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Original Article

Effect of Different Solvents on The Performance of Dye Sensitized Solar Cell (DSSC) Fabricated Using Beetroot Dye

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Abstract - *The Need for energy is increasing day by day worldwide. Conventional sources of energy are not sufficient to meet the global demand for the long future, and it is not environmentally friendly and cost-effective. Searching for renewable energy sources is expected to be the only solution for fulfilling the future energy demand in a green environment. Solar cells are the most promising renewable energy source. Different technologies are used to fabricate solar cells and to improve the cell performance. In this work, Dye-Sensitized Solar Cells (DSSCs) are fabricated using beetroot dye extracted with different organic solvents, viz., distilled water, acetone, ethanol and methanol. A thin film of Titanium dioxide (TiO_2) is coated over Fluorine-doped Tin Oxide (FTO) coated glass surface as a photoanode using the spin coating technique. The crystallinity of the TiO_2 has been studied using X-ray diffraction. UV-Visible Spectroscopy and Fourier Transform Infrared (FTIR) analysis have been carried out for beet root dyes with different solvents. The effects of different solvents on the performance of solar cells have been studied. Here, the highest value of solar cell efficiency is obtained, 0.0155% for an ethanol and methanol-based dye sensitized solar cell, which is found to be better than that of a distilled water-based device.*

Keywords - *DSSC, Beet root, Characterization, Efficiency, Extracted, Solvent.*

1. Introduction

Energy plays an important role in the economic development of a nation. Conventional energy sources, such as fossil fuels, are being reduced because of uncontrolled use, creating a negative environmental impact [1]. Scientific communities are in search of an alternative source of energy that may be renewable, environmentally friendly, low-cost, easy to harness, etc. There are many potential sources of renewable energy on the earth, viz, solar energy, wind energy, biofuel, etc. Solar energy may be the best renewable energy source because of its many advantages: low cost, environmentally friendly, easy to harness worldwide, etc. There are different solar cell technologies, out of which Dye Sanitized Solar Cells (DSSCs) are mostly used because of their easy fabrication technology [2-4].DSSCs are made of an anode such as TiO_2on which dye molecules are deposited as sensitizer, an electrolyte solution and a counter electrode [5]. When sunlight falls on the dye molecules, it excites the electrons of the valence band of the dye molecule and causes them to move to the conduction band of the dye as free electrons. These free electrons then go to the TiO_2 layers and then flow through the external circuit to the counter electrode. These electrons move to the electrolyte solution, and the dye molecules subsequently receive the electrons from the electrolyte and get revived [6-8]. The dye may be natural, artificial, or mixed. The artificial dye is costly and mostly made of inorganic substances. The natural dye has many advantages because of its low cost, nontoxic and ease of extraction, biodegradable, abundance, large light absorption coefficient and better electrical performance, etc. [9-10]. The efficiency of DSSC may depend on varying thickness of TiO_2, different pH value of electrolyte and extracting solvent, different properties of the counter electrode, etc. [11-14]. Because of these suitable properties, DSSC is gaining much interest amongst researchers globally. Natural dyes are environmentally friendly and easy to extract compared to commercial dyes. Here, it is proposed that DSSC be fabricated using natural dye extracted from beetroot, and its photovoltaic properties, viz. light absorption, fill factor, and cell efficiency, are studied. In this work, natural dyes are extracted with four solvents, mainly distilled water, acetone, ethanol and methanol. With these four solvents having different functional groups, the light absorption level of the dye is expected to change, and thereby, the efficiency of the cell may change. Until now, there have been a few major challenges with existing solar cell technology, such as efficiency limitation, high manufacturing cost and durability. Thus, keeping all these things in view in this paper, we present a simple approach for solar cell fabrication along with better performance and stability. To the best of the authors' knowledge, DSSCs prepared by TiO2 and containing natural with different solvents through this procedure have not been reported yet.

In this work, we aim to produce a high-performance solar cell with optoelectronic properties using a natural sensitizer, namely, beetroots, to prepare a low-cost DSSC. Another important study where the photo voltage and current variation with different light intensities is also done using a special arrangement. The question linked with this research is the effectiveness and stability of beetroot dye under normal room temperature conditions and optimal performance in the standard configuration. The main key objectives of this present study are: (i) Fabrication and characterization of dye sensitized organic solar cells using natural dyes. (ii) Dyes are extracted with different solvents having different functional groups. (iii) Observe the device's photo voltage and current during the working hrs. (iii) To calculate the solar cell device's useful parameters, such as fill factor and output efficiency, etc..

The novelty of this study lies in the effective utilization of solar energy for electricity generation using solar cells fabricated with natural dye extracted using different solvents having different functional groups. How does the solvent functional group affect the efficiencies of solar cells? That may give a new idea about an organic solar cell. Also, the effect of light intensity on cell efficiency is studied, where solvents with different functional groups are used. This is also expected to be a fresh and innovative approach by employing Beetroot dye in dye-sensitized organic solar cells. The developed solar cell demonstrates the ability to generate electricity even under low-light conditions. Although the initial output was modest, the findings are notable due to the distinctiveness of the study

2. Materials and Methods

2.1. Materials

Materials are the important components of any device fabrication process; for this study, materials are generally purchased and arranged locally. Beetroots are collected from the local market. The ethical source of beet roots may be certified agricultural firms where the product is tested for its optimal natural values. FTO (Fluorine-Doped Tin Oxide) coated glass substrates, Titanium Dioxide (TiO_2) powder (0.13nm particle size), nitric acid (HNO_3), distilled water, acetone, ethanol, methanol, ethylene glycol, iodine crystal, and potassium iodide are purchased from Merck chemicals with analytical grade purity. Carbons (Graphite), beetroot for organic dyes, are arranged locally. The good quality measuring devices, viz., solar cell apparatus (specially designed, shown in Figure 5 (b)), digital balance, multimeter (Mastech-MS8264) and lux meter (HTC^{TM} Instrument-Model-LX-101A) are purchased from the local market.

