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Full Length Article

Extraction and application of natural pigments for fabrication of green dye-sensitized solar cells

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ABSTRACT

Four dye-sensitized solar cell devices are designed and fabricated based on natural dyes extracted from Celosia Cristata, Saffron, Cynoglossum, and eggplant peel, as photosensitizers. The UV–vis technique has been served to determine maximum absorption of natural extract and pre-dyed photoanode. The Fourier transform infrared (FT-IR) was employed to cover the presence of functional groups. The cyclic voltammetry method has been employed to assess the possibility of charge transfer from dried natural dyes to the photoelectrode. The performance of natural-based dye-sensitized solar cells is determined subsequently. The highest power conversion efficiency was ca. 1.38%, which belonged to Celosia Cristata extract. The devices were examined for higher efficiencies, individually, co-sensitized arrangement and/or in tandem with each other.

1. Introduction

Todays, the primary sources of energy production are fossil fuels such as oil, gasoline, natural gas and coal which cause environmental pollution. On the other hand, these resources are not endless [1]. Dye-sensitized solar cells (DSSCs) are ideal and unlimited options for generating electrical energy [2]. The cause for the spectacular growth of this technology is low cost and environmentally friendly [3]. The photosensitizers as a key component of DSSCs devices play the role of electron production [4]. Several researches have focused on studies of photosensitizers engineering for the improvement of a dye-sensitized solar cell performance [5].

The photosensitizers used in DSSCs devices can be divided into metal-based complex dyes, organic dyes and natural dyes [6]. The literature indicates that metal-based complex dyes and organic dyes have been frequently applied in the manufacture of DSSCs devices, but they could not be good choices for environmental and cost perspective [7]. Natural dyes obtained from flowers, leaves, fruits and roots are promising selection for fabrication of DSSCs device due to inexpensive, abundant and sustainable [8]. Polo and Iha extracted blue anthocyanin from various fruits as sensitizers and applied them in DSSCs, and attained the higher efficiency in case of Jabotica [9]. Chang and Lo used natural dyes extracted from pomegranate leaf and mulberry and reported power conversion efficiency of 0.59 and 0.722% for the resulting cells, respectively [10]. Hosseinnezhad et al. extracted five natural dyes and used in dye-sensitized solar cells and a higher power conversion efficiency of 1.41% has been achieved for radish [11]. Some studies were also constructed to improve the efficiency of natural dye based DSSCs, for instance Sandquist and McHale fabricated a green DSSCs based on beet root and reported an efficiency about 2.70% [12]; and Calogero et al. worked on a different type of berry and reached efficiency of 2.06% in case of Sicilian prickly pear [13]. Hosseinnezhad et al. fabricated a clean and low cost DSSCs based on Sambucusebulus extraction and investigated various pH in the extraction to increase the PCE. The results show that the higher PCE has obtained for 1 N HCl media [14]. Mozaffari et al. developed DSSCs based on Siahkooti fruit natural sensitizers with and without purification. At best, the power efficiency was 0.32% prior to purification [15].

In this study, four sensitizer from nature sources was extracted to enhance the power conversion efficiency of solar cell devices. Thus, different groups of natural dyes are extracted from Celosia Cristata, Saffron petals, Cynoglossum, and eggplant peel of Iran farms. The performance of derivatives towards UV–vis properties of extractions in the solution and on a photoelectrode substrate was then investigated. The FT-IR ATR spectra were examined to assess pre-dye treated TiO_2 substrate. The energy level properties of the aforesaid environmentally dyes as sensitizers were measured on account of their potential in transferring charge from dye molecules to photelectrode. The photovoltaic properties were detected in cells

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configured individually, in co-sensitized arrangement and in tandem with each other, and their efficiencies were compared.

2. Experimental

2.1. Materials and instruments

Natural resources used in this study were Celosia Cristata, Saffron petals, Cynoglossum, and eggplant skin, all received from trees and underbrush grown in Iran. All chemical reagents and solvents were analytical grades provided by Merck Co. and used without further purification. Transparent conducting oxide, FTO (F-doped SnO_2, DyeSol), TiO_2 pastes, scattering layer and Di-tetrabutylammonium Cis-bis(isothiocyanato)bis(2,2′-bipyridyl-4,4′-dicarboxylato)-Ruthenium (II) (N719 Grade) were purchased from Sharif Solar Co. The absorbance spectra of the green sensitizers were measured in the UV–vis range using Cecil 9200 double beam transmission spectrophotometer (Super Aquarius spectrophotometer, UK). FT-IR ATR measurements were carried out on a Perkin Elmer instrument (Spectrum one, wavelength range: 7.800–350 cm^{-1} with beam splitter, USA) to place the functional groups present in the samples.

