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Fabrication of Thin Film Solar Cell Sensitized by Dye: Making Affordable Via Natural Dye Extracted from *Chenopodium album* (Bathua)

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ABSTRACT

Dye-sensitized solar cell is an application of solar cell technology based on electrochemical principles. In these cells TiO_2 photoelectrode layer absorbs the sensitive dye. The present study investigated the mechanism of this eco-friendly solar cell's fabrication sensitized by a natural dye *Chenopodium album*. The pigment, chlorophyll, was isolated from *Chenopodium album* (Bathua) and subjected to FTIR, UV-Visible spectroscopy, and FESEM analysis. The solar cell's current-voltage (I-V) properties were tested using three different solvents: ethanol, dimethyl sulphoxide (DMSO) and isopropanol. The energy conversion efficiency η of the fabricated DSSC with three solvents were found 1.37%, 1.07%, and 1.44%, respectively.

Keywords: DSSC, Photo-sensitizer, Nanocrystalline TiO_2, Energy conversion efficiency, Fill factor.

INTRODUCTION

The need for the development of renewable energy sources is great due to the world's ongoing increase in energy consumption. The biggest problem facing our global society is figuring out how to prevent the harmful impacts of the current energy system on the environment, public health, and climate while also finding ways to replace the slowly but surely running out supplies of fossil fuels with renewable resources. Environmental and energy-related issues will be the main concerns in the next fifty years[1]. Solar energy is a great option for a future green energy source because it produces clean, plentiful electricity. In order to create a sustainable energy source that is affordable, solar cell research aims to boost solar energy conversion efficiency at a cheap cost. A solar energy's annual output is 3.8 million EJ/year. Solar cells come in a variety of forms, currently, inorganic silicon semiconductors serve as the foundation for commercially available solar cells. In future silicon will become much more in demand and more expensive. Thin films solar cells are shown more advantageous than conventional silicon-based solar modules in terms of weight, flexibility, and cost per module, making them a superior option for the PV energy industry[2,3]. Among four primary generations of PV cells[4], thin-film solar cell or DSSC, also known as third-generation solar cells, is one of the most exciting alternatives for solar panels made from silicon due to its energy conversion efficiency, quick production and price[5,6]. It is the newest low cost energy conversion devices with straightforward manufacturing processes.

Dye sensitized solar cells invented by O'Regan and Grätzel in 1991 represent a remarkable advancement in solar cell technology today. The DSSC efficiency was a pitiful 6.4% in 1991, but by 1997, it had risen dramatically to 11.1%.The efficiency rise from 12.3% in 2019 to 13.0% in 2020 is the biggest[7]. When it comes to producing energy from sunshine, DSSCs are comparatively efficient. They are excellent for a variety of applications, such as portable devices, outdoor lighting, and low-light areas[8,9], since they can function in a wide range of lighting circumstances[10]. The photocathode electrode, the nanocrystalline porous wide band gap semiconductor electrode, and the electrolyte containing oxidoreductive ions make up the DSSC. The dye employed as the sensitizer has a major impact on how well DSSCs work. Every part of the DSSC contributes to the solar cell's photocurrent efficiency, and a well-designed DSSC always optimizes and balances various parts. The preference of photo-anode material and structure is the most crucial and significant aspect of the DSSC as it determines the I-V characteristics, such as the open-circuit voltage (V_{oc}), photo-generated current density (J_{sc}), dye pickup, light absorption properties, and cell fill factor (FF).