2.2. Preparation of TiO_2 Based Photo Electrode (Photo-Anode)

Here, we consider an FTO-coated glass sheet as a substrate with a sheet resistance of 15 Ohm/sq, 2.2mm thickness, and a 5x5 cm2 area. The FTO-coated glass is cleaned initially with detergent, which is rinsed with sufficient distilled water, then cleaned in an ultrasonic bath of isopropanol for 15 min and dried for some time at almost 70 ^{0}C.

Then it is fixed with paper tape for spin-coating. TiO_2 paste is prepared by mixing 0.1 g of TiO_2 powder with 25 drops of dilute nitric acid (5N) and keeping stirring until a smooth creamy paste is formed [15, 16]. After that, titanium dioxide paste (TiO_2) is spin-coated (~1000 rpm for 60 seconds at room temperature, ~27 ^{0}C) over FTO-coated glass as shown in Figure 1(a) and (b). Then, it is air-dried for 24 hours, and after that, it is heated to almost 100 0C for some time to remove the water content. The thickness of the film is approximately 0.15mm.

(a)

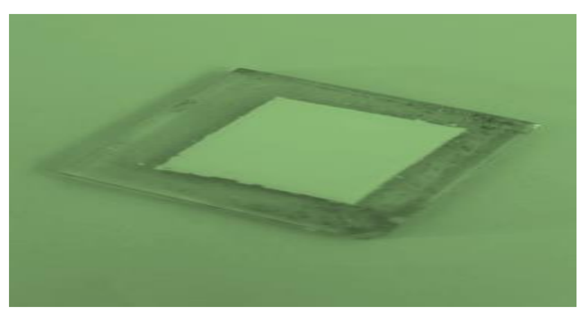


Fig. 1(a) FTO coated glass fixed with paper tape, and (b) Thin film of TiO_2 on FTO-coated glass after spin coating.

2.3 Preparation of Photosensitizer or Dye and Loading on the Photoanode

Photosensitizes are agents that absorb light of a specific wavelength and transform it into useful energy. Beetroot is extracted using different solvents: distilled water, acetone, ethanol and methanol. Since these solvents have the ability to dissolve organic dye into them effectively and extract more and more dye molecules from the organic dye source.

If more dye molecules are present as absorbers in the cell, the performance of the device is expected to be better. Because of the different properties of common solvents, such as polarity, dissolving power, volatility, miscibility, nontoxicity, low odour, chemical stability, etc., solvents are selected for dye extraction. For these individual properties of solvents, some solvents can dissolve more dye molecules from the source compound, showing suitable candidates for solar cell fabrication compared to others.

About 15g of Beta Vulgaris (beetroot), peels are rinsed with distilled water and subsequently are cut into small pieces, grinded before dissolving into distilled water, acetone, ethanol or methanol(50:50 ratio of dye and solvents), etc. And extracted solutions are denoted as 2(A) to 2(D), respectively. The solutions are kept stirring and heating for 45 minutes at room temperature. Later, the dye solutions were stored overnight at 4°C under dark conditions before being filtered and centrifuged [17, 18].

The final solution is kept overnight before further use. Photographic representation is shown below. The FTO-coated glass with a TiO2 layer is immersed in one of the dye solutions (say, beetroot with distilled water) and kept there overnight to absorb the maximum amount of dye on the TiO2 layer. After that, it is removed from the dye solution and dried at room temperature for at least 24 hours.

It is repeated for all three remaining solutions. Finally, four sets of samples, beet root with distilled water over TiO2, beet root with acetone over TiO2, beet root with ethanol over TiO2 and beet root with methanol over TiO2are ready for the fabrication of DSSC.

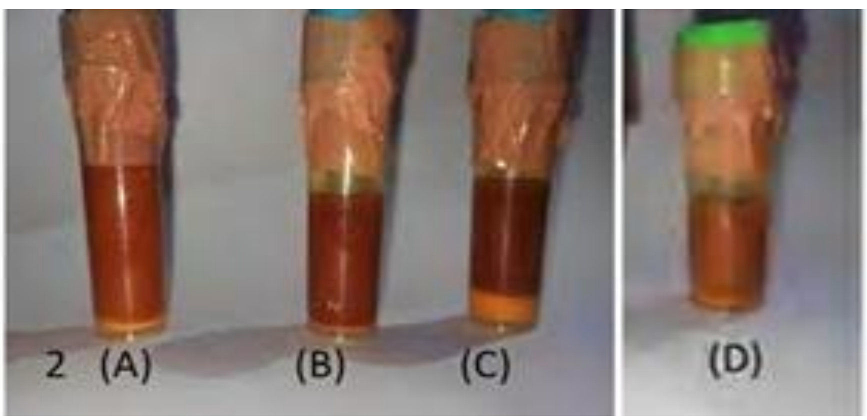


Fig. 2(a) Beetroot with distilled water, (b) Beetroot with acetone, (c) Beetroot with ethanol, and (d) Beetroot with methanol.

2.4. Preparation of Electrolyte

The electrolyte solution is mainly responsible for dye regeneration and charge carrier transportation during the working operation of DSSC. In the operation of DSSC, liquid electrolytes play an important role in device configuration.