2.2. Preparation of green sensitizers

The organic extract process was utilized for preparation of green sensitizer. The natural plant (Celosia Cristata, Saffron petals, Cynoglossum, and eggplant peel) was washed with water and vacuum dried at 45 °C. The cleaned and ground plants (10 g) were respectively dipped into the extracting solution which was consisted of ethanol (50 ml) for 48 h under darkness to prevent light decomposition. Then the dye solution was filtered repeatedly and were concentrated with a rotary evaporator at 30 °C to obtain green sensitizers.

2.3. Electrochemical measurements

Electrochemical measurements of the natural dyes were carried out in solution by cyclic voltammetry (CV) method. The oxidation potential (E_{ox}) was measured using three small-sized electrodes. Ag quasi reference electrode (QRE) was used as the reference. Platinum wires were used as the working and the counter electrodes. All electrode potentials were calibrated with respect to ferrocene (Fc)/ferrocenium (Fc^+) redox couplet. An acetonitrile solution of each dye containing tetrabutylammonium perchlorate (0.1 mol dm^{-3}) and ferrocene (ca. 1 mmol dm^{-3}) was prepared. The electrochemical measurements were performed at a scan rate of 100 mV s^{-1} [16].

2.4. Fabrication of DSSCs

In this work, three types of DSSCs containing green sensitizers were fabricated and put into practice, individually, co-sensitized, and tandem.

In case of individual solar cells, a nanocrystalline TiO_2 film was coated on a FTO coated glass support. The dye extracts were adsorbed by dipping the coated glass for 18 h in natural dyes. Then, the film was washed with ethanol solvent. A 1:4 vol ratio of acenonitrile-ethylenecarbonate containing 0.5 mol dm^{-3} tetrabutyl ammonium iodide was employed as electrolyte. Next, dye-adsorbed TiO_2 electrode, the Pt counter electrode and the electrolyte solution were assembled into a sealed sandwich type solar cell [11,16,17]. Reference spectrum was obtained under monochromatic light with a constant photon number of 5×10^{15} photons cm^{-2} s^{-1}. J-V characteristics were determined under illumination with AM 1.5 simulated sunlight (100 mW cm^{-2}) via a shading mask (5.0 mm × 4 mm) by using a Bunko-Keiki CEP-2000 system.

For construction of co-sensitized solar cells, the photoelectrode were prepared by employing two dye layers, where dried TiO_2 was immersed in a first natural sensitizer for 18 h followed by drying at room temperature under dark condition. Tetraethyl ammonium hydroxide in methanol and ethylene glycol solutions were used as desorption solutions. The sensitized TiO_2 was dipped into solution for 30 s and washed with ethanol for 20 s. Desorption process was repeated three times followed by immersion of dried photoelectrode into the second natural sensitizers for 8 h and washed with ethanol [18,19].

The third kind of configuration was the case where two dye-sensitized natural dyes enclosed in tandem. The configuration was as Fluorine doped tin oxide (FTO) glass/TiO_2/dye 1/electrolyte/semi-transparent Pt-FTO glass/FTO glass/TiO_2 /dye 2/electrolyte/Pt-FTO glass. More details on solar cells of this type are available elsewhere [20].

3. Results and discussion

Natural dyes derived from plants, vegetable and minerals are environmentally friendly, low cost and available everywhere compared to organic derivatives used in dye-sensitized solar cells [21]. Figure 1 displays natural dyes used in this study extracted from Celosia Cristata, Saffron petals, Cynoglossumand eggplant peel. Natural dyes based on anthocyanine were obtained from Celosia Cristata, eggplant peel and Cynoglossum and flavonoids was taken from Saffron petals. In this way, different families could be tested for their sensitization effects on power conversion efficiency when used in dye-sensitized solar cells. There was a clue that all natural dyes used in this work could be linked to the TiO_2 surface in DSSCs thanks to the presence of the carbonyl and hydroxyl groups

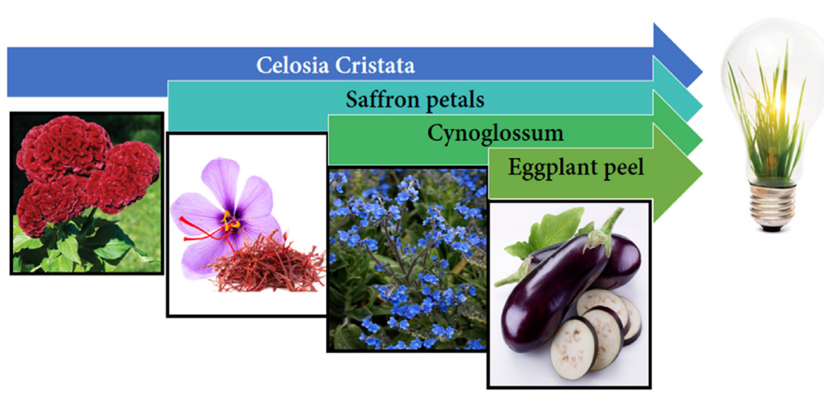

Fig. 1. The origin of the natural dye sources used in this study.