The operation of the DSSC is depicted in the Fig. 1[11]. DSSC uses the idea of photosynthesis to function. It is a photo electrochemical cell, which means that light is used to produce solar energy. The influx of electrons into the FTO electrode covered with titanium dioxide can be stimulated by light as it travels through the transparent electrode and into the dye layer[12]. To power a load, the electrons travel toward and accumulate at the counter electrode. Once they pass through the external circuit, they are poured into the electrolyte and reintroduced into the cell onto a metal electrode at the back. The electrons are subsequently returned to the dye molecules by the electrolyte[13]

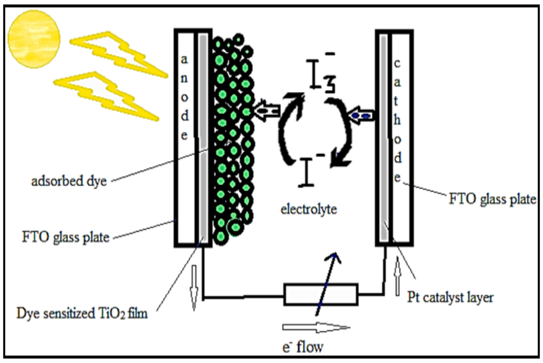


Fig. 1. Working principle of DSSC[11]

Naturally occurring dyes that are inexpensive and widely available are favored as sensitizers due to the unfavorable ecological consequences of Ru compounds[14-16]. A schematic depiction of the several dyes used in the past for the fabrication of DSSC is represented by Sekaran and Marimuthu[17]. Akila *et al.,*[18] describe the classification of main plant pigments in their research work using the many color schemes and pigments found in fruits, flowers, leaves, and microorganisms presents an interesting path in the field of DSSCs. Many benefits come with extracting and using these natural compounds, such as strong absorption coefficients in the visible spectrum, widespread availability, simple synthesis processes, and ecological compatibility[19]. The pigment color of a natural plant varies depending on its section. Furthermore, compared to ruthenium compounds, the process of collecting natural dyes and optimizing extraction techniques is less complex, meaning that the adverse effects on the environment can be minimized[20]. Absorption in the visible region range of 400–700 nm is a characteristic of natural sensitizers[21,22]. Natural dyes come in a broad range of colors, from pale yellow to deep brown. These materials are frequently employed in educational settings to assess the kinds of dyes that are best suited for sensitization. The most studied of them include flavonoids, carotenoids, anthocyanins, and chlorophyll[23]. Since chlorophyll is essential to plant photosynthesis, the DSSCs that used derivatives of chlorophyll as sensitizers achieved comparatively high conversion efficiency[24,25]. This is due to the fact that interactions between activated dye molecules and TiO_2 molecules allow electrons to go from the dye molecules to the TiO_2 layer. This finding suggests that improving the η of DSSCs requires careful consideration of the way the TiO_2 coating and sensitizer interplay[26-28].

This work describes the fabrication of DSSC using naturally available pigment. The working electrode used in the DSSC construction process was sensitized with a natural dye that was separated from *Chenopodium album*. FESEM, UV–Vis, and FTIR spectroscopic analysis were used to examine the photovoitaic properties of the fabricated cells. Additionally, I–V characteristics examination is carried out for all prepared cell assembly.

MATERIALS AND METHODS

Materials

FTO conducting glass (Aldrich, sheet resistance 13 Ω/sq), nanocrystalline titanium di-oxide (TiO_2) powder (Sigma Aldrich), Triton X-100, glacial acetic acid, absolute ethanol, Isopropanol, PEG (M.W 10,000), HCl (ASES chemicals), HNO_3 (Sigma Aldrich), liquid electrolyte (potassium Iodide and Iodine), Chloroplatinic acid (Aldrich) and Dimethyl sulfoxide were utilized in present work for fabrication of natural dye sensitized solar cells.

Measurements

FT-IR spectroscopy (BRUKER ALPHA II COMPACT Spectrometer) was used to do the chemical characterization. FESEM (ZIESS Sigma) was employed to determine the surface property of TiO_2. A UV-vis spectroscopy (Perkin Elmer Lambda 35) was used to record absorption spectra of the dye in three different solvents. I-V curves of DSSCs were obtained using a digital multimeter this device gives the reading of Current (I) and Voltage (V) in various units.