There are three main components in liquid electrolytes: a solvent, an ionic conductor (i.e., a redox), and a necessary additive. These electrolytes must possess some peculiar properties for successful device fabrication and characterization. Like chemical and photochemical stability, a high dielectric constant allows solubilization of the electrolytic salts and low viscosity to promote high diffusion coefficients of the redox mediators. Here, 127 mg of iodine crystal and 830 mg of potassium iodide are dissolved in 10 ml of ethylene glycol and mixed thoroughly with the help of a magnetic stirrer [19, 20]. The final product of the electrolyte is shown in Figure 3.

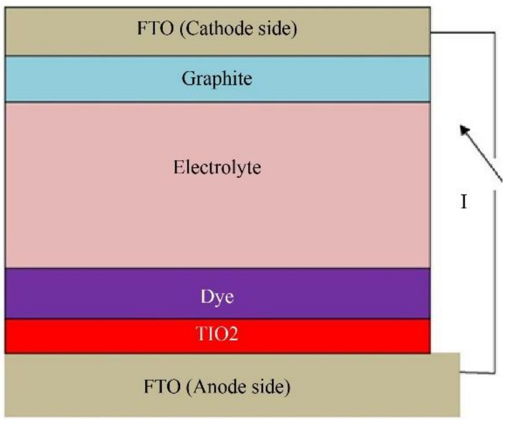
2.5 Preparation of Counter Electrode (Cathode)

In solar cell operation, the main function of the cathode is to make available electrons from the external circuit in the form of the redox couple. In general, the counter electrode or cathode layer is composed of an FTO sheet to provide mechanical support for the graphite material.

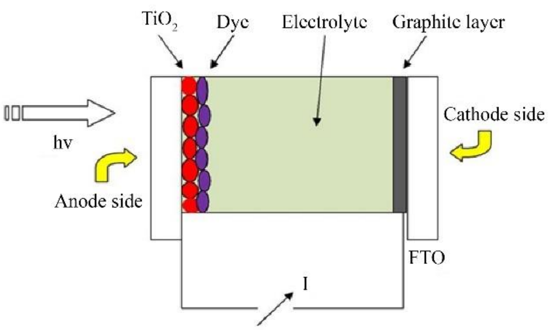
This catalytic layer is necessary to obtain fast kinetics for the reduction of the redox couple. Therefore, in this work, a graphite layer is used over an FTO sheet to make the counter electrode for the operation of a solar cell.

A 10B graphite pencil is used to darken the conductive surface of the FTO sheet in such a way that no gap is left in the graphite coating. Schematic representation and the operation of DSSC are shown in Figure 4(a) and Figure 4(b), respectively.

Fig. 3. Electrolyte solution prepared under laboratory conditions



(a)



(b)

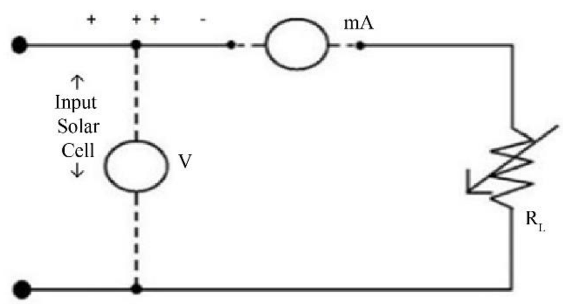
Fig. 4(a) Schematic representation of DSSC, and (b) Schematic operation of DSSC.

2.6. Fabrication of DSSC

As discussed above, the prepared electrode and counter electrode (i.e., anode and cathode) are combined with the help of the titanium dioxide coating surface and the graphite coating surface, which face each other. Next, the electrolyte solution is used dropwise in the contact region of two glasses, and because of the capillary action, the electrolyte uniformly spreads throughout the stained TiO_2 film. Cotton or tissue paper may be used to wipe off the excess electrolytic solution from the exposed area. The complete cell is then taken to sunlight for illumination. Figure 5) indicates the assembly of the solar cell, cell apparatus and circuit diagram for studying the J-V characteristics of the fabricated solar cell. In our work, the testing temperature is 27^0. In another study, the voltage and current are recorded with a change in light intensity. The light intensity on the photo cell was changed manually with some translucent papers, and the resistance was kept constant at 100Ω at that time.

(a)

(b)



(c)

Fig. 5(a) Assembling of DSSC, and (b) Solar cell apparatus, (c) Basic solar cell circuit diagram.

3. Result and Discussion

3.1. Characterisation of Materials

3.1.1. XRD of TiO_2

To study the structural pattern of the TiO_2, an XRD spectrum is taken using an XRD machine with model-PANalitical, Empyrean in SAIF, USIC, Gauhati University, India, as shown in Figure 6. It is observed that the strongest diffraction peak of the (101) plane is seen at $2\theta = 24.643°$. This is followed by some other strong peaks of (004), (200), (105), (211), (204) planes at $2\theta = 36.757°, 46.734°, 52.360°, 53.536°$ and $60.884°$ respectively as shown in the diffraction graph.. The peaks at $2\theta=24.643°$ and at around $46.734°$ indicate TiO_2 in the anatase phase [21-25].

