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Assemblage of Dye-Sensitized Solar Module Using Extract of *Lonchocarpus cyanescens* as a Photosensitizer

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Abstract

The global challenge of power today necessitates the deployment of clean and renewable energy of which the Dye Sensitized Solar Cell (DSSC), is considered a promising technology. A survey of the literature shows that efforts in the development of dye sensitized solar modules are unimpressive despite the high demand of silicon solar modules. A dye sensitized solar module was fabricated in this study using dye extract from the leaves of *Lonchocarpus cyanescens* (LC), plant. A Power conversion efficiency of 0.120% was obtained for a single solar cell and a maximum power of 0. 183 μW from twenty-four solar cells connected in series. This result shows that *Lonchocarpus cyanescens* is a potential resource for the fabrication of cheap dye sensitized solar cells and modules in accordance with item 7 of the government's Sustainable Development Goals (SDGs), the provision of affordable and clean energy.

Keywords

Lonchocarpus cyanescens, Photosensitizer, Solar Module, Sustainable, Energy

1. Introduction

Energy is a major factor in meeting the Sustainable Development Goals [1] and so alleviating energy poverty is a necessity [2]. The worldwide use of energy is rising by 2.5% a year [3], most of which is attributable to the accelerated consumption in the developed countries. The fast industrialization of the developing and underdeveloped countries and the world's population growth will result in an increase in power consumption. In addition, fossil fuel from which over 60% of today's power is generated [4], will soon be depleted and there are serious environmental concerns associated with its use. The resultant effect of extracting, transporting and burning fossil fuels causes different forms of pollution. It is evidenced from literature that fossil fuel-based energy can be replaced with emerging photovoltaics specifically dye-sensitized solar cells (DSSCs) [5]. They have become a topic of significant research in the last two decades because of their fundamental and scientific importance in the area of energy conversion [6]. DSSCs are easy to fabricate, less expensive, environment-friendly and less sensitive to the variation of incident light intensity in comparison to conventional solar cells [7]. **Figure 1** shows the basic steps involved in the fabrication of a dye sensitized solar cell. The major advantages of DSSCs are cell's mechanical robustness and their ability to work under cloudy skies and non-direct sunlight. Another special advantage of the DSSC with respect to competing technologies is that its performance is remarkably insensitive to temperature change. Thus, raising the temperature has practically no effect on the power conversion efficiency [8].

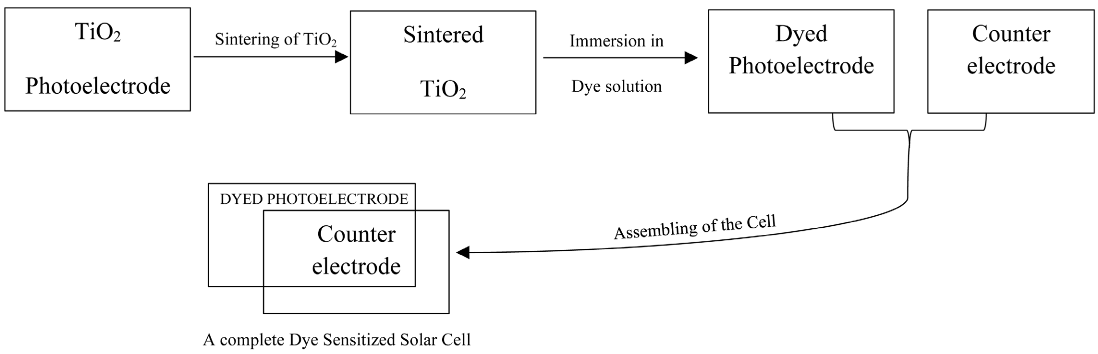

Figure 1. Basic steps involved in the fabrication of a DSSC.

