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Electrical Performance of *Curcuma longa* Extract Dye using SnO_2-Based Photoanode Dye-Sensitized Solar Cell

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ABSTRACT

Due to their low output costs, straightforward manufacturing, and high effectiveness, dye-sensitized solar cell (DSSC) has a large following interest in the solar energy industry. Furthermore, due to its outstanding properties, tin oxide (SnO_2) is an appealing semiconducting material suitable as a photoanode in DSSCs. In this research, the photoelectrodes of DSSC were fabricated using commercial SnO_2 nanoparticles and sensitized with inorganic and organic dyes, N719 and Curcuma longa (turmeric) extract dye. On top of that, a platinum (Pt) counter electrode, iodide electrolyte and fluorine-doped tin oxide (FTO) coated glass substrate were used to fabricate the DSSC. The crystallographic structure and surface morphology of the SnO_2 nanopowder were identified using X-ray diffraction (XRD) and scanning electron microscopy (SEM) characterizations respectively. In addition, UV-Visible and current density-voltage curves were used to analyze the optical properties of the photoanodes and the cell's electrical performance. As a result, it was found that the DSSC fabricated with N719 dye exhibited higher efficiency in contrast with the turmeric extract dye with SnO_2 photoanodes.

Keywords: *Curcuma longa*, dye-sensitized solar cell (DSSC), electrical performance, renewable energy, solar cells, tin oxide (SnO_2)

1. INTRODUCTION

With the increasing global energy demand and the potential to increase the amount of greenhouse gases in the atmosphere, fossil fuels with finite reserves are being used up at an alarming rate [1, 2]. Solar energy is a renewable energy sources that is trending up because of its benefits, including cleanliness, ample, and bargain expenses [3, 4]. A solar cell, also referred as photovoltaic cell, is a device that turns solar energy into electricity via the photovoltaic (PV) effect [5, 6]. Solar cells are divided into various classification hinge on their historic development or operating principles [7, 8]. PV device technology started with the advancement of silicon solar cells followed by thin film technology in the second generation [9]. Dye-sensitized solar cells (DSSC), bulk heterojunction (BHJ), photoelectrochemical cells (PEC), quantum dot-sensitized solar cells (QDSSC) and perovskite solar cells make up the third generation in solar cells development [10]. DSSC can be produced on rigid and flexible substrates, and it is almost ready for commercialization [11, 12].

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The concept of the DSSC was developed by Brian O'Regan and Michael Grätzel in 1991 [11]. The four main steps in its operating principle are light absorption, electron injection, current collection, and carrier transportation, as shown in Figure 1. First, a photosensitizer, known as a dye, absorbs the incident light. During the absorption of photon, the electrons get excited from the dye's ground state (S/S^+) to its excited state (S^*). The excited electrons are then injected into the semiconductor electrode's conduction band. The metal oxide absorbs the photons produced by the UV region and the dyes oxidizes. The injected electrons are dispersed by the metal oxide nanoparticles, and they are transported to the transparent conductive oxide (TCO) film. Lastly, the electrons completed the circuit through the counter electrode via the external circuit and reduced I^{-3} to I^-. Meanwhile, the dye's ground state regeneration appears because of the acceptance of electrons from I^- oxidized to I^{-3} (oxidized state). At this stage, the I^{-3} diffuses to the counter electrode and reduces to the I ion.

