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Sensitized solar cells based on natural dyes

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We have employed several natural dyes for application in dye sensitized solar cells (DSSC). Spinach, beet, red cabbage and strawberry are well known and have been already used. We then checked the opportunity to realize good DSSC with dyes available in Tunisia: Henna and Mallow (Mloukhya). Henna is a herb which has interesting reddish brownish dyeing properties used since antiquity for traditional decoration of skin, hair and fingernails in the Middle East and North Africa. The mallow is a green vegetable which is widely consumed in the same region. The optical absorption of the extracted dyes diluted in ethanol or distilled water were measured using UV–Vis spectrophotometer. The absorption in beet and red cabbage is more significant compared to the other dyes. Mallow and henna dyes present a noticeable band in the region 660 nm. Infra-red spectroscopy measurements were done to probe the structure and dynamics in our used dyes. In this paper, we present the steps followed in the making of our solar cells. The DSSC were assembled using two glass plates (supporting electrode and counter electrode) which are coated with transparent conducting oxide (TCO). The counter electrode is coated by a catalyst Pt (Platinum) to speed up the redox reaction with the electrolyte solution. The typical J–V curves of our solar cells under AM 1.5 using a density of power 100 mW/cm^2 were measured. Cells using henna and mallow as dyes present less degradation with time in the photoelectric characteristics. The mallow cell shows a good fill factor of 55% and a noticeable photoelectric conversion efficiency of 0.215%.

1. Introduction

Dye-sensitized solar cells (DSSC) [1] are devices for the conversion of light to electricity imitating photosynthesis of plants [2]. It is based on the sensitization of wide band gap n-type semiconductor through a dye used as sensitizer. The absorption spectrum of the dye and the anchorage of the dye to the surface of titanium dioxide (TiO_2) are important parameters determining the efficiency of the cell [3,4].

Transition metal compounds such as ruthenium polyridyl complexes were used widely as effective dye-sensitizers [5]. However, this type of dye is expensive and raises public environmental awareness [6]. Nonetheless, the natural dyes found in flowers, leaves, and fruits can be extracted by simple procedure. Due to their cost efficiency, non-toxicity, and complete biodegradation, natural dyes are still a popular subject of research. In this study, we use well-known natural dyes: henna and mallow.

A typical DSSC comprises a nanocrystalline titanium dioxide (TiO_2) electrode modified with a dye fabricated on a transparent conducting oxide (TCO), a platinum Pt) counter electrode, and an electrolyte solution placed between the two electrodes based on the iodide/iodine redox couple ($I^-/I^-{}_3$). In this paper, we also present results of photoelectrical measurements done on sensitized solar cells using these natural pigments.

2. Materials and methods

The transparent conductive oxide (TCO) coated glass (TCO22-7: 2 mm thick glass substrate with a 7Ω/sq fluorine doped tin oxide coating on one side 5×5 cm^2) was employed and TCO30-8: 3 mm thick glass substrate with a 8 Ω/sq fluorine doped tin oxide coating on the second side). We have used nanocrystalline TiO_2 (Prolabo, purity 98°/°, M = 79.9 g/mol), and Iodolyte AN-50 (Iodide based low viscosity electrolyte with 50 mM of tri-iodide in acetonitrile). Platisol T/SP (A paste for the deposition of a catalytic and quasi-transparent layer of activated platinum by screen-printing or slot-coating) were purchased from Solaronix. The dyes have been extracted from natural products.

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2.1. Preparation of photo anodes

We grind about 5 g of nanocrystalline titanium dioxide (TiO_2) in a porcelain mortar and pestle with a few drops (3 ml) of very dilute acetic acid (prepared by adding 0.1 ml concentrated acetic acid to 50 ml of distilled water). We alternated grinding and added a few drops of very dilute acetic acid until obtaining a colloidal suspension, a 7 ml ethanol (10%) and a few drops of the non–ionic surfactant Tritron X100. We grind about half an hour the titania paste. In order to start with a homogenous paste, we have to avoid shaking the bottle. Otherwise this can form air bubbles and prevent a good deposition. The TiO_2 colloid was dropped on the FTO glass plate following doctor blade technique. After that we left the slide drying. While heating up the electrode to sinter the film at 450 °C for 40 min, the film first turns brownish and later to yellowish-white due to the temperature dependent band-gap narrowing in the pure titanium dioxide. This is the sign that the sintering process is completed. The last step of the preparation is to allow the slide to cool down naturally to ambient temperature. Fig. 1 shows an electron micrograph of TiO_2 sample. We note that the grain size ranges from 39 to 194 nm but most of the grains have a size around 120 nm.