They belong to the third generation solar cells and emerged due to the high cost of the first generation cells and the toxicity and limited availability of materials for the second generation solar cells. They are made from a variety of new materials besides silicon, including nanoparticles, silicon wires, and solar inks, using conventional printing press technologies, organic dyes, and conductive glasses [9]. Their origin can be dated back to the 1960s, when it was shown by Gerischer & Tributsch [10] that photoexcited dye molecules can inject electrons into the conduction band of semiconductor substrates. They are photonic devices that convert visible light into electricity based on a porous, thin film of a wide band gap semiconductor oxide modified by dye molecules [11]. DSSC comprises of a photoanode, which consists of a transparent conducting oxide (typically Indium doped Tin Oxide, ITO, or Fluorine doped Tin Oxide, FTO), substrate coated with a thin film of titanium dioxide semiconductor covered or sensitized by dye, an electrolyte system and a counter electrode. Molecular dyes have become an essential part of dye sensitized solar cells [12], they are anchored to the surface of the semiconductor material to enhance visible light absorption. This is an effective approach to improve the photocatalytic activity of semiconductors [13]. The history of dye sensitization started with the work of Tributsch [14]. The major role of the dye sensitizers is the absorption of solar photons and the injection of the photoexcited electrons into the conduction band of the semiconductor [15]. Ruthenium based complexes sensitizers have been widely used because they have better efficiency and high durability. However, these advantages are offset by their high cost, their complicated synthetic routes and the tendency to undergo degradation in the presence of water. Also, noble metals are considered as resources that are limited in amount, and their production is costly. This limitation necessitated the use of metal-free dyes as sensitizers which also because of its shortcomings led to the emergence of natural dyes as sensitizers in DSSCs. Natural dyes, have appreciable light absorption properties and are preferable in terms of their eco-friendly nature, low cost and abundance [16] [17], complete biodegradation, simplicity and safe preparation, as sensitizers in solar cell fabrication. Thus far, several dyes such as anthocyanins, carotenoids, betalains and chlorophylls extracted from parts of different plants have been used as natural sensitizers in DSSC [18]. Natural dyes are found to provide a viable alternative to expensive organic dyes for DSSCs [19], but their efficiency is dissatisfied [17]. State-of-the-art DSSCs based on single sensitizers for synthetic dyes have reached power conversion efficiencies (PCEs) of >11.5% for ruthenium dyes, >13% for porphyrin dyes, and >14% for metal-free organic dyes. However, the highest efficiency officially recognized by the National Renewable Energy Laboratory is only 11.9%, achieved by the Sharp Company, Japan, in 2013 [20] and that of the natural dye is 2.7% from a betalein pigment [21]. Several studies have been carried out on the DSSC but research on the dye sensitized solar module is limited [22] [23]. A solar module is a series of solar cells connected together to generate energy proportional to the amount of sunlight it receives [24]. In this study, we have assembled twenty-four fabricated dye solar cells into a module using leaves extract of *Lonchocarpus cyanescens* (LC) plant as a photosensitizer in a bid to promote the provision of cheap and clean energy affordable to all which is one of the Sustainable Development Goals (SDGs).

2. Methodology

2.1. Sourcing and Preparation of Extract of *Lonchocarpus cyanescens*

Samples of Lonchocarpus cyanescens leaves were collected from Igbara odo, Ifedore local Government of Ekiti, Ekiti state, Nigeria (7˚30'9.04"N and 5˚03'45.29"E) and authenticated at the Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo state, Nigeria (FHL 110288). Samples were air dried for two weeks and finally in the oven at 45˚C followed by grinding. Ground samples were soaked in ethyl acetate for one week and filtered. Ethyl acetate, though gave a similar spectral response compared with other solvents such as ethanol, methanol, N-hexane was preferred because it is relatively non-toxic, moderately polar and requires a lower temperature for concentration of filtrate to give dye extract using the rotary evaporator. Dye extract was characterized with UV spectroscopy in the region of 300-800 nm. The phytochemical screening of the sample was carried out as described in [25] and [26].

FTO conductive glasses coated with the TiO_2 semiconductor were sintered at about 400˚C for 45 minutes and used as the photoanodes. Each was sensitized by immersion in an ethanol solution of *Lonchocarpus cyanescens* dye extract at room temperature overnight [27] [28]. Thereafter, the TiO_2 film and substrates were rinsed with ethanol. The dye coated TiO_2 electrode laced with a meltonix foil (sealant) and Pt coated counter electrode were assembled into a sandwiched type cell. Sealing was done by keeping the structure under a hot press at 80˚C and the liquid electrolyte, iodolyte was injected through the small hole on the counter electrode. **Figure 2** shows the picture of a complete dye sensitized solar cell fabricated in the laboratory. Twenty-four cells were fabricated and connected in series using aluminium foil as connecting wires to build a solar module [22].