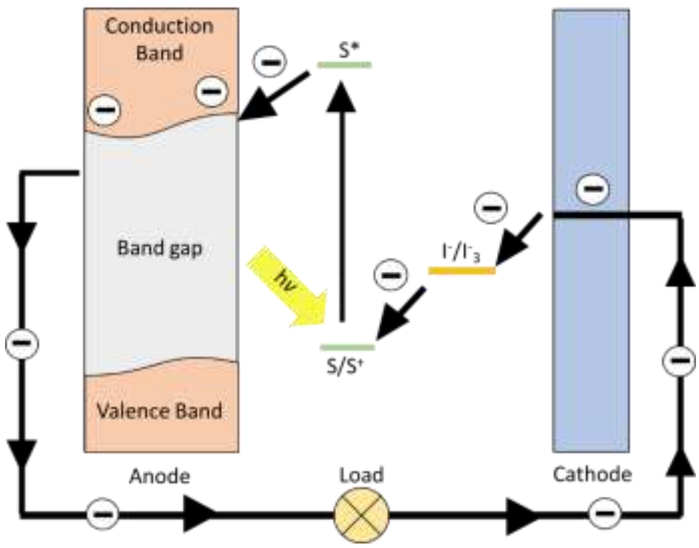

Figure 1. Principle of DSSC [13].

In the commercial DSSC, titanium dioxide (TiO_2) nanoparticles and ruthenium are used as the photoanode and dye respectively with the highest recorded efficiency of 14.3 %. TiO_2 has been selected in this technology due to its attractive advantages of low-cost price, abundance, stability, and photoactive [11, 14, 15]. However, since TiO_2 has low electron mobility, carrier recombination tends to occur resulting in poor carrier collection [16]. Therefore, tungsten trioxide (WO_3), niobium pentoxide (Nb_2O_5), zinc oxide (ZnO) and tin oxide (SnO_2), among other capable metal oxides, have been investigated as alternative materials for more effective photoanodes [17, 18, 19].

Nanostructured SnO_2 materials have been extensively researched for photoelectrodes in DSSC [20, 21]. SnO_2 enhances charge transfer as it has higher electron mobility (100–500 $cm^2V^{-1}s^{-1}$) as opposed to TiO_2 (0.1–10 $cm^2V^{-1}s^{-1}$), which is approximately greater by two orders of magnitude [22]. Second, SnO_2 has a broader energy band gap (3.6 eV) in comparison to TiO_2 (3.2 eV) [21, 23]. In DSSC, the dye acts as a sensitizer, absorbing sunlight and converting it into electric energy [24, 25]. Sensitizers in DSSCs have been chemically categorized as inorganic and organic dyes [26, 27]. However, based on previous reports, organic dyes have lower conversion efficiencies than inorganic dyes [28, 29].

In this study, SnO_2 nanoparticles were employed as DSSC photoanodes by the doctor blade technique. Inorganic and organic materials of N719 and *Curcuma longa* (turmeric) were used as dye sensitizers. Besides, a SnO_2-based DSSC without dye has also been developed for performance comparison. Platinum (Pt) film served as the counter electrode and an iodide electrolyte was used as the mediator for the redox process.

2. EXPERIMENTAL METHODS

2.1 Materials

In this research, fluorine-doped tin oxide (FTO) glass 7 Ω/sq, tin (IV) oxide nanopowder (Sigma Aldrich, ≤100 nm avg. part. size), acetic acid, Triton X-100, Ruthenizer 535-BIS TBA (Sigma Aldrich) or known as N719, *Curcuma longa* (turmeric), ethanol, potassium iodide, iodine, acetone, and deionized water were used.

2.2 Preparation of SnO_2 Films

300 mg of SnO_2 powder was mixed with 200 µl of acetic acid, 100 µl of Triton X-100 and 1 ml of ethanol in a mortar. The mixture was grounded well for about 15 minutes to obtain paste. Doctor blade method was used to apply SnO_2 paste in a 1 cm x 1 cm area on the conductive side of the fluorine-doped tin oxide-coated glass (FTO), which had already been framed by scotch tape. Prior to applying the paste, the glass substrates were cleaned in an ultrasonic bath for 10 minutes in each solution with deionized (DI) water, ethanol, and acetone. Next, the prepared SnO_2 photoanode was heated on a hotplate for 10 minutes at 150 °C and undergo hardbake for 1 h at 450 °C in a tube furnace. Next, the photoanode was soaked in 0.3 mM of N719 dye and *Curcuma longa* (turmeric) extract dye overnight in a dark condition after cooling to ambient temperature. Finally, the films were removed from the soaking process and dried in ambient conditions.

