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Characterization of a green and environmentally friendly sensitizer for a low cost dye-sensitized solar cell

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ABSTRACT

Clean and cheap device, namely dye-sensitized solar cells (DSSCs) were fabricated using a natural dye extracted from *Sambucus ebulus*. We prepared five sample solutions with various pH in the extraction process to improve power conversion efficiency. The UV–visible absorption investigation of sample solutions and on photoanode show the dyes from J-type aggregation on a photoanode substrate. Redox properties of all sample solutions certify thermodynamically a charge transfer from excited state to conduction band TiO_2. The optical properties of various dye solutions were investigated and results showed darkness and bluish tint effect of dye solutions extracted in basic environment rather than those extracted in acidic condition. Moreover, in comparison to the basic condition, the dye solutions extracted in acidic environment were more saturated and colorimetrically less different from that one which extracted in neutral condition. Photophysical and photoelectrochemical performance of natural extraction dyes have been studied in dye-sensitized solar cell devices. The results show the rather high conversion efficiency of 0.57%, 1.15%, 1.02%, 0.35% and 0.15% of each individual dye extraction, respectively.

1. Introduction

Dye-sensitized solar cells (DSSCs) are key photovoltaic devices for production of clean and renewable energy [1,2]. Numerous studies on the DSSCs have been carried out in the last years and the results show that the photosensitizers are important materials in DSSCs [3,4]. DSSCs efficiency was determined by a dye absorption spectrum and the amount of anchoring to the photoelectrode surface. Thus, the selection of a suitable dye sensitizer in DSSCS is very important [5,6].

One of the photosensitizers in DSSCs is the natural dyes that can be extracted from some flowers, leaves and fruits [6,7]. Since, natural dyes are low cost, complete biodegradation, easy preparation and environmentally friendly, there is interest toward using these for dye-sensitized solar cells in the future research [8–10]. To the best of our knowledge, the highest efficiency of 1.6% was achieved from the methanol of the Mulberry [11]. Alhamed et al. reported a power conversion efficiency of 1.50% using the natural dye extracted from Raspberriec fruit [12]. The leaves of Ficusreusa and Hibiscus surattensis were employed as photosensitizers in a DSSCs' structure by Fernando et al. [13] and Lai et al. [14], while their power conversion efficiency were 1.14% and 1.18%. Hamadanian et al. showed that using Reseda Luteola as photosensitizer, J_{sc} of 0.54 mA cm^{-2}, V_{oc} of 0.64 V and power conversion efficiency of 0.22% can be achieved [15]. Zhou et al. used 20 natural dyes as sensitizers in a dye-sensitized device and the results show that the power conversion efficiency of the ethanol extract of Mangosteen pericarp without purification reached 1.17% [16].

In the current study, a natural dye containing ebulosid extracted from the fruit of *Sambucus ebulus*, which grows in Iran, was used as photosensitizers in the manufacturing DSSCs. To the best of our knowledge, the natural dye extracted of this plant sources have never been used as photosensitizer in DSSCs and the investigation presents a new view on the application of this extract in the DSSCs. The spectrophotometric properties of the prepared natural dyes in a solution with various pH and on a nanoanatase titanium dioxide (TiO_2) substrate were examined. The absorption maxima and intensities of the resultant natural dyes were also obtained. Finally, the optical and photovoltaic of DSSCs made of this extract, as well as their colorimetric attributes were determined and discussed.

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2. Experimental

2.1. Materials and instruments

The samples of *S. ebulus* used in this study were obtained from underbrush are grown in north of Iran (Mazandaran-Ramsar). All chemical materials and solvents utilized in this study were analytical grades provided by Merck Co. without further purification. Transparent conducting oxide, fluorine doped tin oxide (FTO, F-doped SnO_2, DyeSol), TiO_2 pastes, scattering layer (Sharif Solar Co.) and di-tetrabutylammonium cis–bis(isothiocyanato)bis(2,2′-bipyridyl-4,4′-dicarboxylato) ruthenium(II) (N719, Sharif Solar Co.) were purchased. Ultraviolet–visible (UV–vis) spectrophotometry was carried out on a Cecil 9200 double beam transmission spectrophotometer.

2.2. Preparation of a natural dye

The extract of *S. ebulus* was obtained from a fresh fruit. The clean fruit was extracted from 100 mL ethanol. Four extracts were prepared by immersing the fresh fruit in HCl (0.1 N and 1 N) and NaOH (0.1 N and 1 N) solutions (ethanol extract). The mixture was kept overnight at 4 °C, then solid residues were filtered out to obtain the clean dye solution. All solution was protected from direct light and stored in the refrigerator at 4 °C until tested (Table 1).