2.2. Preparation of natural dye sensitizers

Natural dyes were extracted from beet, red cabbage, strawberry, spinach, mallow and henna. We heat in a water bath at 100 ml of distilled water, let boil for 2 min, then we put beet (55 g) or red cabbage (64 g) cut into very small pieces. The henna powder (5.25 g) and mallow powder (3.25 g) are placed in two beakers. We put into each beaker 40 ml of ethanol, we mix each with a Pasteur pipette and we let it rest for 10 min. We take three spinach leaves (13 g) washed with distilled water then placed in a mortar and pestle. We add 15 ml of ethanol for 5 min then grinding. We put 3 fresh strawberries in a mortar and add 30 ml of distilled water then stirring around with a pestle. More details on the preparation have been published in another paper [7].

2.3. Cell assembly

The platinum catalyst is obtained by using the Pt-Catalyst T/SP product by Solaronix which is screen-printed using a plate polyester mesh of 0.2. Dry at 100 °C for 10 min prior firing at 450 °C for 30 min. Working electrode (titanium dioxide impregnated with natural dyes for 12 h (Fig. 2a), rinse with absolute ethanol and dry with hair-dryer. The two electrodes were assembled together using binder clips and sealed with a sealing frame Meltonix 1170-60 PF (Fig. 2b). When sealing the electrodes, two small holes should be left from which the electrolyte Iodolyte AN-50 is introduced carefully to fill the space between the two electrodes and finally seal the two holes (Fig. 2c).

2.4. Characterization and measurements

The absorbance of our films in the UV–Vis was measured by the spectrometer (UV-Cecil CE 3041) in the region 400–800 nm. To probe the structure and dynamics of the dyes we used a Nicolet 560 FTIR spectrometer in region 400–4000 cm^{-1} with suitable scan resolution 2 cm^{-1}. For solar cells, the spectral response was determined using a halogen lamp 150 W and a monochromator (SP-2150 Oriel) placed at the exit of the light beam A mechanical modulator (SR540 Stanford) centered on the output of the monochromator provides a periodic excitation f at modulation frequency of 13 Hz. An optical bench was used to focus the incident light on the sample. A pyroelectric detector (Oriel type) provides a constant spectral response and a lock in amplifier SR530 in the end of the set up to receive the signal and its reference. The electrical measurements were performed under AM 1.5 conditions with incident light power density of 100 mW/cm^2. The J–V curves were obtained using a digital Keithley 6517A electrometer connected to a computer. The short circuit current J_{sc} and the open circuit voltage V_{oc} were determined from the J–V curve. The fill factor FF (Eq. (1)) and efficiency η (Eq. (2)) were calculated using the following relations:

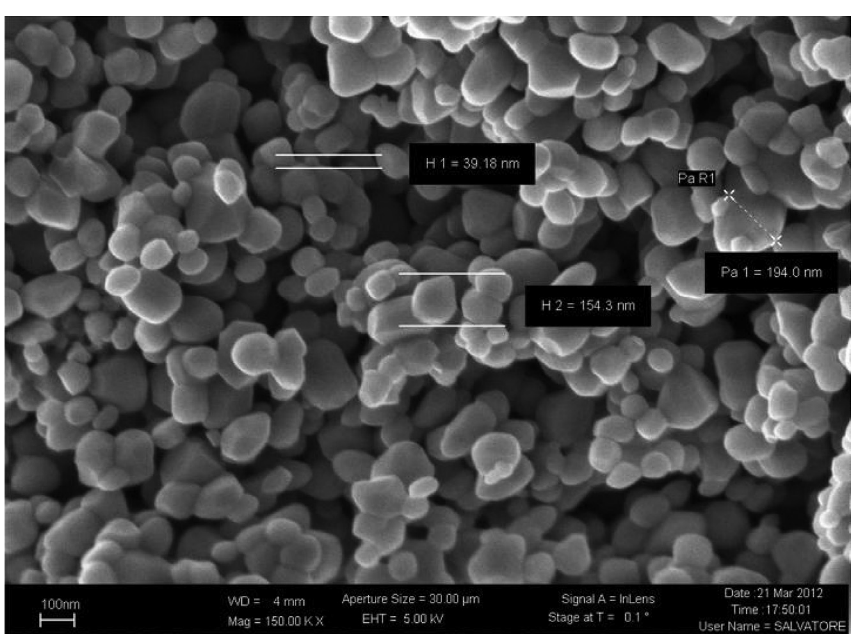

Fig. 1. A typical micrograph of TiO_2 Thin film obtained by scanning electron microscopy.