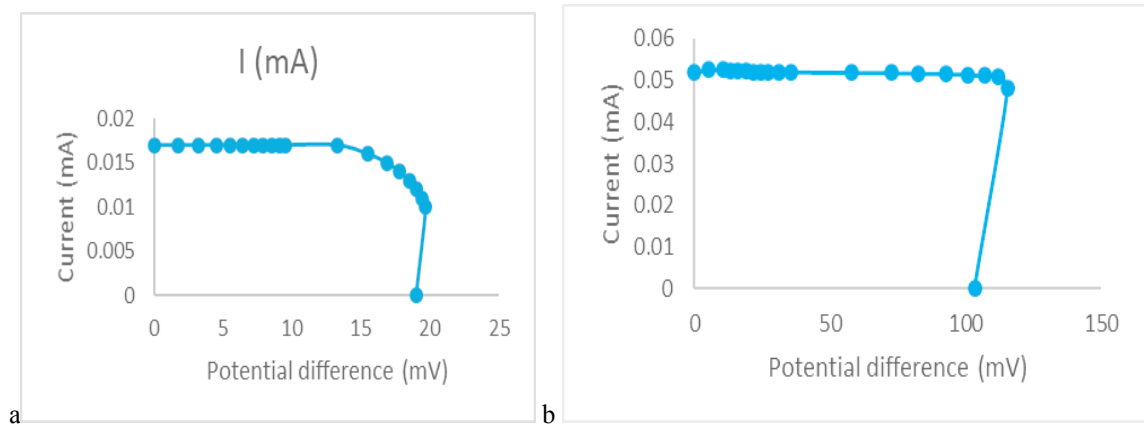


Figure 2. I-V curve of *P. macrophylla* B. dye (a) without LSL; (b) with LSL.

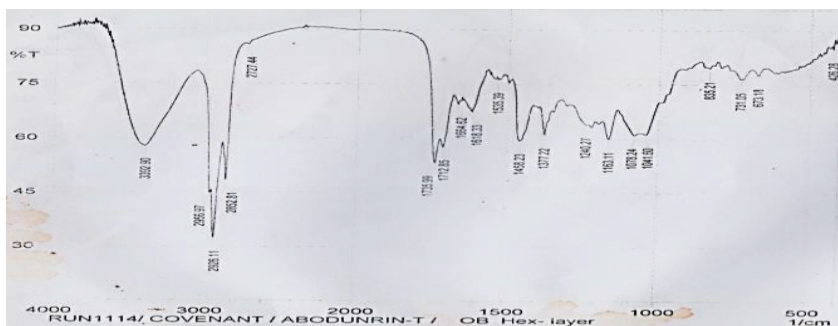


Figure 3. FTIR spectrograph of *P. macrophylla B.*

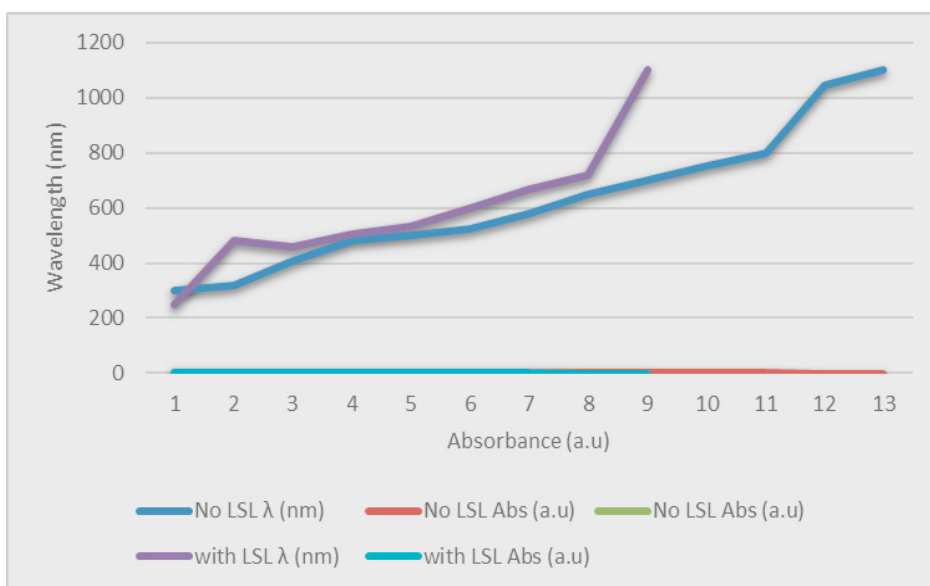


Figure 4. Comparative Analysis of *P. macrophylla* DSCs

3.4. Conclusion

The outcome obtained from the dye-sensitized solar cells with light scattering layer reveals that the presence of this light scattering layer increases the photovoltaic performance of *P. macrophylla B.* dye-sensitized solar cell compared to that of *P. macrophylla B.* without a light scattering layer.

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