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ساخت سلول خورشیدی حساس شده با رنگدانه با استفاده از نانوکامپوزیت TiO₂/ZnO به منظور افزایش بازده

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چکیده- در این مقاله کامپوزیتی از نانوذرات TiO₂/ZnO به عنوان مواد مورد استفاده در فوتوآند برای ساخت سلول‌های خورشیدی حساس شده با رنگدانه سنتز و به وسیله آنالیزهای پراش پرتو ایکس (XRD) و طیف سنج مادون قرمز (FT-IR) ارزیابی شده و سپس نانوپودر سنتز شده با استفاده از محلول ساخته شده به خمیر تبدیل گردید. طبق بررسی‌های پیشین، استفاده از فوتوآند‌های ساخته شده از کامپوزیت این دو ماده نیمه رسانا در مقایسه با استفاده از یکی از آنها، عملکرد فوتوولتائی بهتری را فراهم می‌کند. عملکرد سلول ساخته شده با استفاده از دستگاه شبیه ساز نور خورشید (100 mW/cm²) ارزیابی شده و بازده تبدیل نور به انرژی الکتریکی معادل ۱/۰۴٪ بدست آمد. همچنین دیگر مشخصه‌های فوتوولتائی شامل جریان مدار کوتاه، ولتاژ مدار باز و فاکتور پر شدن نیز به ترتیب ۰/۳۰۴۷ و ۰/۷۰۴۵ V، ۴/۸۴ mA/cm² بدست آمدند.

کلید واژه- سلول‌های خورشیدی حساس شده با رنگدانه، فتوآند، فوتوولتائی، نانوکامپوزیت TiO₂/ZnO

Fabrication of dye-sensitized solar cell using TiO₂/ZnO nanocomposite for efficiency enhancement

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Abstract- In this paper, composite of TiO₂/ZnO nanoparticles were synthesized as photoanode material in fabrication of dye-sensitized solar cell (DSSC) and characterized by X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FT-IR) analyses and then synthesized nano-powder turned into a paste using prepared solution. It is demonstrated that this nano-composite photoanode provides better photovoltaic performance compare with using bare form of mentioned semiconductor oxides. The performance of fabricated cell was evaluated with solar simulator (100 mW/cm²) and photoelectric conversion efficiency (PEC) of 1.04% is given. Also, other photovoltaic parameters include short circuit current density (I_{sc}), open circuit voltage and fill factor are 4.84 mA/cm², 0.7045 V and 0.3047, respectively.

Keywords: Dye-sensitized solar cells, Nanostructure, Photoanode, Photovoltaic, TiO₂/ZnO nanocomposite.

1. Introduction

In the recent past, solar energy have attracted significant attention due to being sustainable and clean without carbon emission. In 1991, O'Regan and Grätzel introduced first dye-sensitize solar cells (DSSCs) based on TiO_2 [1]. A typical DSSC consist of a semiconductor film coated on a fluorine-doped tin oxide (FTO) glass substrate to form photoanode, a platinum-coated FTO to form counter electrode, a liquid redox electrolyte and a solution contains dye molecules. Dye solution acts as a light absorber and injects electrons into the conduction band of a semiconductor. Injected electrons then diffuse through the semiconductor film, afterwards to the conductive glass substrate. The oxidized dye molecules regenerate by the redox system then these oxidized redox, regenerate by diffusing to the counter electrode where electrons receive from photoanode [2].

Semiconductor photoanode is the backbone of DSSCs and plays a vital role in the performance of DSSCs. TiO_2 is the most-used and well-known semiconductor material because of its advantages such as stability, non-toxicity, high surface area, low cost and high charge transfer capability [3, 4]. Besides TiO_2 , semiconductors such as ZnO , SnO_2 , Fe_2O_3 , Nb_2O_5 , ZrO_2 , Al_2O_3 and etc. have been studied. Among all semiconductor materials, ZnO showed better properties; however, its conversion efficiency is much lower than TiO_2 . In despite of TiO_2 , ZnO possess higher electron mobility but on the other hand it has lower stability [5]. Subsequently, to use all benefits of these two materials, fabrication of TiO_2/ZnO based DSSCs showed better performance compared with using one of them [6-8].