2.3 Preparation of Electrolyte

Potassium iodide (KI) mixed with iodine (I_2) in ethylene glycol, contains 10 ml of ethylene glycol, 1 ml of iodine and 0.83 g of potassium iodide. The solution was stirred on a hotplate for an hour to make it homogenous. The iodide electrolyte was stored in a tightly sealed bottle and covered with aluminum foil to avoid the solution picking up moisture from the air.

2.4 Preparation of Counter Electrode

4 mm holes were made on the active area of the FTO glass using a hand drill to allow the electrolyte can be added into the cell. Next, sputter coating was used to deposit the platinum on the FTO glass to serve as a counter electrode. The sputter coating was done for 45 seconds at 40 mA on the conductive side of the glass.

2.5 Preparation of Dye Sensitizer Solutions

N719 dye was prepared by adding 10 mg of Ruthenizer 535-BIS TBA into 25 ml of ethanol and the solution was stirred for 2 hours. Conical flask covered in aluminum foil was used to prepare the dye as to avoid interaction with light.

For the organic dye, approximately 2 g of *Curcuma longa* (turmeric) roots were thoroughly ground well and mixed with 25 ml of ethanol. The product was centrifuged for 15 mins and filtered. The extractant was stored in a conical flask covered with aluminum foil and protected from direct sunlight.

2.6 Cell Fabrication

Paraffin film was used to seal the platinum counter electrode and the SnO_2 photoanode. Iodide electrolyte was added after sealing through the hole on the counter electrode. The holes were covered with tape to avoid electrolyte leakage from the cell. The assembled cells as in Figure 2 (a), (b), and (c), then undergo characterization.

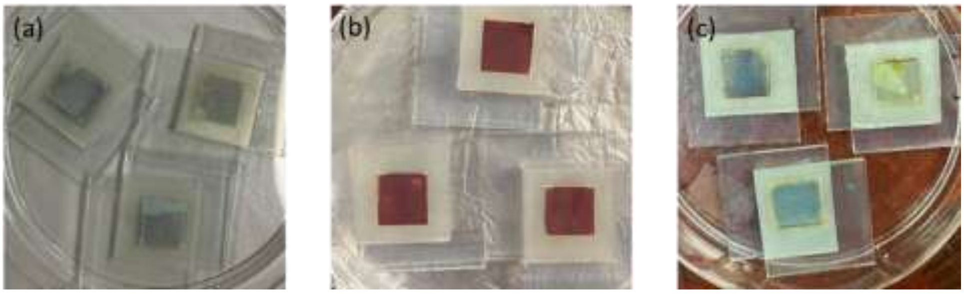

Figure 2. (a) Assembled cells without dye (b) Assembled cells with N719 dye (c) Assembled cells with turmeric extract dye.

3. RESULTS AND DISCUSSIONS

3.1 Structural and Surface Morphological Analysis

The powder XRD patterns from the commercially available high-purity SnO_2 particles annealed at 450 °C are shown in Figure 3. No impurity peaks were observed in the nanoparticles.