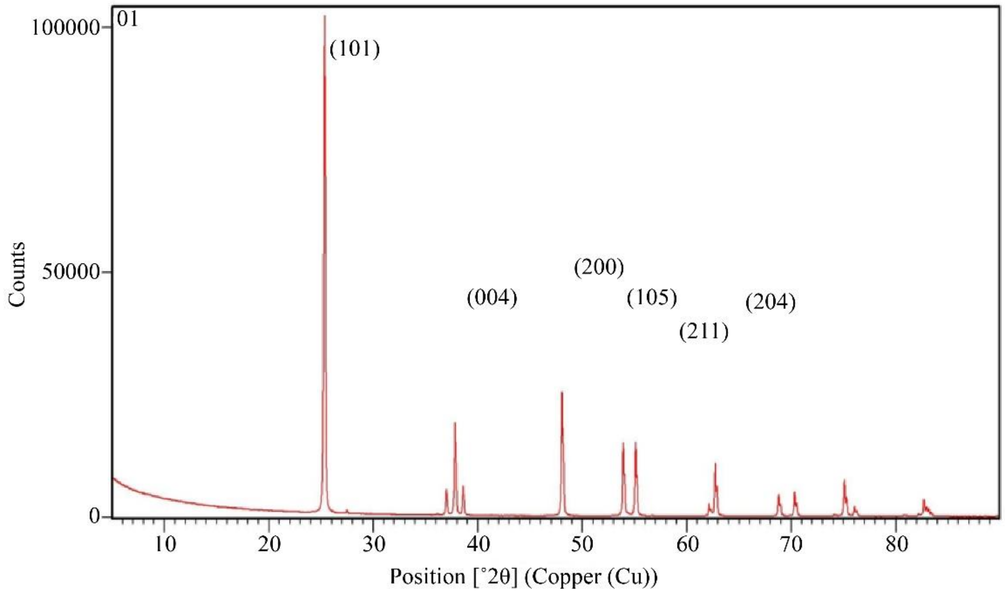


Fig. 6. XRD pattern of a thin TiO_2 film

3.1.2. UV-Vis Spectroscopic Analysis of Beetroot Dyes Extracted with Different Solvents

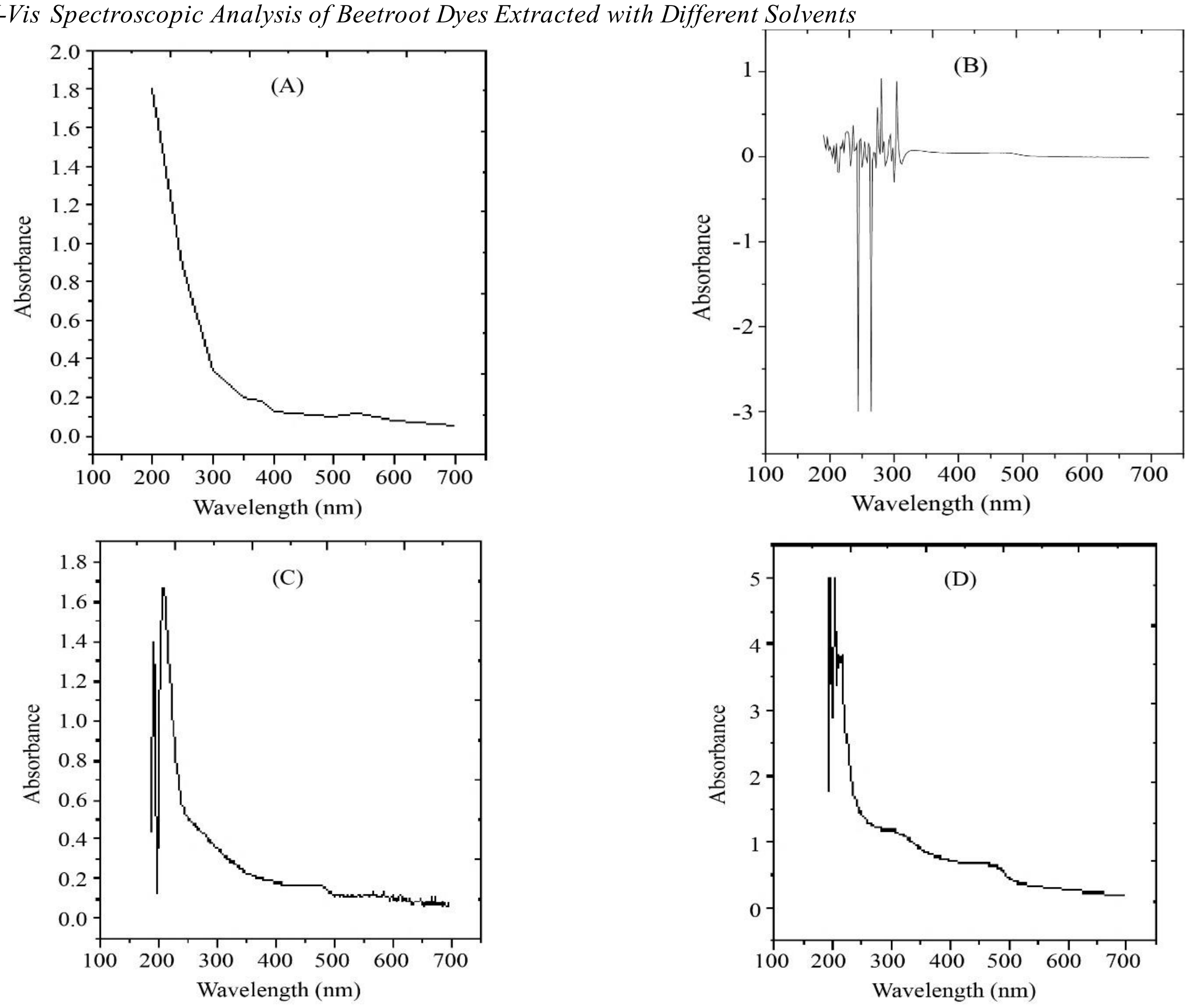


Fig. 7 UV-Vis absorption spectra of beetroot dyes extracted in different solvents (a) Distilled water, (b) Acetone, (c) Ethanol, and (d) Methanc

