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PERFORMANCE ANALYSIS OF SPECTRAL RESPONSES OF *A.CEPA* PEEL DYE-SENSITIZED SOLAR CELLS TO LIQUID ELECTROLYTES

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ABSTRACT

This study investigates the effect of variation of electrolyte on the output performance of A.cepa peel dye-sensitized solar cells. Four A.cepa dye-sensitized solar cells were sensitized with different liquid electrolytes. The criteria used for assessing their performance was the short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum power (P_{max}), fill factor (ff), output efficiency (η) and the incident photon to conversion efficiency (IPCE). The responses produced by the A.cepa dye solar cells were varied. The most efficient electrolyte was Mercury chloride ($HgCl_2$) with an efficiency of 0.27%, potassium bromide (KBr) recorded the highest value in maximum power (P_{max}), fill factor (ff) and open circuit voltage (V_{oc}) with the following values: 38.09 W, 2.83 and 700 V respectively. $HgCl_2$ also had the highest I_{sc}, with a value of 0.04 mA and the best IPCE was obtained with KCl with a value of 1.64%. The significance of this outcome is that, $HgCl_2$ and KCl electrolytes influenced the performance of A.cepa peel dye-sensitized solar cell by suppressing dye agglutination while KBr electrolyte improved A.cepa peel dye-sensitized solar cell's electrochemical stability.

Keywords: Energy harvesting, Electrolyte sensitizer, Photovoltaic characterization, Fourier transform infrared spectroscopy, Nanocomposite

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Performance Analysis of Spectral Responses of A.Cepa Peel Dye-Sensitized Solar Cells to Liquid Electrolytes

1. INTRODUCTION

An electrolyte plays a very crucial role in dye-sensitized solar cell technology. It is responsible for the ionic conductivity which characterizes a solar cell, it conveys majority of the solution, rejuvenates the dye after it is oxidized, and also determines the potential barrier required for energy conversion [1]. Basically, the electrolyte comprises of a redox mediator in an organic matrix [2]. it can be in the form of iodide (I^-/I_3^-), thiocyanate composite polymer ($SCN^-/(SCN)_2$, sulphide (S/S^{2-}) and cobalt complexes ($CO^{2+; 3+}$) [2]. A good electrolyte has the following attributes; high dielectric properties, high boiling point, negligible vapor pressure and very low viscosity. Industrially, an electrolyte must also possess: ease of processing, chemical inertness and environmental sustainability [3]. Ionic liquid electrolytes resemble a solid but possess liquid attributes and have high conductivity. Inorganic ionic liquid (IL) electrolytes are usually made of salts or mixture of salts. While, organic solvents such as iodide and acetonitrile are the most commonly used as a result of their high rate of ionic diffusion and percolation into the TiO_2 structure. This feat has brought about the accomplishment of the outstanding efficiency record of liquid electrolyte sensitized solar cells relative to other DSC types [4]. A peculiar set back is that, their potency and chemical stability reduces after a long period of time, thus its efficiency deteriorates. Although liquid electrolytes are more commonly used in dye-sensitized solar cells (DSCs) than the quasi-solid or solid electrolyte types, the problem of long term stability due to volatilization of liquid has hindered its wider application [5]. On the otherhand, quasi and solid type electrolytes do not have the challenge of sealing peculiar to liquid electrolyte dye-sensitized solar cells. They gained popularity because of their comparative high efficiency and stability in dye-sensitized solar cells. However, they also had limitations such as complex process of preparation, high cost, low charge transport, instability over time and crystallization makes it difficult for them to fill in the porous TiO_2 pore spaces. All of these factors have restricted their further applications [6]. This ushered an era of intense inquiry into the electron kinematics of redox reactions in DSCs [7]. The problem of percolation in solid electrolyte was eliminated by introducing ionic liquids into the electrolyte [8]. Other researchers reported copper iodide (CuI) as the best p-type electrolyte due to its transparency, high band gap and low cost. Their results showed I_{sc} and V_{oc} values of 2.5 mA/cm^2 and 375 mV respectively under 800 W/m^2 light intensity and incident photon conversion efficiency of 0.8%. In this light, Kawano *et al*. uses ionic liquid electrolyte to sensitize their DSC under conditions of 1000 W/m^2 light intensity and recorded an efficiency of 5.5% [9]. In addition, some researchers reported that an effective cell process is described by a speedy charge transport balanced by a slower back transfer of electrons, which are resulted from photo injection. This is in order to allow electrons can accumulate in the oxide and generate voltage [10]. In this event, the most successful redox mediator reported in DSCs is a liquid electrolyte containing the redox couple iodide/triiodide. The redox electrolyte consists of iodides, iodine and additional additives. The presence of different additives influences the semiconductor/dye/electrolyte energy level interface. The success of the iodide/triiodide redox couple is attributable to a suitable redox potential which provides efficient dye regeneration [11]. Microstructure spectroscopy also reveals that recombination of electrons in TiO_2 is minimal compared to the redox couple in other charge mediators. The recombination rate and high diffusion rate are necessary prerequisites for effective charge transfer. The two factors determine the quality linked with conductivity and quantity associated with viscosity of charge transport in a DSC [12]. In this study, a number of solvents with different concentrations of I^-, Br^-, Cl^-, K^+ and Hg^{2+} were prepared, and the influence of these electrolytes proportion on the performance of *A.cepa* dye-sensitized solar cell is reported.

