Chemical Physics Letters 679 (2017) 97–101

Contents lists available at ScienceDirect

Chemical Physics Letters

journal homepage: www.elsevier.com/locate/cplett

Research paper

Dye-sensitized solar cells using Aloe Vera and Cladode of Cactus extracts as natural sensitizers

D. Ganta *,[1], J. Jara [1], R. Villanueva

School of Engineering, Texas A&M International University, Laredo, TX 78041, USA

ARTICLE INFO

Article history:
Received 4 April 2017
In final form 28 April 2017
Available online 29 April 2017

Keywords:
Dye-sensitized solar cells
TiO_2 film
Nanomaterials
Green energy
Natural dyes

ABSTRACT

The purpose of this study is to develop dye-sensitized solar cells (DSSCs) from natural plant-based dyes, extracted from the Cladode (*nopal*) of the Thornless Prickly Pear Cactus (*Opuntia ficus-indica*), the gel of Aloe Vera (*Aloe barbadensis miller*), and the combination of Cladode and Aloe Vera extracts on side-by-side configuration. Optical properties were analyzed using UV–Vis Absorption and Fourier Transform Infrared Spectroscopy. Open circuit voltages (V_{oc}) varied from 0.440 to 0.676 V, fill factors (*FF*) were greater than 40%, short-circuit photocurrent densities (J_{sc}) ranged from 0.112 to 0.290 mA/cm^2 and highest conversion efficiency of 0.740% was reported for the Cladode DSSC.

1. Introduction

DSSCs were initially developed in 1991 by Gratzel et al., gaining significant interest in the scientific community, due to their low cost of production and environmental friendliness [1]. DSSCs sensitized by ruthenium complex dyes (N719) adsorbed on TiO_2 currently recorded the highest efficiency of 11–12% [2,3]. Although such DSSCs have provided a rather high efficiency, there exist a few disadvantages of utilizing these metals as a dye. These chemical metal dyes are rather expensive, environmentally non-friendly and were tedious to fabricate. To assemble inexpensive and green solar cells, it is desirable to substitute low-cost catalytic materials for Pt, with inexpensive carbon black as the counter electrode [4]. In contrast, organic dyes are not only a cheaper alternative but have also been reported to reach an efficiency as high as 9.8% [5]. However, organic dyes have certain limitations, such as low yields and complicated extraction methods.

Natural plant-based DSSCs gained significance due to their low cost, non-toxicity, environmental friendliness and availability. Plant dyes serve as a sensitizer, which absorbs sunlight and convert solar energy into electric energy. To date, several natural plant-based dyes have been employed as sensitizers in DSSCs, such as mangosteen [6,7], coumarin [8,9], cyanin [10–15], red turnip dye extract [15], *Callindra haematophata* [16], *Luffa cylindra* L. [17], *Amaranthus caudatus* flower [18], Rose bengal [19], and carotene [20]. The conversion efficiencies of the natural plant dyes were reported to be in the range of 0.03–2.09%. Additionally, Wang et al. carried out structural adjustment of coumarin and used the derivation dye of the coumarin as the sensitizer in a DSSC, which delivered an efficiency of 7.6% [8,9]. Some of the plants from which dyes were extracted for DSSCs were rare to find, with tedious extraction or synthetic methods and lack the stability. The combination method of mixing plant-based dyes proved unsuccessful and have yielded poor results, due to the variation in the chemistry of the final product from the mixture [6,18]. The motivation for this work is to explore natural pigments from non-toxic plants, which can survive in dry conditions, and abundant in nature, with simple and inexpensive extraction methods. Further, investigate methods for fabricating DSSCs from the combination of natural plant-based dye extracts.

In this paper, we explore a relatively inexpensive and simple method to develop DSSCs from two types of natural plant-based dyes extracted from Cladode and a leaf of Aloe Vera. To the best of our knowledge, these natural dyes from these plants were reported as sensitizers of DSSCs for the first time. We also investigated the performance of DSSCs fabricated from a combination of plant dyes, on a side-by-side configuration avoiding mixing of the dyes. Titanium dioxide (TiO_2) nanopowder, which provides a wide band-gap and serves as an electron transporter, was utilized for the fabrication of the DSSCs sensitized by the natural plant dye extracts. Optical properties of the dye were investigated with UV–Vis Absorption Spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR). The photoelectrochemical parameters of the

* Corresponding author.
E-mail address: deepak.ganta@tamiu.edu (D. Ganta).
[1] Equal contribution.

http://dx.doi.org/10.1016/j.cplett.2017.04.094
0009-2614/

DSSCs were obtained from the current density-voltage (*J-V*) curve, upon exposure to standard AM 1.5 G sunlight source.

2. Methods

2.1. Preparation of dye sensitizers

Cladodes of the Thornless Prickly Pear Cactus and Aloe Vera leaves were gathered and separately rinsed with water. The Cladodes were cut into small pieces and then inserted in a blender to obtain a liquid dye solution. Similarly, the Aloe Vera leaves were cut open to obtain the gel from the inside and was blended, to obtain a liquid dye solution. Once liquefied, the natural plant dyes were separately extracted in absolute ethanol in 1:1 ratio. The plant dye solutions were poured into glass containers, and covered with aluminum foil to prevent contamination. The containers were kept in the dark for 24 h at room temperature. Afterward, the solid residues were filtered out from each solution to acquire clear dye ethanol extracts for use as sensitizers, as illustrated in Fig. 1.