In this study, to fabricate composite based DSSC, first TiO_2/ZnO composite paste was prepared as semiconductor film and then, the photovoltaic performance was evaluated.

2. Experimental

2.1. Materials and chemicals

Titanium oxide nanopowders (TiO_2 -anatase, 30-50 nm), zinc acetate dehydrate ($\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$, 98%), isopropoxide ($\text{Ti}[\text{OCH}(\text{CH}_3)_2]_3$), citric acid ($\text{C}_6\text{H}_8\text{O}_7$). Acetonitrile ($\text{C}_2\text{H}_3\text{N}$), potassium iodide (KIO_3) and iodine (I_2) for preparing electrolyte solution. Ruthenium based dye ($\text{N}719$), platinum (Pt), FTO conductive glass (sheet resistance $15\ \Omega/\square$).

2.2. Preparation of TiO_2/ZnO paste

Ethylene glycol was heated at 70°C then titanium (IV) isopropoxide was added and slowly stirred. Then, citric acid was added and the solution was stirred at a constant temperature of 70°C to get clear viscose solution. Zinc acetate dehydrate and TiO_2 nanoparticles powder at the optimum weight ratio ($\text{ZnO}/\text{TiO}_2 = 2/97$) [6, 9] along with prepared solution were ground well to the mortar to obtain a viscous paste [10].

2.3. Preparation of electrolyte

For preparation of electrolyte solution, first, 10 ml acetonitrile was added to 20 ml ethylene glycol under stirring. Subsequently, 1.0370 g potassium iodide and 0.3307 g iodine was added respectively. Prepared electrolyte was stirred until homogenous solution appeared [11].

2.4. Fabrication of DSSC

For cleaning FTO glass substrate, it was sonicated with deionized water, hydrochloric acid, acetone and ethanol respectively and dried at 70°C . To prepare the photoanode, TiO_2/ZnO paste was deposited onto a conductive glass substrate using doctor blade method. This electrode first pre-heated

at 120 °C, then calcined at 450 °C. For dye loading, the photoanode was immersed in 0.3 mM dye solution (N719) in darkness for 24 hrs. Counter electrode was obtained by depositing a thin layer of platinum on another conductive glass substrate. Finally, two electrodes were bonded together using surlyn sheet and then electrolyte solution was injected through a small hole on the counter electrode to fill the space between the two electrodes. The active area of fabricated cell is 0.6 cm². The photograph of the fabricated DSSC in laboratory scale is shown in Fig. 1.

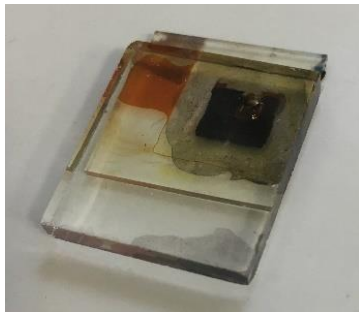


Fig. 1: The fabricated DSSC

3. Results and Discussion

The FT-IR spectroscopy was measured and given in Fig. 2, which obviously revealed the formation of ZnO in TiO₂ nanoparticles. The broad IR transmittance peak is in the 3000–3500 cm⁻¹ range which indicated high amount of alcohol based component in prepared nanocomposite. In this curve, peaks at 516.98 cm⁻¹ and 668.69 cm⁻¹ are for O–Ti–O bonding in anatase morphology and ZnO. Similarly, Fig. 3 shows the XRD pattern of TiO₂/ZnO powder to examine the phase and crystallinity of the as-prepared nanocomposite. Sharp peaks indicate high crystallinity of TiO₂ and ZnO in the nanocomposite. The XRD peaks in the range of 2θ from 25.3°, 38.0°, 48.1°, 54.1°, 55.1°, 62.8°, 68.9°, 75.2°, 77.2° attributed to (101), (001), (200), (102), (211), (202), (116), and (210) crystalline structures of anatase. As well, several slight diffraction peaks at 2θ value of 31.7° (100), 34.4° (002), 36.3° (101), 47.0° (201) were

observed which was known as hexagonal ZnO nanoparticles.

These XRD results further confirmed the successful preparation of the nanocomposites consisting of both TiO₂ and ZnO phases. The sharpness, as well as line widths of the peaks, were certified that the ZnO has a nanocrystalline structure.

