University of Benghazi
Faculty of Education Almarj

جامعة بنغازي
كلية التربية – المرج
ISSN 2518-5845

Global Libyan Journal

المجلة الليبية العالمية

العدد التاسع و الستون / يونيو / 2023

Performance improvement of dye sensitized solar cell using vanadium (V) oxide as additives

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Abstract

Additives treatment is a common way to improve the performance of dye sensitized solar cells. This project aims to investigate the performance improvement of DSSCs by treating Pt as a counter electrode and TiO_2-mesoporous layer with Vanadium(V) oxide (V_2O_{5-x}). The electrical performance of the DSSCs show improvement and that was clear on their open-circuit voltage (Voc), short-circuit current density (Jsc), and overall efficiency (η). The calculation of power conversion efficiency (PCE %) is improved from 8.25 % without Vanadium(V) oxide (V_2O_{5-x}) to 9.10 % with the device treated TiO_2-mesoporous layer with Vanadium(V) oxide (V_2O_{5-x}) and PCE 8.70 % with the device treated Pt with Vanadium(V) oxide (V_2O_{5-x}).

Keywords: dye-sensitized solar cell; Pt counter electrodes; Vanadium(V) oxide (V_2O_{5-x}); TiO_2 mesoporous layers.

تحسين أداء الخلايا الشمسية الصبغية باستخدام أكسيد الفاناديوم كمادة منشطة

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الملخص :

الخلايا الشمسية الصبغية تم دراستها بشكل مكثف وذلك لسهولة وقلة تكلفة انتاجها وكذلك بسبب ثبات الطاقة المنتجة منها. ولكن لاتزال تعاني الخلايا الشمسية الصبغية من ضعف في كفأه الإنتاج. في هذا العمل تم معالجة كلا من مادة البلاتين التي تستخدم كإلكترود مضاد والطبقة المسامية من TiO_2 بمادة (V_2O_{5-x}). هذه المعالجة بيت تحسن في الأداء الكهربي للخلايا المنتجة. هذا التحسن تمثل في كل من Voc و Jsc بذلك كفأة الخلايا ازدادت من 8.25 % بدون استخدام مادة (V_2O_{5-x}) الى 9.10 % بمعالجة الطبقة المسامية من TiO_2 بمادة (V_2O_{5-x}) و 8.70 % بمعالجة Pt وهي الأقل.

الكلمات المفتاحية: خلية شمسية حساسة للصبغة. أقطاب عداد Pt ؛ أكسيد الفاناديوم (V2O5-x) (V) ؛ طبقات TiO2 المسامية.

1. Introduction

Dye-sensitized solar cell (DSSC) was first introduced by Grätzel et al. in 1991 [1, 2]. Dye-sensitized solar cells (DSSCs) have received considerable attention as a potential alternative to conventional silicon-based solar cells due to their low cost, ease of fabrication, and high efficiency [3]. The highest efficiency of dye sensitized solar cells is approximately 13% [4, 5]. However, DSSCs still suffer from some drawbacks such as low efficiency, stability, and durability [6, 7]. In recent years, researchers have been exploring various approaches to enhance the performance of DSSCs. One of the most promising methods is the use of additives in the electrolyte and electrodes materials [8, 9, 10, 11, 12]. Among different types of additives, metal oxides have shown great potential to enhance the efficiency of DSSCs [13]. TiO_2 as photoanode materials were dipped in urea solution which gives remarkably improvement in the photoconversion efficiency of the TiO_2 DSSCs [14]. Hydroxypropyl methyl cellulose (HPMC) was used as an additive to TiO_2 electrode and electrochemistry impedance spectroscopy (EIS) analysis indicated that the resistance of TiO_2 film markedly decreased and the overall efficiency was increased [15]. Hydroxypropyl cellulose (HPC) were used as additive in the Pt precursor solution. The addition of HPC to a Pt electrode as a cathode increase the overall conversion efficiency of DSSCs [16]. Dye sensitized solar cells fabricated using 3-(2-aminoethylamino) propyl-methyldimethoxysilane (Me-EDA-Si) as an additive to Pt counter electrode. The addition of Me-EDA-Si resulting in Pt electrode with high active surface area and as a result the overall efficiency increased [17].