Figure 7 shows the absorption spectra for beetroot dyes extracted in different solvents, taken at Tezpur University, India, using the UV-Vis spectrometer with make-SHIMADZU and model-UV-2600i. It is clear that the maximum absorption peaks for distilled water are at 270.00nm and band-gap energy is 4.59eV; similarly, the maximum absorption peaks for the based dye are at 503 nm and 538 nm. Corresponding band-gap energies are 2.46eV and 2.30eV, respectively. Meanwhile, the maximum absorption peaks for ethanol and methanol are at 476nm and 589nm and 310nm and 478nm, respectively. Corresponding band-gap energies are 2.60eV, 2.10eV, 3.99eV and 2.59eV, respectively. Thus, with the help of these UV-Vis absorption spectra, it is possible to find out the energy band gap of the dye and hence the conductivity of the material, which directly affects the device performance. In this work, the band gap energies of the dyes are calculated using the same procedure reported by Kulkarni et al. and others [26-30]. A detailed study and analysis of band gap energies of beetroot dyes extracted with different solvents is shown in the following Table 1.

Table 1. Absorption wavelength peak and band gap energies

Dye	Solvent	Absorption Wavelength Peaks (nm)	Band Gap Energy (eV)
Beetroot	Distilled Water	540.00	2.30
	Acetone	503.26	2.46
		538.59	2.30
	Ethanol	476.60	2.60
		589.83	2.10
	Methanol	310.52	3.99
		478.88	2.59

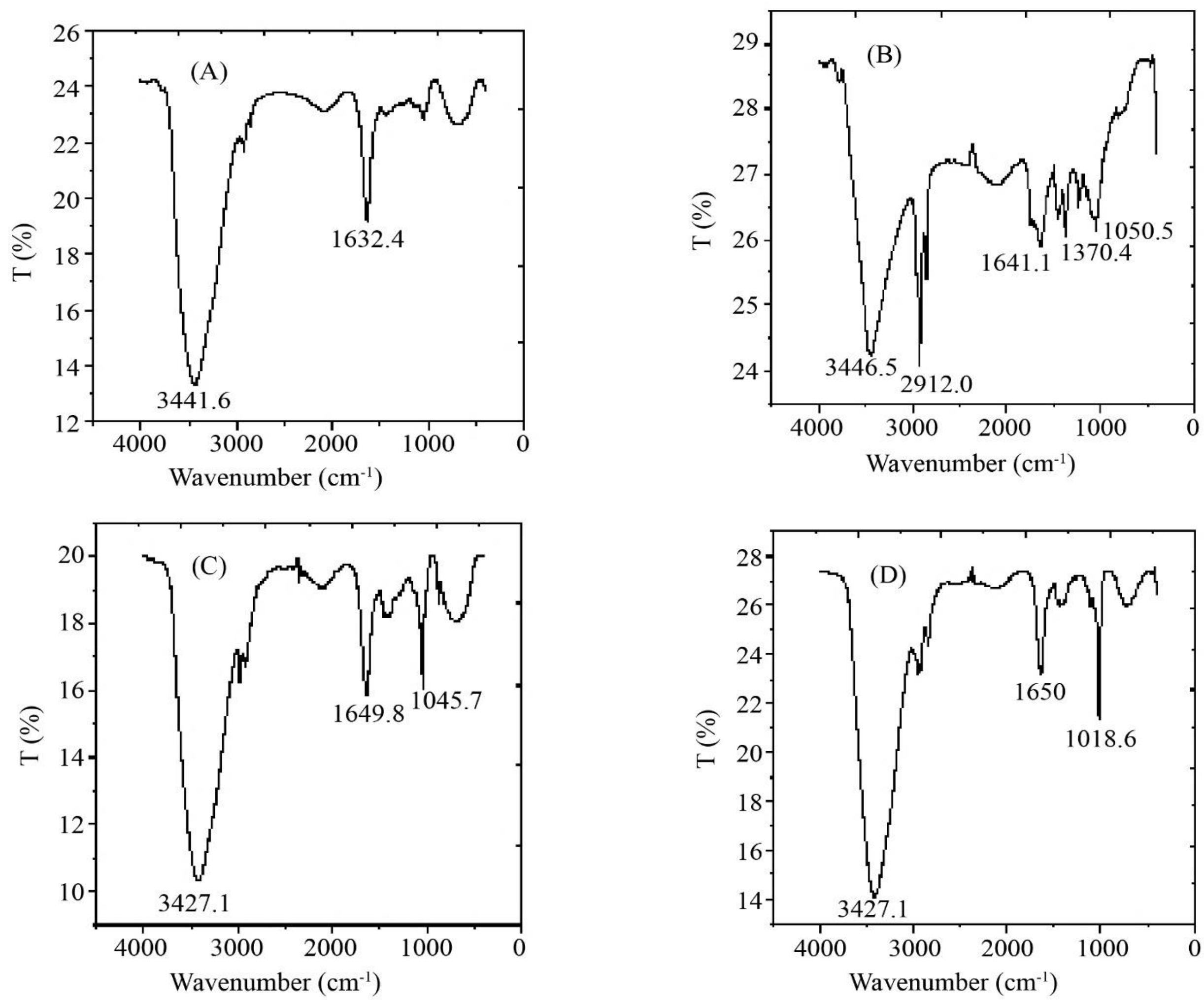


Fig. 8 FTIR spectra of beetroot dye extracted in (a) Distilled water, (b) Acetone, (c) Ethanol, and (d) Methanol.