2.2. Characterization

2.3.1. Photovoltaic Performance of Dye Sensitized Solar Cell

The Photoelectrochemical measurements of DSSCs were performed under 1 sun illumination (1000W/m^2) [29], using the circuit below (**Figure 3**) The resistance in the circuit was varied with a potentiometer and varying output of current and voltage were obtained as response of the solar cell to direct sunlight using a multimeter [30] and J-V curves were obtained. Based on the J-V curve (**Figure 6**), the power conversion efficiency was calculated according to the equation:

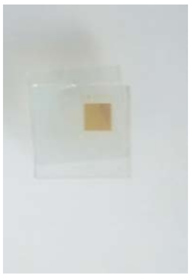

Figure 2. A complete dye-sensitized solar cell.

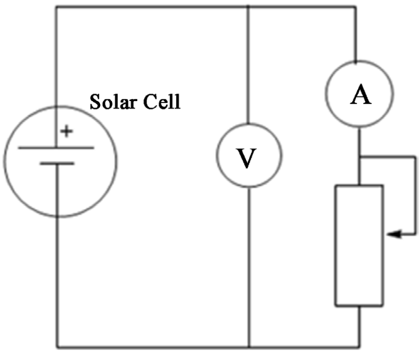

Figure 3. Circuit for the measurement of current and voltage of a DSSC.

$$\eta(\%) = \frac{J_{sc} \times V_{oc} \times FF}{P_{in}}$$

where J_{sc} is the short-circuit current, P_{in} is the intensity of the incident light (W/m^2), V_{oc} is the open circuit voltage (volts) and FF is the fill factor.

2.2.2. Electrical Performance of Solar Module

The electrical performance of the solar module was measured under a 100 Ω - 1000 Ω resistor load using the circuit below and based on these values (Table 3), the maximum power of the solar module was calculated according to the equation:

$$P = IV;$$

where P = power, V = voltage and I = current. The circuit for the measurement is shown below (Figure 4)

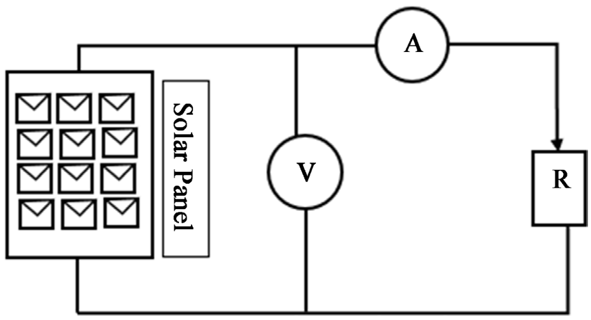

Figure 4. Circuit for the measurement of voltage and current of solar panel under a resistor load.

3. Results and Discussion

3.1. Light Absorption Capability of Extract of LC

The color of a molecule in solution or in solid phase is due to its ability to absorb light energy characterized by the maximum absorption wavelength (λmax) on raising the ground energy state to an excited state. In this study, the dye extract exhibited intense absorption bands in the visible region with peaks at 410 nm, 664 nm and minor multiplet bands at 500 nm, 542 nm and 604 nm (Figure 5), which show the presence of colour imparting chromophores in the dye extract. The peaks at 410 nm and 664 nm are due to the presence of chlorophyl-a.

3.2. Phytochemical Analysis

Phytochemical analysis of the crude ethanolic extract of *Lonchocarpus cyanescens* (Table 1), showed the presence of tannins, flavonoids, cardiac glycosides and combined anthraquinones. Tannins, flavonoid and anthraquinones have been reported as natural dyes [31]. The presence of these phytoconstituents reveals that extract from *Lonchocarpus cyanescens* exhibit dye properties.