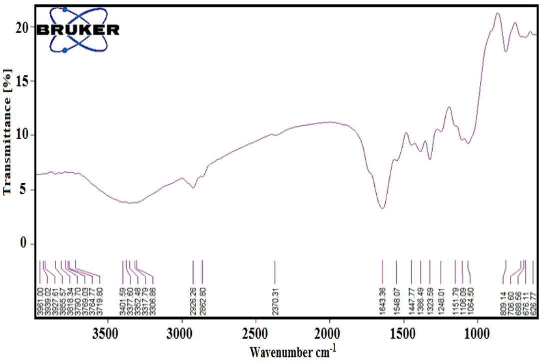
Method

Tin oxide (FTO) doped with fluorine glass was utilised. The conductive glass substrate was cleaned using 10% ethanol in an ultrasonicator, dry at room temperature and then covered with a layer of nanostructure TiO_2 paste using a doctor blade approach to create the functional electrode. For the preparation of TiO_2 Paste nanocrystalline TiO_2 was stirred with glacial acetic acid (1:1 ratio) for 1 hour. To maintain acidic nature of paste add few drops of HCl/HNO_3, triton X-100 and 1 mL of ethanol and stir using magnetic stirrer for 24 hours. After stirring this working electrode was heated to 500°C for 30 minutes. The working electrode was submerged in dye solution for 48 h at room temperature after being allowed to cool to 40°C. The clear conductive oxide glass was coated with chloroplatinic acid and propanol (1:4 ratio), which was subsequently heated to 350°C to create the counter electrode. To create the electrolytic solution, 0.05 M I2 solution, 0.5 M KI solution, and polyethylene glycol were utilized. Thirty minutes of ultrasonication were required to prepare a homogenous solution of the mixture of these three. DSSC was fabricated using dye-stained TiO_2 photo anodes which were placed on platinum counter electrodes, facing each other, and then attached together using binder clips. By using capillary action, a few drops of electrolyte solution were applied to the plate borders and allowed to spread between them and clear the extra electrolyte using tissue paper at the margins of prepared setup.

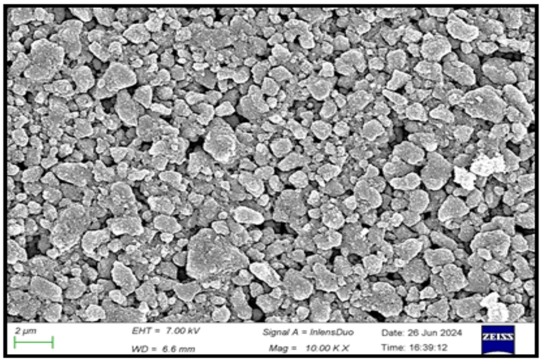
RESULTS AND DISCUSSION

FT-IR spectroscopy method was used to do the chemical characterization. The lines in the FT-IR spectra displayed in the Fig. 2(a) at wave number 1643.36 cm^{-1} are indicative of the C double bond C present in chloroplasts and their byproducts[29,30]. This amide II N-H stretching is responsible for the bands, which have a width of 1580–1510 cm^{-1} [31]. The quinone and chlorine ring bands' features are found in the bands between 1490 and 1440 cm^{-1} [32]. Among these characteristics are the C=O at 1489 cm^{-1}, the stretching for C-N bond at 1466 cm^{-1}, and for C-H bond at 1444 cm^{-1}. The CH_2 wagging mode and the amide III vibration are both influenced by the region between 1320 and 1300 cm^{-1} [33]. For the ester groups, the stretching vibrations of C single bond O are assigned wavenumbers of 1280 cm^{-1} [34]. The bands at 1152 and 1106 cm^{-1} affected the paired C–C and C–O vibrations to demonstrate carbohydrates[35]. Based on both, the bands, the quantitative frameworks are viewed from the distinctive band perspective a more accurate prediction model might be established by using extensive information about both bands, which is the basis for the quantitative models from the characteristic band perspective[36].

The prepared TiO_2 thin-film FESEM images are shown in Fig. 2 (b, c). It is evident from the SEM image that the films consist of densely packed TiO_2 nanocrystalline particles. The amount of HCl used greatly affects the rate of titanium hydrolysis by producing an acidic environment. Through homogeneous nucleation, a large number of clusters are formed in the solution, and these clusters act as nucleating nuclei for the formation of more nanoparticles. The produced film electrode has a homogeneous shape from TiO_2 nanoparticles, as seen in the FE-SEM image. This provides a large surface area for the dye to be adsorbed.