3.1.3 Fourier Transform Infrared (FTIR) Spectra Analysis

Fourier transform analysis techniques are used to find out the functional group present in the dye molecules extracted with different solvents. It is done in SAIC, Tezpur University, India, with the instrument make-Perkin Elmer and model SPECTRUM 100 and FORNTIER IR.

The presence of functional groups like (–COOH), (–OH) and (C=O) shows better conductivity of the cell and results in better cell performance [31-33]. Figure 8 shows the graph of FTIR spectra and The presence of peaks corresponding to the respective functional group of each solvent is mentioned below. Peaks at 1642.1 cm^{-1}, 3427.1 cm^{-1} and 3427.1 cm^{-1} for organic solvents showed the presence of (–OH) and (C=O) groups. The presence of such types of functional groups in the dye solutions with different solvents improves the adsorption ability of dye on TiO_2 and therefore facilitates easy charge transfer [34-36].

3.2. DSSC Parameters

3.2.1. Formulae Used

The DSSC parameters like fill factor (FF) and conversion efficiency (η) are calculated using the following formulae :

$$FF = \frac{I_{max}}{I_{sc}} \times \frac{V_{max}}{V_{oc}} \quad (1)$$

$$\eta = \frac{I_{sc} \times V_{oc} \times FF}{P_{in}} \times 100\% \quad (2)$$

Where I_{max} and V_{max} are the maximum current and maximum voltage, respectively, at the maximum power point (P_{max}). I_{sc} and V_{oc} are the short-circuit current and open-circuit voltage, respectively, in (1).In (2), P_{in} is the power of incident solar light [37-39]. Solar light is measured in lux and later converted into power (W/m^2) using the following relation (3).

$$P = Lux \times 0.0081 \quad (3)$$

To calculate the current density, the output current is to be divided by the area of the TiO_2 layer on the DSSC [40, 41]. In this study, the area is 1.44cm^2, and all the output currents (I) are divided by this area, and current densities (J) are represented as follows.

$$J = \frac{I}{1.44} \, mA/cm^2 \quad (4)$$

3.2.2. J-V and P-V Characteristics of DSSCs

In this study, four solar cell devices have been fabricated, viz., device 1, where beetroot dye is extracted using distilled water, device 2, where beetroot dye is extracted using acetone, device 3, where beetroot dye is extracted using ethanol, and device 4, where beetroot dye is extracted using methanol. J-V characteristics are drawn for all the devices as shown in Figure 9. P-V characteristics are also drawn from these values, and J_{max} and V_{max} are evaluated then using these data. Then, field factors and efficiencies are calculated using relations (1) and (2), respectively. It is found that the performance of a beetroot dye-based solar cell using organic solvents is better than that of a distilled water-based device, and it is concluded that DSSCs using organic solvents may be a promising alternative to conventional silicon solar cell devices. Table 2 shows the photovoltaic properties of all the solar cells in our work.