2. PRELIMINARY PROCEDURE

The sample was prepared from 50.0 g of *A.cepa* peel. Adam PGW 453e electronic balance was used to determine the mass of each of the samples. The peels were air dried in the laboratory until they assumed constant weight and then milled. This coarse blend of leaves was allowed to cool for 2 hours, soaked in methanol inside thin layer chromatography (TLC) tanks and left covered. The set up was left for eleven days to extract the dye. The methanolic mixture was filtered and a Stuart RE 300 series was used to extract the dye [11].

2.1. Preparation of the electrode

An active area of 3.16 m^2 was marked as the active area of the indium doped tin oxide (ITO). A uniform blend consisting of concentrated HNO_3 and zinc Oxide in a ratio of 20 ml: 50 g with a few drops of cellulose was prepared. Doctor blade method of application was employed for putting the Zinc Oxide paste on the ITO. The set up was allowed to air dry for 6 hours and then sintered at a high temperature of 450 ^{0}C for 1 hour 30 minutes. The baked photoanode was brought out of the furnace and re-heated to allow the characteristic colour change to occur. The photoanode was removed from the furnace after 30 minutes. After it cooled to room temperature, 1g of each dye extract was dissolved in 10 ml was deposited on the photoanode via capillary growth. The counter electrode was prepared by masking the second ITO with uniform layers of soot from a naked Bunsen flame. This was carried out in a simulated vacuum-like enclosure. The two electrodes were couple together. Two drops of electrolyte mixed in a ratio of 1 ml: 100 ml distilled water was introduced in-between the pair of electrodes for four different DSCs. Consequently, the fabricated solar cell was sealed off with a thin liquid barrier. A variable resistor was connected to the DSC in parallel with a digital multimeter to obtain readings under standard condition of air mass. This is according to standard procedure described by Abodunrin *et al.*, 2014 [12]. The output efficiency and IPCE of the *A.cepa* DSCs were determined by equation (1) and (2) respectively.

$$\eta = \frac{I_{sc} \times V_{oc} \times ff}{A \times G} \tag{1}$$

$$IPCE = \frac{1240 \times J_{sc}}{\lambda \times P_{in}} \tag{2}$$

where, η is the efficiency (in %), I_{sc} is the short circuit current in (mA), V_{oc} is the open circuit voltage (in volts), ff is the fill factor, A is the active area of ITO exposed to insolation, G represents the power of irradiance (in Watts/m^2), J_{sc} is the current density (mA/m^2) and λ is the wavelength (in nm).