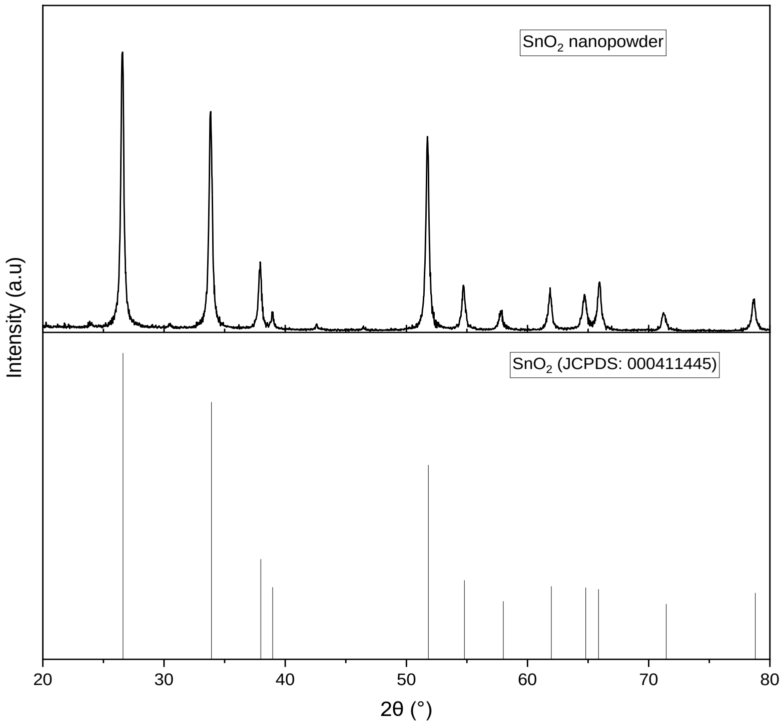

Figure 3. XRD patterns for SnO_2 nanopowder.

Figure 4 shows the SEM image of the thin films of SnO_2 nanoparticles, respectively after heating at 450 °C for 1 h. The pores in the image (red circles) indicating the structure's porosity, resulting in more dye absorption, thus enhance the cell performance.

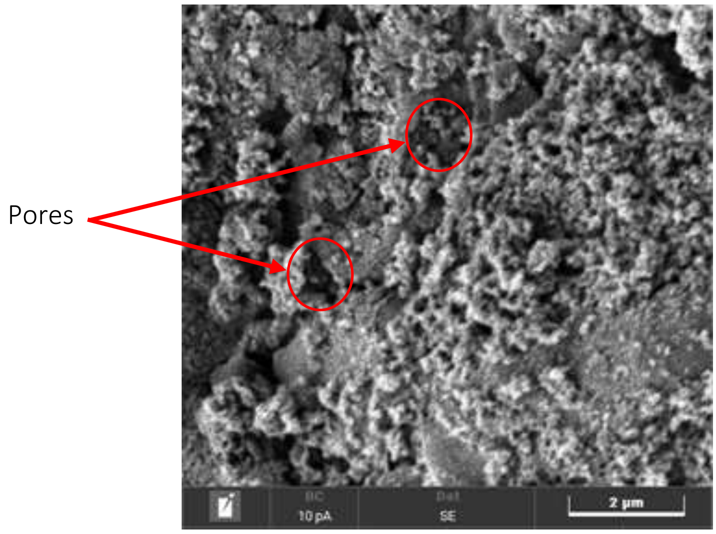

Figure 4. SEM image of SnO_2 nanopowder.

3.2 Optical Properties

UV-Visible absorption spectra of SnO_2 nanostructures are shown in Figure 5. By using a beam spectrometer, the UV-Vis spectra of SnO_2 nanoparticles were recorded in relation to the FTO glass substrate positioned in the reference beam (range 200 to 800 nm). The optical absorption of the samples increases as the wavelength decreases. SnO_2 without dye has peak around 250 nm in absorbance spectra. In the other hand, N719 dye absorption peaks are observed in the range of 200 nm to 300 nm.

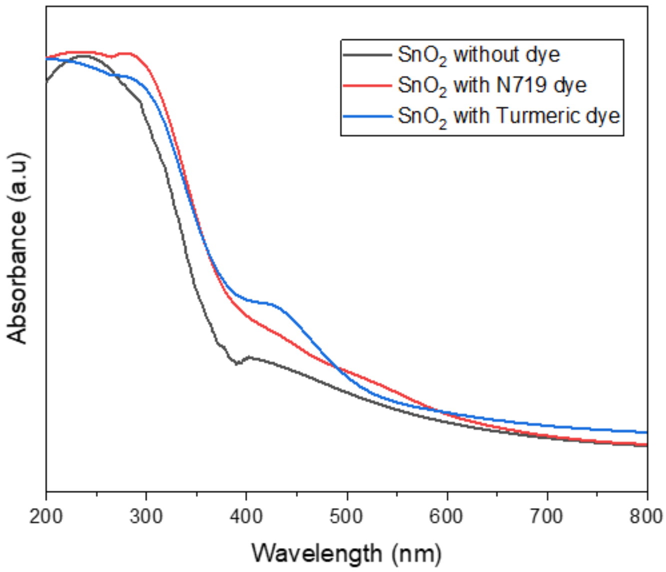

Figure 5. Absorption spectra of SnO_2 nanoparticles.