In this work, we investigate the performance improvement of DSSCs using vanadium (V) oxide as an additive to Pt cathode and TiO_2 photoanode (with the mesoporous TiO_2 layer). Different concentration of vanadium (V) oxide additive used but only the best concentration showing which was 2 wt%.

2. Experimental procedures

2.1. Device fabrication

Nine devices have been fabricated: three without using Vanadium(V) oxide (V_2O_{5-x}) additives (reference cells); three with using photoanodes treatment; and three with using Pt counter electrode treatment.

2.1.1. Device Fabrication – Glass Substrate Preparation

FTO coated glass substrates were cleaned ultrasonically while being bathed in solutions of detergent, de-ionized (DI) H_2O, acetone, and 2-propanol sequentially. Each bath lasted for 25 minutes. This was followed by the UV ozone treatment of the cleaned substrates for 20 minutes.

2.1.2. Device Fabrication – Photoanode Fabrication

The photoanode fabrication was divided into two categories, six untreated photoanodes and three treated photoanode. The untreated photoanode was prepared as follows. A compact TiO_2 layer was deposited onto the conductive side of the treated FTO glass substrates by spin coating a solution consisting of 75% ethanol solution with 0.3 M titanium diisopropoxide bis(acetylacetonate) at 3000 rpm for 20 seconds. This was followed by annealing of the substrates, first at 125 °C for 15 minutes, then at 470 °C for 20 minutes under normal atmospheric conditions. After annealing the compact layer, a 0.2 cm^2 x 12 μm thick layer of nano-crystalline TiO_2 (Ti-Nanoxide HT/SP, Solaronix) was deposited onto the top of the compact layers using the doctor blading technique. The substrates were then annealed at 125 °C for 15 minutes, then at 470 °C for 20 minutes. A TiO_2 light scattering layer was doctor bladed using Ti-Nanoxide R/SP paste (particle size > 100 nm) and was sintered at 450 ^oC for 30 minutes. After the annealing, the photoanodes were soaked for 30 minutes in a 40 mM aqueous solution of $TiCl_4$ at 70 °C, then rinsed with DI H_2O and ethanol and dried using compressed nitrogen. The photoanodes were soaked in a 0.3 mM N-719 dye solution in acetonitrile/valeronitrile with volume ratio (1:1) for 24 hours to allow dye attachment on to the mesoporous TiO_2 surface. Finally, the dye-attached photoanodes were rinsed with acetonitrile to remove any excess dye and dried using compressed nitrogen. The treated photoanodes was prepared similarly as we did with untreated photoanode excepted the nano-crystalline TiO_2 paste will treated by Vanadium(V) oxide (V_2O_{5-x}) before using.

2.1.3. Device Fabrication – Counter Electrode (CE) Fabrication

As the way we did with photoanodes fabrication the Pt counter electrode fabrication was divided into two categories, six untreated Pt counter electrodes and three treated Pt counter electrodes. The untreated Pt counter-electrode (CE) was fabricated on to the conductive side of the glass substrates as following: first, prepare Pt solution which containing a 20 mM solution of hydrogen hexachloroplatinate (IV) hexahydrate (99.9% trace metal basis). Second, spin coating the solution at 2000 rpm for 10 seconds. The substrates were then annealed at 400 °C for 15 minutes. The treated counter electrode was fabricated by same way we did with untreated counter electrode just we treated the Pt solution by Vanadium(V) oxide (V_2O_{5-x}) and then follow the same way.

2.1.4. Device Fabrication – Final Assembly

The CE was assembled with the photoanode using a 25 µm thick thermoplastic sealant. A circular hole approximately 9 mm in diameter was punched into the sealant. Outside the hole, two narrow channels approximately 1 mm in width were made along the line of the diameter of the hole for injection of the electrolyte. Three untreated photoanodes assembled with three untreated counter electrodes and these will be untreated devices or reference devices, three treated photoanodes assembled with three untreated counter electrodes and these will be treated TiO_2 photoanode devices, and three untreated photoanodes assembled with three treated counter electrodes and these will be Pt counter electrode devices.

2.1.5. Device Fabrication – Electrolyte Preparation

The iodide/tri-iodide electrolyte solution was then injected in between the electrodes. Finally, once the electrolyte solution has been injected, the channels were sealed with wax glue to ensure no leakage.