(a)



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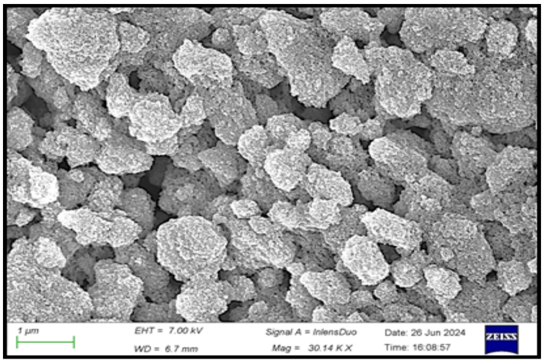
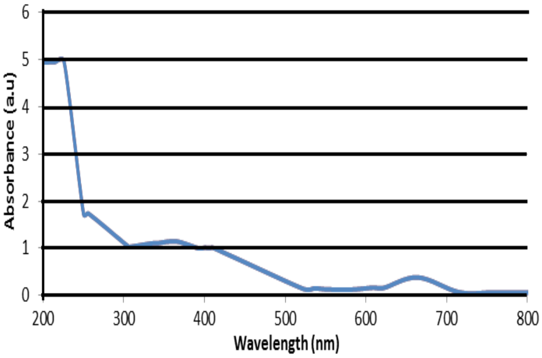


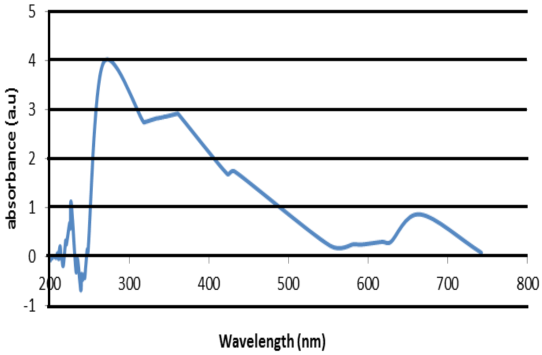
(c)

Fig. 2(a). FT-IR spectra of Chlorophyll extracted from *Chenopodium album*, (b) FE-SEM image of TiO_2 coated on FTO glass at 10.00 KX magnifications (c) FE-SEM image of TiO_2 coated on FTO glass at 30.14 KX magnifications

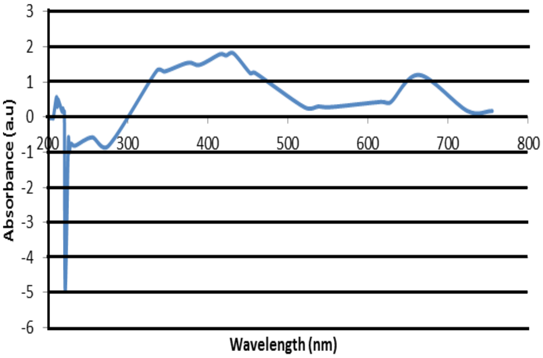
UV-Vis Spectrophotometer was used to study spectral and absorbance properties of dye solution. The absorption characteristics of dye solutions were examined for the dye extracted from *Chenopodium album*. Investigations were conducted on photo-sensitizers dissolved in three distinct solvents (200nm-800nm) to look for variations in the absorption peak and frequency within the same photo-sensitizers. The shift in frequency and wavelength was attributed to various types of solvents and materials within the photo-sensitizers. Fig. 3 displaying peak of absorption in the visible spectrum (a) Photosensitizer in ethanol: exhibit absorbance peak at +4.96 at the wavelength of 226 cm^{-1} very small peak at the wavelength of 385 cm^{-1} and 664 cm^{-1}; (b) Photosensitizer in DMSO: exhibits a broad absorption peak at +4au at the wavelength of 267 cm^{-1}, 361 cm^{-1} and 665 cm^{-1}; (c) photosensitizer in Iso-propanol: exhibits absorbance valley at -4.9au at the wavelength of 222 cm^{-1} and broad absorbance peak at 432 cm^{-1} and 664 cm^{-1}.