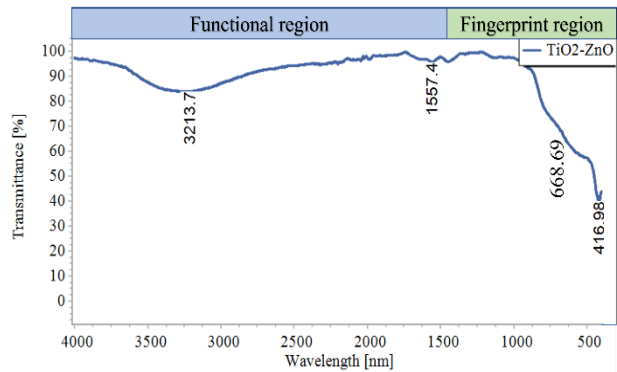


Fig. 2: FTIR spectra of the TiO₂/ZnO nanocomposite

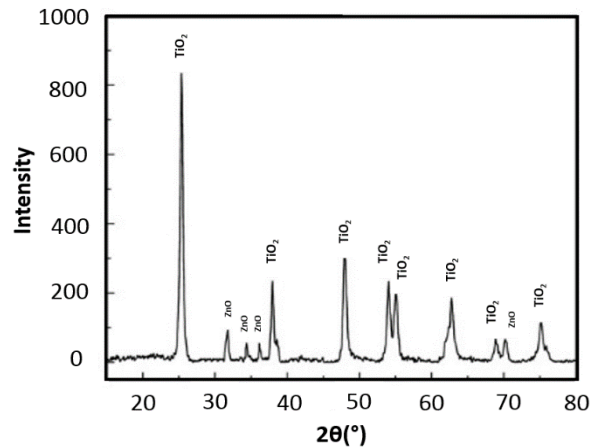


Fig. 3: XRD pattern of the TiO₂/ZnO nanocomposite

The current-voltage (I-V) measurements under light sources of 100 mW/cm² and 1.0 air mass (AM) is represented in Fig. 4. The photovoltaic parameters include I_{sc}, V_{oc} and FF are 1.04%, 4.82 mA/cm², 0.304 V and 0.304 V, respectively. The existence of free carriers by light photons absorption.

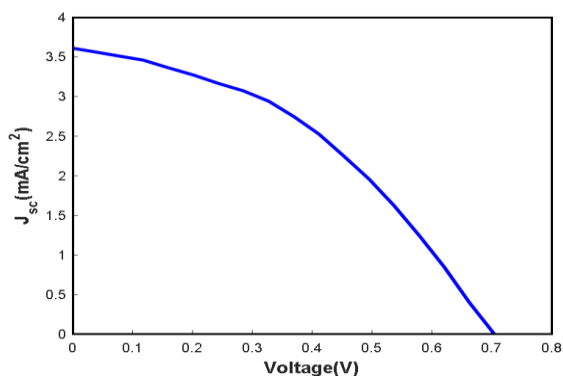


Fig. 4: I-V curve of the fabricated DSSC

4. Conclusion

DSSC based on TiO₂-ZnO nanocomposite have been successfully fabricated using optimum amount of ZnO in prepared nanocomposite. The produced nanoparticles were used as a part of photoanode in the DSSC and the paste were prepared with simple method to use in the photoanode of the DSSC. Fabrication of electrolyte was also done at the laboratory. The fabricated nanocomposite was characterized using XRD, and FTIR techniques. The crystallography of the pastes, using X-ray experiment, illustrated the existence of both TiO₂ and ZnO in high crystalline structure. Presence of ZnO contents on TiO₂ surface enhance the rapid transport of free electrons. Consequently, the solar cell performance improved due to J_{sc} improvement. From the results of I-V curve characterization, with a short-circuit current of 3.6 mA/cm², open-circuit voltage of 0.72 V and fill factor of 0.34 represented photoelectric conversion efficiency of 1.04%. The gained results were attributed to the nanocrystalline TiO₂ and ZnO nanocomposite structure, which considerably enhanced the light absorption by multi-scattering effects, and dye adsorption due to smaller crystal size, more grain boundaries, and a bigger surface area.

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