2.2. Preparation of working TiO_2 electrode

Fluorine-doped Tin Oxide (FTO) conductive glass slides (2.5 cm × 5.0 cm × 0.22 cm) (Delta Technologies, sheet resistance: 14 Ω/sq) were cleaned with acetone and ethanol for 10 min in each step with an ultrasonic bath. The preparation of nanocrystalline films employed titanium dioxide nanopowder (Alfa Aesar, titanium (IV) oxide, 15 nm, anatase, 99.7%). The TiO_2 nanopowder (2.5 g) was ground in a porcelain mortar, with a small amount of nitric acid (4 mL) containing a molarity of 0.001 M. This is crucial to the process, as the nitric acid prevents aggregation of the nanopowder, allowing the chemical's particles to be separated. After continuous grinding of the nanopowder, a TiO_2 paste is formed. The FTO slides used for the Cladode and Aloe Vera gel dye ethanol extracts were covered on two parallel vertical edges, using Kapton tape with a width of 1.27 cm, leaving an area of ~6.45 cm^2. As for the FTO slides used for the combination of the dye ethanol extracts, two vertical spaces half the width of the Kapton tape (0.889 cm) and one vertical space of 1.27 cm were all covered with tape, leaving two separate areas of ~3.23 cm^2.

The TiO_2 paste was then deposited on each FTO conductive slide, uniformly distributed by sliding a scraping blade over the tape-covered areas, in order to obtain TiO_2 films with a thickness of approximately 60 μm, as illustrated in Fig. 2(A) and (C). Non-coated areas were left on the FTO slides to provide electrical contact. After air drying, the TiO_2 coated slides (electrodes) were preheated at 80 °C on a hot plate for 5 min, followed by heating for 15 min at 400 °C. The process of preheating was necessary, in order to prevent the FTO glass slides from cracking. Afterward, the TiO_2-coated slides were removed from the hot plate and left to cool at room temperature for 10 min. TiO_2 film (6.45 cm^2) was than immersed in dye extract for 24 h. However, in the case of FTO slide containing two TiO_2 films (3.23 cm^2) in the side-by-side configuration, both of the films were coated with different dyes. Proper care was taken to prevent the Cladode and Aloe Vera dyes from mixing. After completion of the dye adsorption, the TiO_2 film was withdrawn from the dye solutions and left to dry for 20 min.

2.3. Preparation of counter electrode

FTO glass slides were used to prepare the counter electrode. The slides were each cleaned with acetone and ethanol for 10 min in each step with an ultrasonic bath and were left to dry for 10 min. Nonconductive glass slides were placed on top of two FTO slides to cover a single vertical space of 1.27 cm, leaving an area of 6.54 cm^2, as illustrated in Fig. 2(B). The preparation of the counter electrodes was accomplished by burning the 6.54 cm^2 areas with an electric lighter, forming a carbon film. Additionally, a separate FTO conductive slide was burned completely. Afterward, a clear vertical space of 0.889 cm and another of 1.27 cm were each left by cleaning off part of the carbon film, leaving two separate carbon-coated films with an area of 3.23 cm^2, as illustrated in Fig. 2(D). Non-carbon-coated spaces were left present in order to provide an area of electrical contact. The carbon-coated slides were left to cool for 15 min at room temperature.

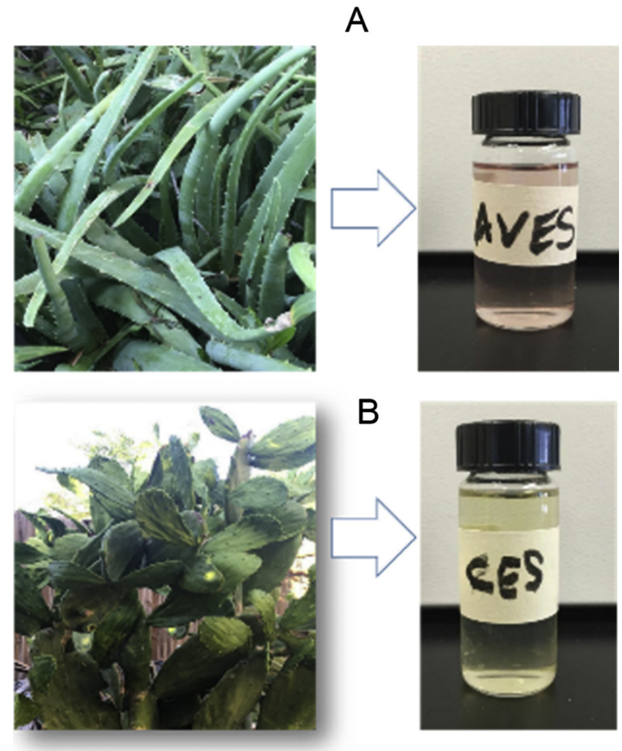

Fig. 1. Photographs of the plants and extracted dye: (A) *Aloe barbadensis miller* (Aloe Vera gel), and (B) *Opuntia ficus-indica* (Cladode).

The TiO_2 electrode and carbon electrode were held together. Electrolyte solution (Flinn Scientific) composed of 0.5 M potassium iodide, 0.5 M iodine, water, and ethylene glycol, were injected into the small space between the electrodes filling it completely with the aid of capillary effect.

2.4. Measurements

The Absorption Spectra of the dye ethanol solutions was recorded with a UV-2450 UV–Vis spectrophotometer (Shimadzu). The photoelectrochemical measurements of the DSSCs were obtained by using a BioLogic SP-150 Potentiostat, through a computer controlled program (EC-Lab). A 150 W Xenon Arc lamp source (ABET technologies, LS-150) with AM 1.5 filter were utilized to illuminate the DSSCs. The intensity or irradiance of the incident light was 100 mW/cm^2.

3. Results and discussion

Fig. 3 illustrates the UV–Vis Absorption Spectra taken between 400–800 nm for the dye ethanol extracts of Cladode and Aloe Vera respectively. The Cladode extract shows a stronger absorption peak at 662 nm, as illustrated in Fig. 3(A), indicating that the main