(a)



(b)



(c)

Fig. 3. Absorption spectra of (a) Dye extracted from ethanol, (b) dye extracted from DMSO D& (c) dye extracted from iso propanol

The I-V curves shown in Fig. 4, the PV characteristics of the DSSC sensitized by the dyes was observed from *Chenopodium album* in different solvents were investigated. Natural dyes' effectiveness as sensitizers in DSSC was assessed using the following metrics: energy conversion efficiency (η), Fill Factor (FF), V_{oc}, and short circuit current density (I_{sc}). The measured and calculated photoelectrochemical parameters are provided in Table 1.

Table 1: I-V characteristics of the fabricated Dye sensitized solar cells by natural dye extracted from Chenopodium album in three solvents

Sr. No	Solvent	I_{sc}(mA)	V_{oc}(mV)	FF	η (%)
1	Ethanol (Et-OH)	1.21	167	0.67	1.37%
2	Dimethyle salphoxide (DMSO)	1.61	164	0.40	1.07%
3	Iso-propanol (IPA)	1.58	198	0.45	1.44%

Chenopodium album extracted dye-solvent DSSC, the following maximal photovoltaic characteristics were obtained for various solvents: In Chenopodium album-ethanol yield η of 1.37%, a FF of 0.67, a V_{oc} of 167 mV, and I_{sc} of 1.21 mA. A V_{oc} of 164 mV, a FF of 0.40, and I_{sc} of 1.61 mA and η of 1.07% were obtained *Chenopodium album*-DMSO cell. η of 1.44%, V_{oc} of 198 mV, a FF of 0.45, and I_{sc} of 1.58 mA were obtained from *Chenopodium album*- isopropanol cell. The dye in isopropanol exhibits the highest conversion efficiency of the among solvents. Fig. 4 showing comparative Current–voltage characteristics curves of DSSCs sensitized with natural pigment *Chenopodium album* extracted from three different solvents viz. ethanol dimethyl sulfoxide (DMSO) isopropanol (IPA).

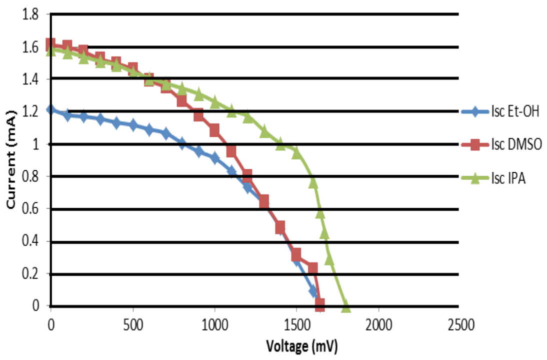


Fig. 4. (I-V) curves for DSSCs sensitized by the extract of *Chenopodium album* in three different solvents

CONCLUSION

The extraction solvent had an impact on the DSSCs' performance, according to dye extracted using various solvents. Fill factors achieved for dye in ethanol, DMSO and IPA is 0.67, 0.4 and 0.45 respectively. When it comes to energy conversion efficiency, DSSC made using isopropanol extract outperforms ethanol and DMSO extracts, with reported values for *Chenopodium album* of 1.37%, 1.07%, and 1.44%, respectively. Consequently, in areas where *Chenopodium album* is commonly available, the isopropanol extract of *Chenopodium album* should be used as an alternate source of chlorophyll for the manufacture of DSSC. Overall, the natural dyes have potential as DSSC sensitizers because of their inexpensive production expenses, easy, green manufacturing technique at and benevolence to the surroundings[37]. A composite of natural dyes has been the subject of extensive research and consequently future work on a mixed dye system employing natural dyes will be carried out.

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Conflict of interest

Authors have no conflict of interest.

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