3. RESULTS AND DISCUSSIONS

3.1. UV/VIS Spectroscopy

The UV/VIS spectroscopy of the dye extracts reveals near ruthenium characteristic absorbance in *A.cepa* peel extract. This is of particular interest because, it absorbs maximally from near ultraviolet to the visible range of the electromagnetic spectrum as shown in Figure 1. This result confirms Beer Lambert's law which implies that, $A = -\log(T\%) = \varepsilon cl$ where ε is the molar absorptivity coefficient (L mol^{-1} cm^{-1}), c is the concentration of the solution (mol dm^{-3}). The absorbance of A.cepa peel dye is directly proportional to the negative logarithm value of transmittance. This is significant because of the outstanding efficiency record of

ruthenium complexes. A limitation to their wide application is due to their high cost, which fortunately does not apply to *A.cepa* peels. *A.cepa* peel extract thus combines the ruthenium attribute with low cost which makes it a viable substitute for application in DSCs.

3.2. Fourier Transform Infrared (FTIR) Spectroscopy

The important functional groups that presented a strong appearance are largely responsible for charge transport in A.cepa peel extract. These include: aromatic meta-disubstituted benzene, carboxylic acids and alcohol (O-H) as shown in Figure 2. The significance of this result is that disubstituted benzene being one of the strongest electron donors directs an electrophilic substitution. As pointed out, both 'meta'- positions in the benzene structure direct to the same position (C-2). The carboxylic acid plays a crucial role of providing anchor for the dye on the photoanode and performance of DSC. Finally, O-H presents the strongest peak of energy which is required for electron orbital transitions.

3.3. Scanning Electron Microscope (SEM) Spectroscopy

The alignment and connectivity of the particles of each dye extract prescribes how effective charge transport was. The micrograph of *A.cepa* has similar tiny rhombic shaped particles. The microstructure of *A.cepa* is characterized by dense clusters with intermittent dark spots. Figure 3 (a) reveals tiny grains which would facilitate electron transport by series of hops. In Figure 3 (b), the details are emphasized, several spots are identified. This would serve as trap or recombination sites during electron transport. However, impedance would be largely due to the roughness factor of *A.cepa* as shown in Figure 4.

3.4. Photovoltaic Characterization

The Photovoltaic (PV) characterization outcome is presented in Table 1. The most efficient electrolyte in *A.cepa* DSC is $HgCl_2$ with 0.27% efficiency. This is attributable to a comparatively high I_{sc} of 0.04 mA, because of effective charge transport along its molecular structure. The best fill factor of 2.83 was given by KBr electrolyte, these accounts for the high V_{oc} and P_{max} values which are 700 mV and 38.09 W respectively. It is noteworthy that the highest IPCE was obtained from KCl electrolyte although it recorded the least V_{oc}, P_{max} and efficiency values. Conversely, KBr had the least IPCE. A detailed examination of Figure 4 reveals that *A.cepa* with KCl microstructure has larger pore size and spaces in-between neighboring molecules. Hence, charge transport is more prone to recombination. This accounts for the reason it recorded the least I_{sc}. This result corroborates with outcomes obtained from turmeric DSCs with an efficiency of 0.264% by Basuki *et al*., 2017.
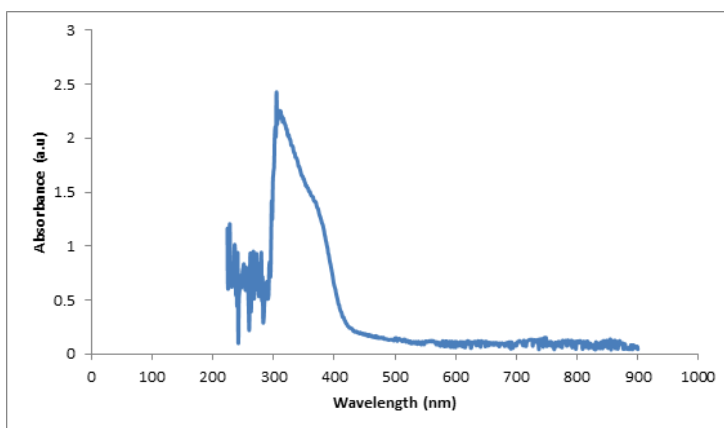