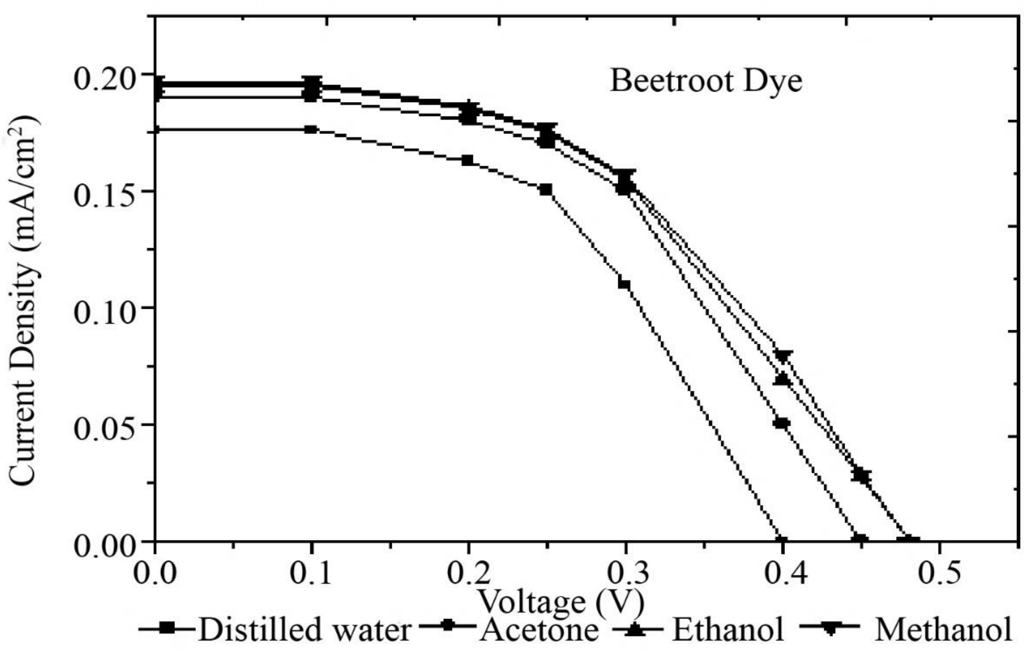


Fig. 9 Current density-voltage curves of the DSSCs

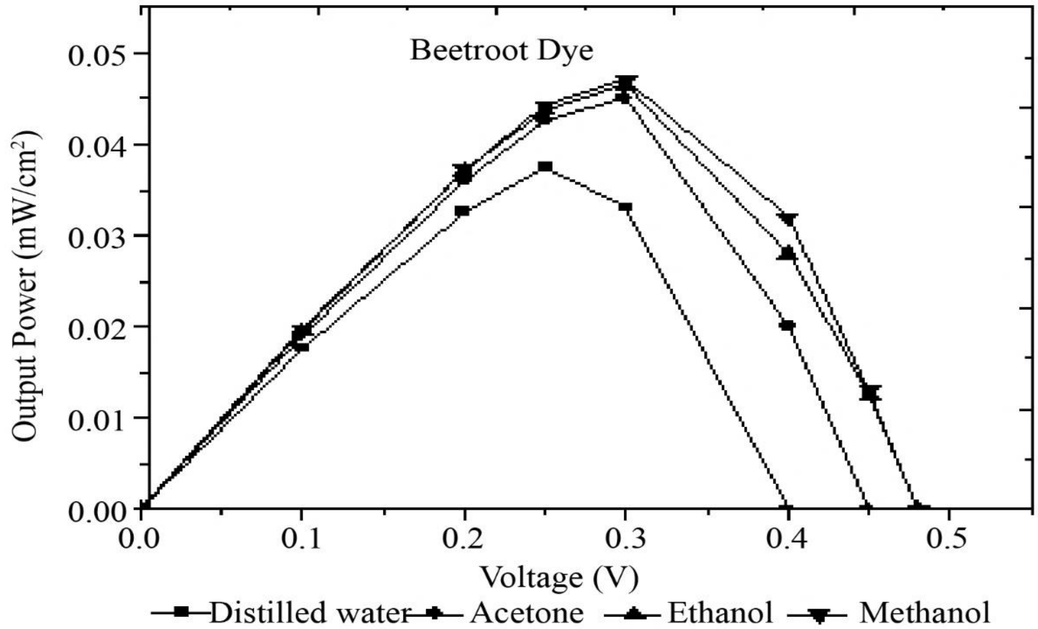


Fig. 10 Output power-voltage curves of DSSCs

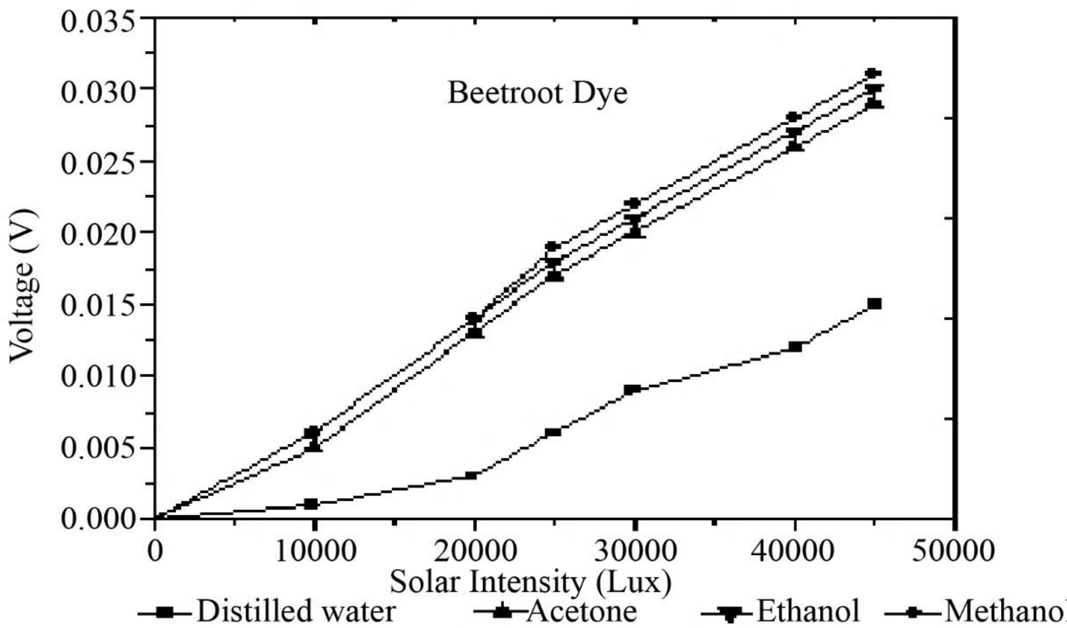


Fig. 11 Output voltage-solar intensity curves of the DSSCs

3.2.3. Comparison of Efficiencies of the Devices

Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. It is the most commonly used parameter to compare the performance of one solar cell with respect to another [42]. In this work, we noticed that the efficiency of the solar cell for acetone, ethanol, and methanol-based devices is greater than that of the distilled water-based device. Solar cell performance may be enhanced using an organic solvent during natural dye extraction. Table 2 shows the summary of device performance, and Table 3 shows the statistical analysis for efficiency results for all the fabricated solar cell devices in our laboratory conditions. Here, we have investigated and concluded that the performance of the organic solvent-based solar cell devices is enhanced with respect to the distilled water-based device.

This is because organic solvents provide a better morphological surface and dissolving property in the active layer of the solar cell, which improves the charge transport property and finally increases the device's performance. In contrast, the presence of water can negatively impact performance by causing charge accumulation and altering the intended morphology. It is also noted that methanol- and ethanol-based devices are better than acetone-based devices. This is due to the special properties of alcohol agents like ethanol and methanol.

They can promote a more even ion distribution, enhance wetting behaviour, and promote optical and photoactive properties. Our study clearly shows that a methanol-based device performs at the highest level. This is because methanol can penetrate the active layer more effectively than the other alcohols.