3.3. Photovoltaic Performance of DSSC Using Extract of *L. cyanescens*

The J-V curve (Figure 6), obtained from the current-voltage characterization of

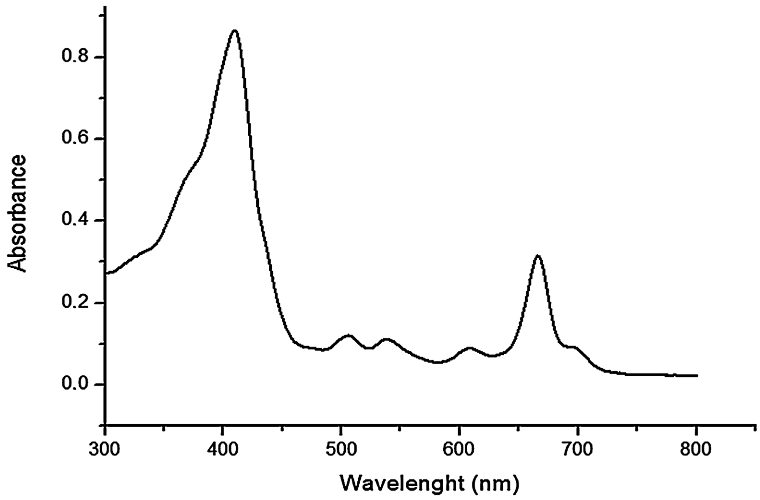

Figure 5. UV-Vis spectrum of dye extract of *Lonchocarpus cyanescens.*

Table 1. Result of Phytochemical screening of crude extract of *Lonchocarpus cyanescens.*

Class of Natural Product	Intensity
Tannins	+++
Phlobatannins	-
Flavonoids	+++
Alkaloids	-
Cardiac glycosides	+++
Combined Anthraquinones	+

Key: +++: High; ++: moderate; +: mild; -: Absent.

Table 2. Values of photovoltaic parameters.

J_{sc} (mA/m^2)	V_{oc} (V)	FF	η (%)
4.24	0.44	0.641	0.120

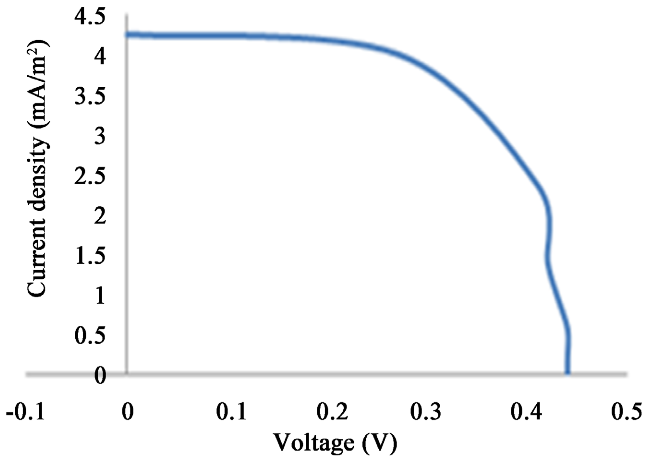

Figure 6. JV Curve of DSSC using crude extract of *Lonchocarpus cyanescens* as a photosensitizer.

the best performing cell is shown below and used to calculate current density, J_{sc} (A/m^2); open-circuit voltage, V_{oc} Fill factor, FF, and power conversion efficiency, η (%).

The power conversion efficiency of the solar cell sensitized with the crude extract of *L. cyanescens* was 0.12% with a fill factor of 0.641, short circuit current; J_{sc} of 4.24 (mA/m^2) and voltage; V_{oc} of 0.44 V. This result shows that the ethylacetate extract of *Lonchocarpus cyanescens* adsorbed onto the TiO_2 surface, acts as a good sensitizer and efficiently promotes electron transfer across the dye/semiconductor interface. **Figure 7** shows the proposed scheme for the attachment or binding of *Lonchocarpus cyanescens* (indigo), to the TiO_2 semiconductor photoelectrode. Indigo is the major pigment in LC [32]. The C=O electron withdrawing group and the NH electron accepting group on the dye provide means of attachment to the TiO_2 surface.