Meanwhile, *Curcuma longa* (turmeric) extract dye is still in the same range (200 nm to 300 nm) but has an extra peak around 440 nm. The SnO_2-based DSSC typically needs to be dye-loaded overnight. The higher dye adsorption indicates higher current density.

3.3 Performance of Fabricated Cell

The photocurrent density-voltage (J-V) curves of the DSSC under standard simulated AM 1.5 illumination (100 mWcm^{-2}) are shown in Figure 6.

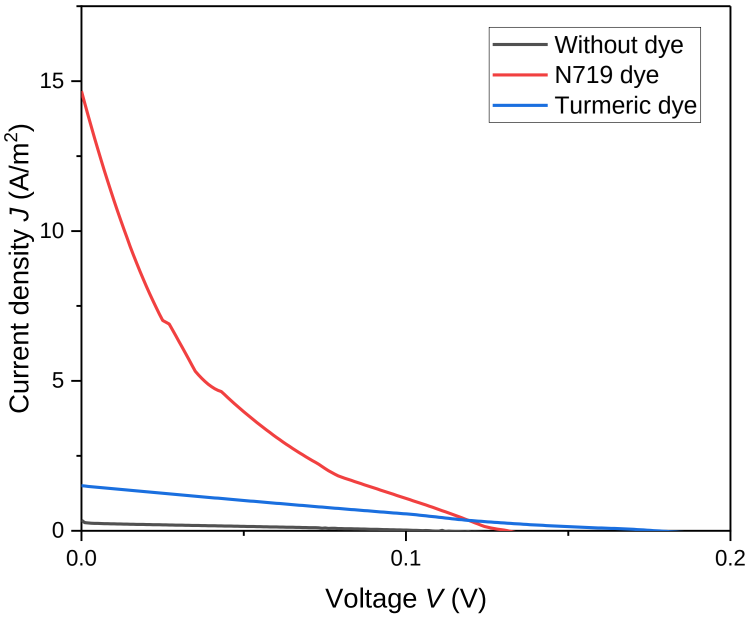

Figure 6. J-V curve of SnO_2-based DSSC

The summarized electrical performance parameters are listed in Table 1. As can be observed, the SnO_2-based DSSC achieved an efficiency of 0.0008 % without any dye sensitization. Higher efficiency was observed in the cell sensitized with N719 dye with 0.02 %. Meanwhile, the efficiency of cell with *Curcuma longa* (turmeric) extract dye was 0.007 %. Short circuit current density (J_{sc}) for the N719 dye cell was spotted to be higher than the turmeric dye cell. This demonstrates that the presence of dye is the primary variable affecting the J_{sc} [30].

Table 1 Electrical Performance of SnO_2-based DSSC

Dye used	J_{sc} (mA/cm^2)	V_{oc} (V)	Fill Factor (FF)	η (%)
Without dye	0.0355	0.1112	0.1941	0.0008
N719 dye	1.8766	0.1302	0.0821	0.0200
***Curcuma longa* (turmeric) extract dye**	0.1535	0.1753	0.2644	0.0071

4. CONCLUSION

SnO_2-based photoanode DSSC using organic and inorganic dyes were studied, analyzed and reported in this paper. Two types of dye, N719 dye and *Curcuma longa* (turmeric) extract dye, were used as sensitizers for the cells to investigate the optical and electrical performance of the DSSCs. In this work, the best efficiency for the SnO_2-based photoanode was 0.02 % using N719 dye, which is an inorganic dye. For the organic dye, turmeric extract dye was used, and the efficiency recorded was 0.007 %. This proved that the N719 dye is considered a better dye to be chosen for the SnO_2-based photoanode DSSC due to its better electrical performance. However, more studies need to be done on turmeric dye-based DSSC as an alternative sensitizer for a better efficiency device.

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