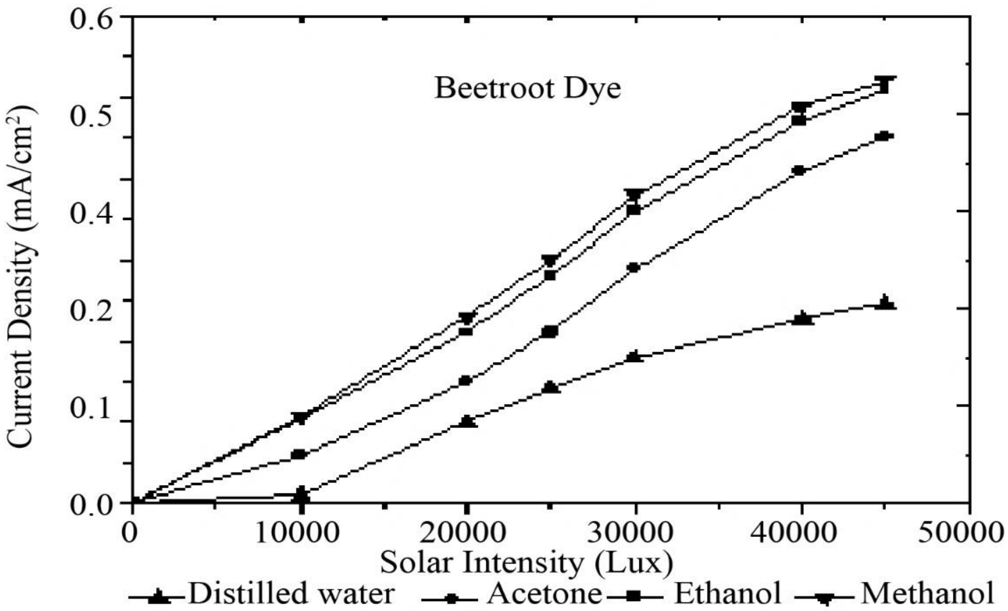


Fig. 12 Output current density-Solar Intensity Curves of the DSSCs

Table 2. Summary of the performance of all the solar cell devices

Name of solvents	V_{OC}(V)	J_{SC}(mA)	V_{max}(V)	J_{max}(mA)	FF(Fill Factor)	P_{in} (lux)	(Efficiency)%
Distilled Water	0.461	0.18	0.25	0.26	0.4460	37000	0.0125
Acetone	0.475	0.20	0.30	0.45	0.4736	37000	0.0150
Ethanol	0.475	0.20	0.30	0.51	0.4894	37000	0.0155
Methanol	0.475	0.20	0.30	0.52	0.4900	37000	0.0157

Table 3. Statistical analysis for efficiency results for all the fabricated solar cell devices

Name of Solvents	Mean Value of Efficiency	Variance of Efficiency	Standard Deviation of Efficiency
Distilled Water	0.02011	0.00023	0.0154
Acetone	0.02321	0.00032	0.0173
Ethanol	0.02341	0.00029	0.0172
Methanol	0.02416	0.00030	0.0175

3.2.4. Light Intensity Dependency of DSSCs

The output intensity of DSSCs is highly dependent upon the redox potential of the electrolyte solution between the two electrodes [43-45]. Here, the variation of output voltage and output current with solar light intensity is studied. Figures 11 and 12 show that both output voltage and output current increase linearly with light intensity. These may be due to more charge generation from the dye molecule. As intensity increases, photons will strike the dye surface and produce more charge carriers. More voltage and current are recorded for the devices where beetroot dye is extracted with organic solvents, viz., methanol, ethanol and acetone having functional groups like (–COOH), (–OH) and (C=O), showing better conductivity, concluding that output voltage and output current are functions of incident light intensity.

4. Conclusion and Future Scope

The performance of DSSCs based on titanium dioxide working electrodes has been compared using the spin coating method over an FTO glass substrate. The amount of TiO_2 powder and solvents has been optimized to prepare a thin film. The dye extracted with different solvents shows better characteristics for photo sensitizer use, resulting in better performance for solar cell characterization. Here, the photovoltaic performances of the different DSSCs fabricated with beetroot dyes with different organic solvents are studied, and DSSCs fabricated with organic solvents show better efficiency (0.0155%) compared with the distilled water-based devices. The functional group of the extracted solvent has clearly impacted cell performance. The selection of the solvent and its functional group should be such that it can enhance the number of charge carriers within the cell. In conclusion, it may be a good competitor for future silicon-based inorganic solar cell devices. There may be several scopes for improving the cell performances and for continuation of this research. Changing the composition of the TiO2 materials, e.g., adding nanoparticles and light scattering layers to it, may change the efficiency of the cells. The effect of the thickness of the TiO_2 layer on cell efficiencies may be a future scope for study. pH values of the extracted solvent may have some influence on the cell efficiencies. Beetroot and its one or several co-absorbers may show improvement of cell efficiency.

Combining DSSC with any inorganic solar cell and a tandem structure of DSSC may be an important topic for future study. Future studies may also be conducted by changing the electrolyte solution, counter electrode materials, etc. There may be a good combination of inorganic and organic dyes, which may enhance the cell performance and may be an important area for future research.

Acknowledgments

We acknowledge that the J B State University authority and Joya Gogoi College authority for supporting us in all respects during this research work.

Abbreviations

DSSCs: Dye sensitized solar cells, FTO: Fluorine-doped tin oxide, TiO_2: Titanium dioxide, J-V characteristics: Current density versus voltage characteristics, XRD : X-ray diffraction, FTIR spectra : Fourier transform infrared spectra.

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