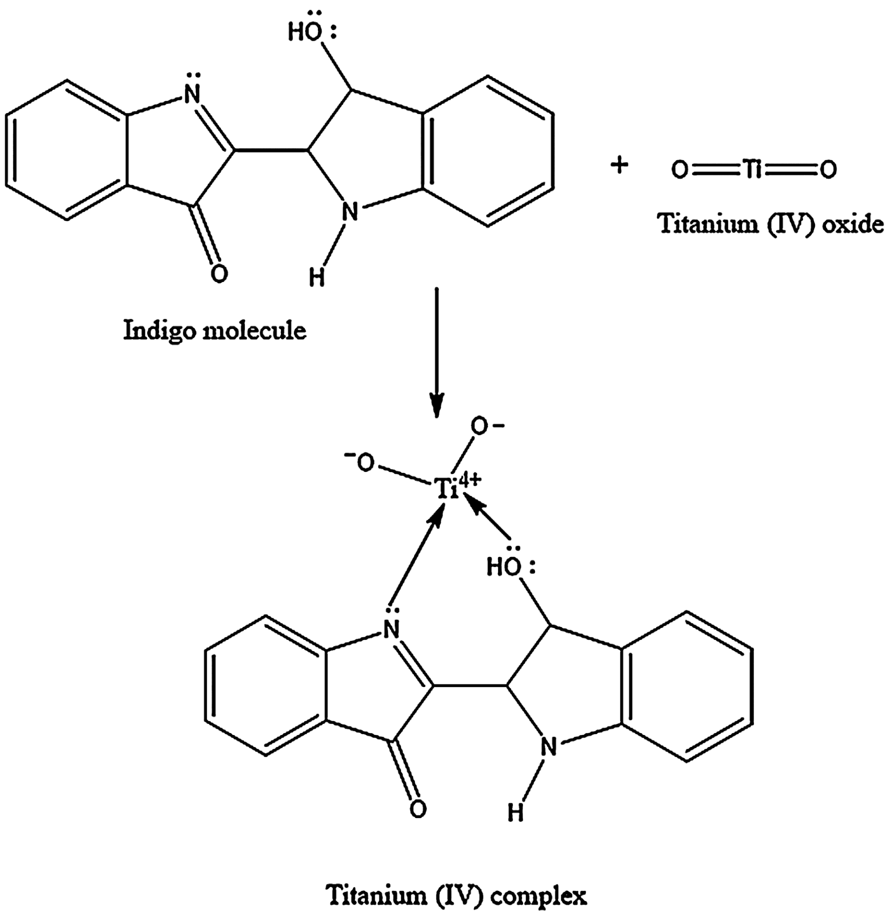

Figure 7. The coordination of indigo to Titanium (iv) oxide

The need for cheaper and environmental friendly alternative dye has spurred researchers into studies on natural dyes and it has been demonstrated that natural dyes can produce acceptable light conversion efficiency in comparison with synthetic dyes [33] [34] [35].

3.4. Electrical Performance of Dye-Sensitized Solar Module

The fabrication of solar module differs from that of single cells primarily due to the electrical connections among neighboring cells. The performance result obtained for the solar module built from the twenty-four cells connected in series under constant resistor loads of 100 - 1000 Ω is as shown in **Table 2**. It produced a maximum power of 0.1830 μW. The low output performance obtained in this study is associated with challenges in connecting the encasing glass of each cell. The new output voltage of the solar module increased as expected. The amount of current that flows through a set of photovoltaic cells in series is the same at all points in a series circuit [36]. However, the slight decrease in current observed was probably due to problem associated with sealing [37] and connection of the cells to make a module. The result (**Table 3**) reveals that the solar module operates to its maximum power point when connected to the 1000 resistor load.

Table 3. Performance of solar panel under a load of 100 ohms - 1000 ohms' resistor.

S/N	R (ohm)	V (10^{-1} V)	I (μA)
1	100	7.7	0.0257
2	200	15.1	0.0252
3	300	22.6	0.0251
4	400	29.8	0.0248
5	500	37.2	0.0248
6	600	44.5	0.0247
7	700	51.8	0.0247
8	800	59.1	0.0246
9	900	66.3	0.0246
10	1000	74.1	0.0247

4. Conclusion

This study has provided valuable information for the design of dye-sensitized solar cells and modules using *Lonchocarpus cyanescens* dye extract and the result obtained revealed that with intense devotion, the dye sensitized solar module will gradually penetrate the solar market. Natural dye obtained from crude extract of *Lonchocarpus cyanescens* gave effective conversion of visible light into electricity by sensitization of TiO_2. The plant extract appears to be a promising sensitizer in DSSCs because of its moderate energy conversion efficiency, simple preparation technique, environmental friendliness and low cost of production. However, there is a need for further improvement on this dye to make them more efficient as sensitizers.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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