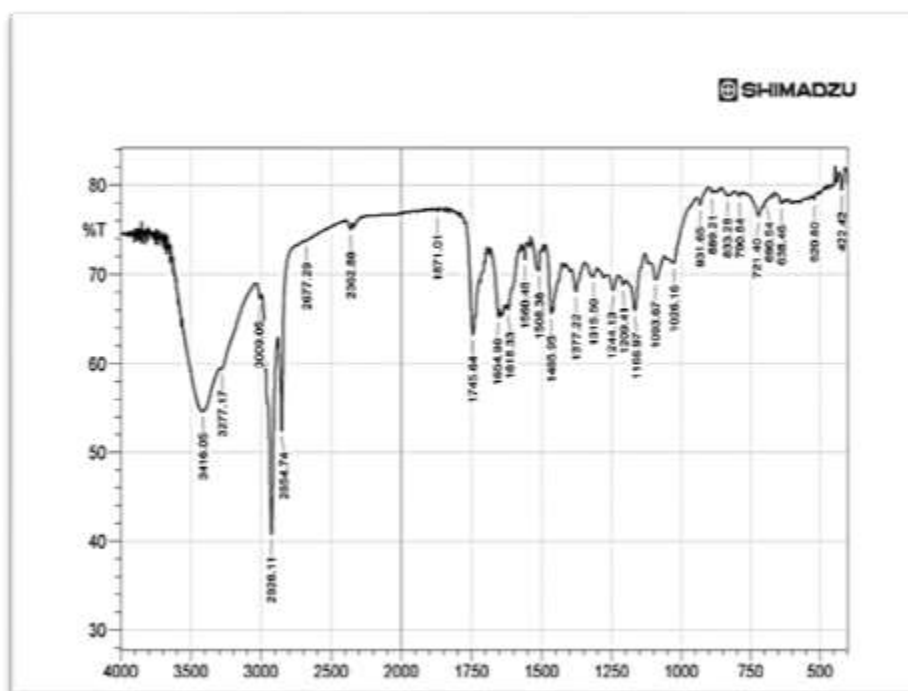**Figure 1** UV/VIS of *A.cepa* plant extract
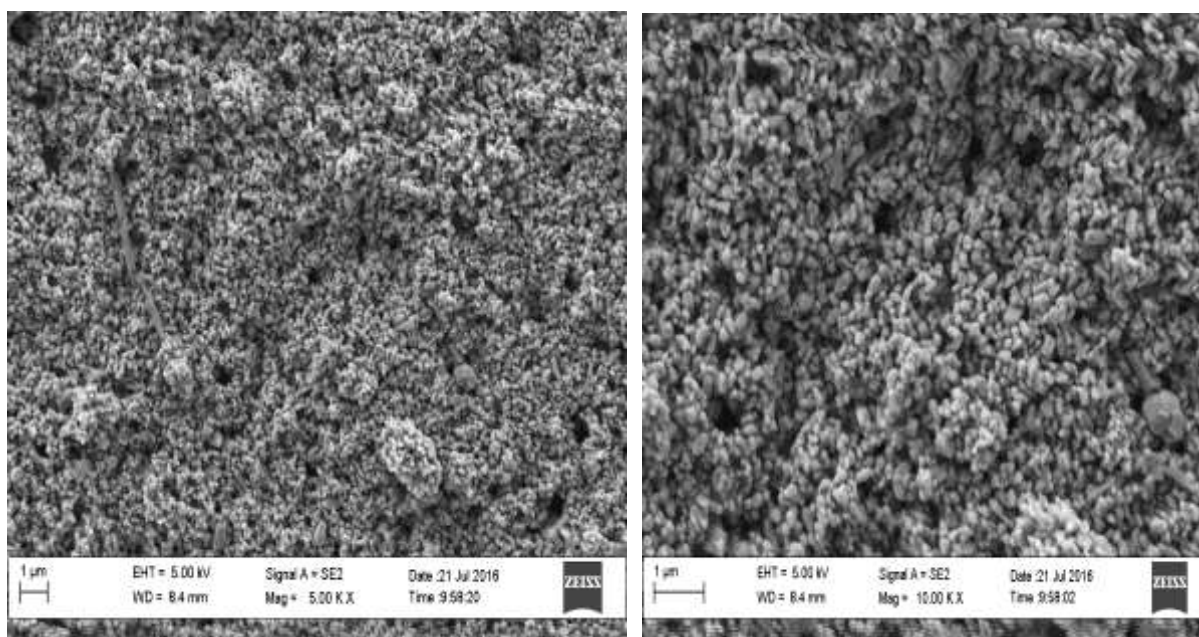
Figure 2 FTIR of *A.cepa* plant extract