2.3. Colour measurement

In order to compute the colourimetric attributes, the percentage of light transmitted from the natural dye solutions were measured over the visible wavelengths from 400 to 700 nm by 10 nm intervals. The measured transmitted spectra were then converted to the colourimetric properties of natural dye solutions. The CIEXYZ tristimulus values of solutions were computed by using Eqs. (1)–(3) where *T* indicates to the dyes solutions transmittance spectra *and x,y and z* refers to the colour matching functions (CMFs) under a D65 standard illuminant [17].

$$X = \int_{\lambda=400}^{\lambda=700} S(\lambda)\bar{x}(\lambda)T(\lambda)d\lambda \quad (1)$$

$$Y = \int_{\lambda=400}^{\lambda=700} S(\lambda)\bar{y}(\lambda)T(\lambda)d\lambda \quad (2)$$

$$Z = \int_{\lambda=400}^{\lambda=700} S(\lambda)\bar{z}(\lambda)T(\lambda)d\lambda \quad (3)$$

where $S(\lambda)$ is the spectral power distribution (SPD) of the light source that is normalized by applying of Eq. (4) [17,18]:

$$100 = \int_{\lambda=400}^{\lambda=700} S(\lambda)\bar{y}(\lambda)d\lambda \quad (4)$$

In the next step, the CIELAB colorimetric attributes [18–20] of natural dye solutions were computed via Eqs. (5)–(7):

$$L^* = 116(Y/Y_n)^{1/3} - 16 \quad (5)$$

$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \quad (6)$$

$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}] \quad (7)$$

where, L^*, a^* and b^* are the colourimetric coordinates of objects in a CIELAB colour space. Fig. 1 schematically shows the CIELAB colour order system. Based on Fig. 1, the horizontal axes of CIELAB colour space indicate to the redness-greenness (from the positive a^* values to the negative one) and yellowness-blueness (from the positive b^* values to the negative one) properties of objects. Based on Fig. 1, the vertical axis of figure shows the lightness attribute of objects while varies from the $L^* = 0$ (for the ideal black) to the $L^* = 100$ (for the ideal white) [19].

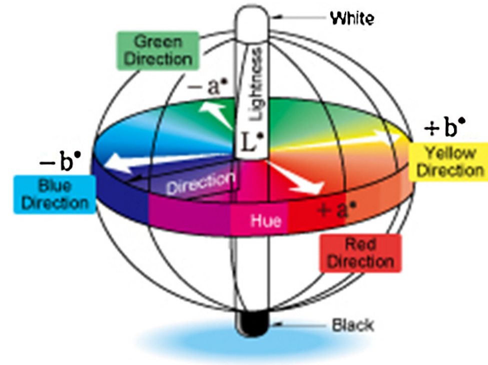

Fig. 1. The CIELAB colour order system [20].

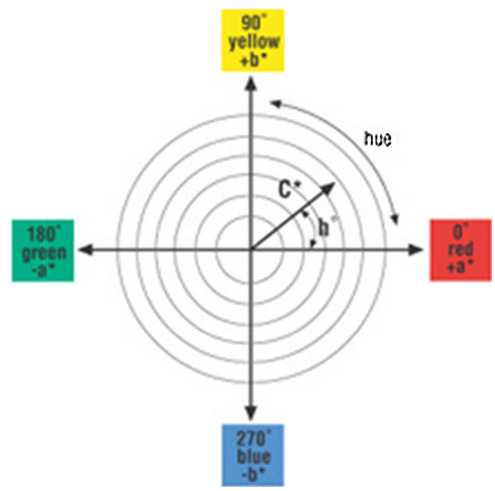

Fig. 2. The schematic definition of objects' colourimetric saturation (chroma) and hue angle [21].

On the other hand, the chroma values and hue angle of natural dye solutions were obtained by applying of Eqs. (8) and (9), respectively.

$$C^* = (a^{*2} + b^{*2})0.5 \quad (8)$$

$$\text{hue angle} = \tan^{-1}(b^*/a^*) \quad (9)$$

where the L^*, C^* and hue angle are the colourimetric coordinates of a CIELCH colour space which is the cylindrical representation of the CIELAB colour order system. Fig. 2 defines the saturation (chroma) and hue angle properties of objects, schematically. The chroma attribute shows that how much the colour appearance of objects is saturated and the hue angle indicates to their tint attribute [19].

2.4. Fabrication and characterization of DSSCs

A nanocrystalline TiO_2 film was coated on a fluorine doped tin oxide (FTO) coated glass support. The dye solutions were adsorbed by dipping the coated glass for overnight in an ethanolic solution of the dye. Finally, the film was washed with an ethanol solvent. Acenonitrile-ethylenecarbonate (v/v = 1:4) containing tetrabutyl ammonium iodide (0.5 mol dm^{-3}) was used as an electrolyte. The dye-adsorbed TiO_2 electrode, the Pt counter electrode and the electrolyte solution were assembled into a sealed sandwich type solar cell [22]. An action spectrum was measured under monochromatic