2.2. Current Density-Voltage Characteristics (J-V)

The current density-voltage (J-V) characteristics were obtained under air mass (AM) 1.5 illumination from a Xenon arc lamp (Newport 67005), at an intensity level of 100 mW/cm^2. National Renewable Energy Laboratory (NREL) Si solar cell was used for calibrating the light illumination intensity.

2.3. Results and discussions

Figure 1 shows the current density-voltage (J-V) curves for DSSCs fabricated devices. Table 1 summarizes the average values of the photovoltaic performance parameters of the devices. Voc increased from 0.68 V without Vanadium(V) oxide to 0.70 V as using Vanadium(V) oxide treated TiO_2-mesoporous layer and does not change by treated Pt-counter electrode. The FF decrease with Vanadium(V) oxide treated TiO_2-mesoporous layer from 0.62 to 0.61 and does not change with f Pt-counter electrode treatment.

Short circuit current density (Jsc) values show increment with the devices treated with Vanadium(V) oxide. This indicates that Vanadium(V) oxide treatment enhances the device's electrical performance due to increasing the conductivity of both Pt counter electrode and the photoanode, which accelerates the electron transfer rate. The Jsc with Vanadium(V) oxide treated photoanode increased more than Pt counter electrode treatment. The overall PCE was improved from ~ 8.25 % at without Vanadium(V) oxide to ~8.70 % with Vanadium(V) oxide treated Pt-counter electrode and the highest efficiency we got with Vanadium(V) oxide treated TiO_2-mesoporous layer (photoanode) which was 9.10 %.

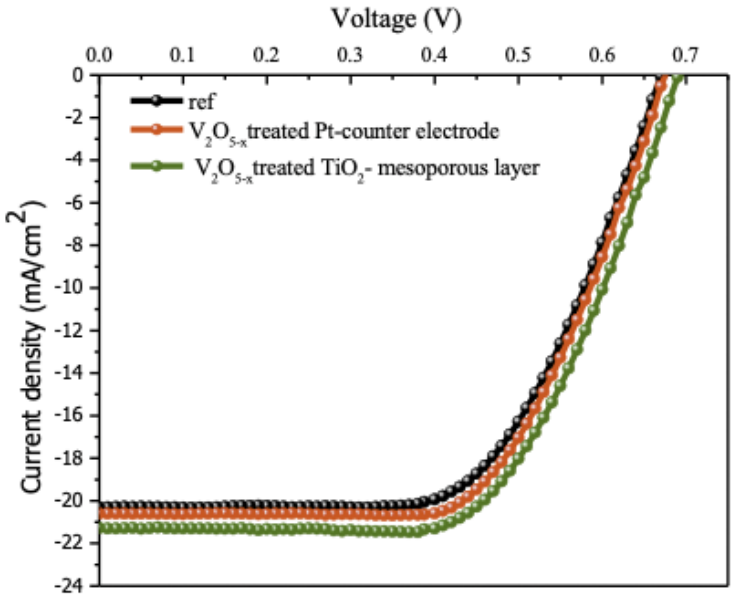

Figure 1. Current density-voltage (J-V) curves of DSSCs made with Pt counter electrode and TiO_2 photoanode treated with Vanadium(V) oxide (V_2O_{5-x})

Table 1. Performance of DSSCs made with Pt counter electrode and TiO_2 photoanode treated with Vanadium(V) oxide (V_2O_{5-x})

Devices	J_{sc} (mA/cm^2)	V_{oc} (V)	FF (%)	η (%)
Ref.	-19.35	0.68	62	8.25
V_2O_{5-x} treated Pt-counter electrode	-20.68	0.68	62	8.70
V_2O_{5-x} treated TiO_2-mesoporous layer	-21.47	0.70	61	9.10

It is expected that the using of vanadium (V) oxide as an additive to the Pt counter electrode and TiO_2-mesoporous layer (photoanode) will improve the performance of DSSCs. The highest performance of DSSCs with vanadium (V) oxide treated photoanode.

3. Conclusions

In summary, our research demonstrated that the addition of vanadium (V) oxide as an additive to the TiO_2 photoanode and Pt counter electrode can improve the electrical performance of DSSCs. The performance improvement can be attributed to the increase of the interconnection which reduces the charge transfer resistance. The improvement was clear in Jsc values. The significant improvement was with the vanadium (V) oxide treated TiO_2-mesoporous layer (photoanode).

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