Figure 3 SEM of *A.cepa*/TiO$_2$/ KBr Peel at magnification of: (a) 5 times and (b) 10 times
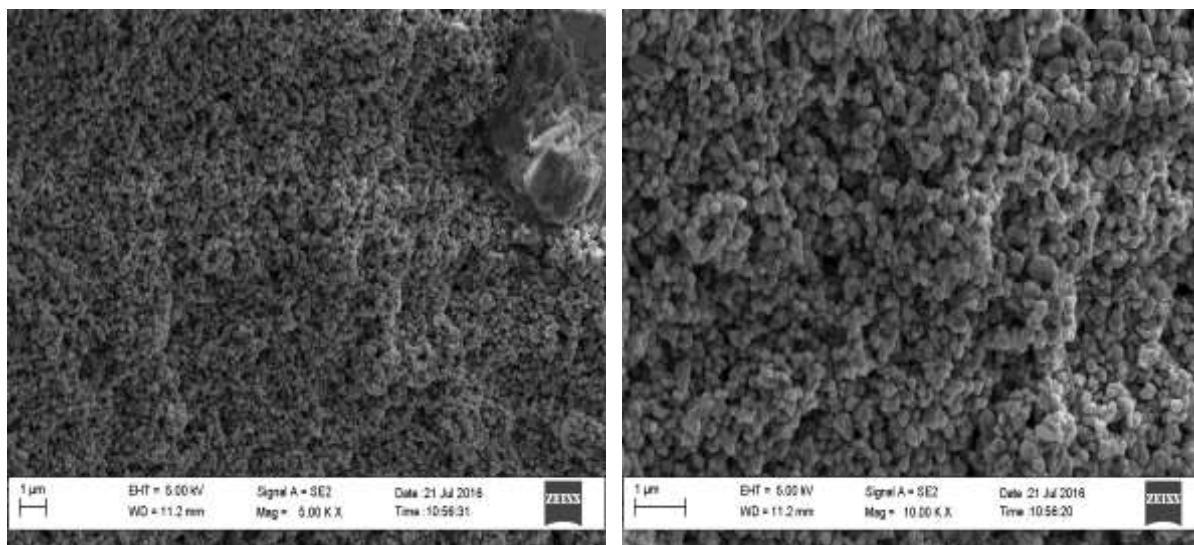
Figure 4 SEM of *A.cepa* peel/TiO2/ KCl at Magnification of: (a) 5 times and (b) 10 times
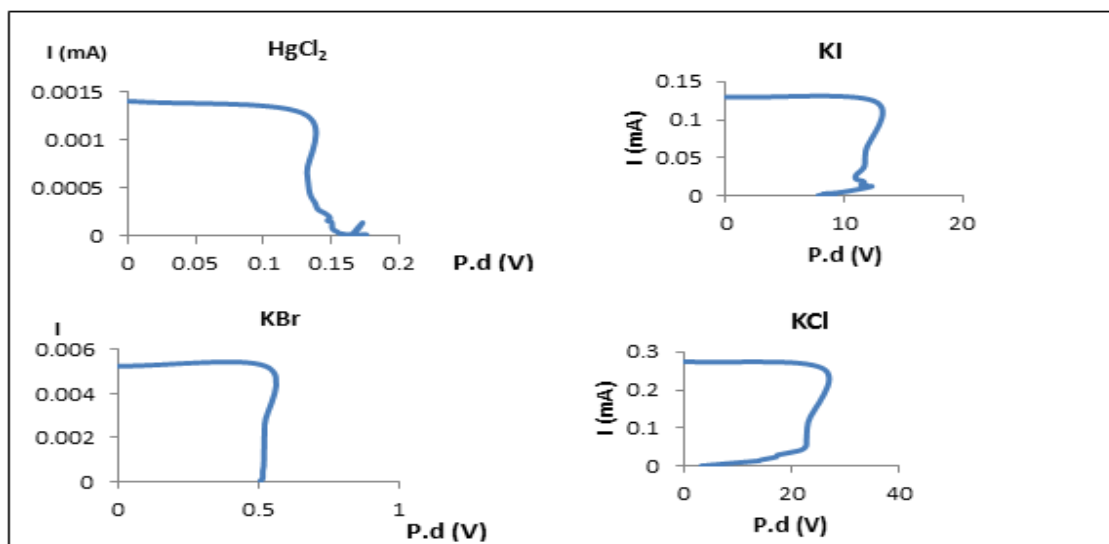

Figure 5 Spectral responses of *A.cepa* peel I-V Curve

Table 1 Photovoltaic Characterization of *A.cepa* DSC

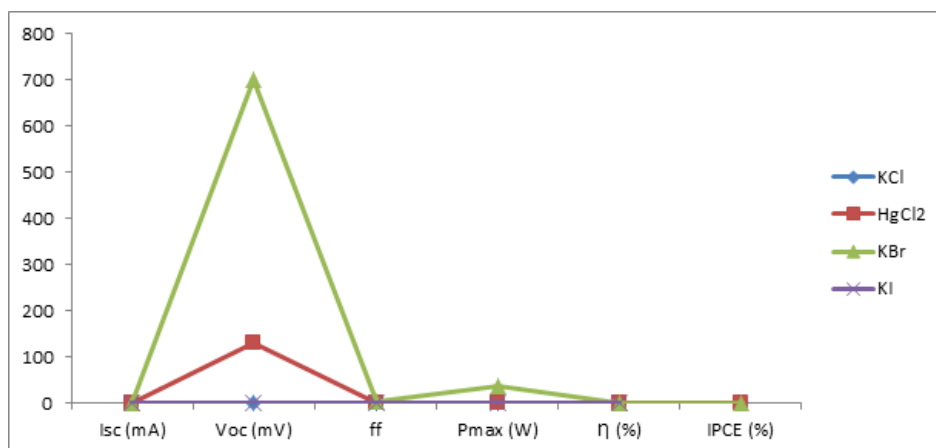| A.cepa	Isc (mA)	Voc (mV)	ff	Pmax (W)	ɳ (%)	IPCE (%)
KCl	0.00015	0.799	0.234	2.8E-5	8.8E-6	1.64
HgCl2	0.039	130.0	0.174	0.884	0.27	0.01
KBr	0.0192	700.0	2.83	38.09	0.121	0.002
KI	0	0	-	-	Negligible	

Figure 6 Trend of spectral responses of *A.cepa* peel photovoltaic characterization

5. CONCLUSION

The study investigated the relative performance of four *A.cepa* DSCs sensitized each with one of four electrolyte sensitizers. The experiment was carried out under similar conditions of 1.5 air mass and laboratory procedure. A comparative analysis of the photovoltaic performance of the DSCs relative to their microstructure was highlighted. The findings show that despite that *A.cepa* KBr sensitized DSC performed better than *A.cepa* $HgCl_2$ DSC, which in turn performed better than KCl sensitized *A.cepa* DSC. KBr electrolyte DSC recorded a higher fill factor which influenced its open circuit voltage and consequently, its maximum power output. The next in performance was $HgCl_2$ electrolyte which revealed the best values of short circuit current which influenced its efficiency. Conversely, KCl electrolyte with the least short circuit current, open circuit voltage, maximum power and efficiency recorded the largest incident photon to conversion efficiency due to better redox reactions with Cl^- ions.

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