The ۲۸th Iranian Conference on Optics and Photonics (ICOP ۲۰۲۲), and the ۱٤th Iranian Conference on Photonics Engineering and Technology (ICPET ۲۰۲۲).
Shahid Chamran University of Ahvaz, Khuzestan, Iran, Feb. ۱-۳, ۲۰۲۲

ساخت سلول خورشیدی حساس شده با رنگدانه با استفاده از نانوکامپوزیت TiO_2/ZnO به منظور افزایش بازده

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چکیده- در این مقاله کامپوزیتی از نانوذرات TiO_2/ZnO به عنوان مواد مورد استفاده در فوتوآند برای ساخت سلول‌های خورشیدی حساس شده با رنگدانه سنتز و به وسیلهٔ 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 ($۱۰۰\ mW/cm^2$) ارزیابی شده و بازده تبدیل نور به انرژی الکتریکی معادل ۱/۰۴٪ بدست‌آمد. همچنین دیگر مشخصه‌های فوتوولتائی شامل جریان مدار کوتاه، ولتاژ مدار باز و فاکتور پرشدن نیز به ترتیب $۴/۸۴\ mA/cm^2$، $۰/۷۰۴۵\ V$ و ۰/۳۰۴۷ بدست آمدند.

کلید واژه- سلول‌های خورشیدی حساس شده با رنگدانه، فتوآند، فوتوولتائی، نانوکامپوزیت TiO_2/ZnO

Fabrication of dye-sensitized solar cell using TiO_2/ZnO nanocomposite for efficiency enhancement

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Abstract- In this paper, composite of TiO_2/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 (۱۰۰ mW/cm^2) and photoelectric conversion efficiency (PEC) of ۱,۰٤٪ is given. Also, other photovoltaic parameters include short circuit current density (I_{SC}), open circuit voltage and fill factor are ٤,۸٤ mA/cm^2, ۰,۷۰٤٥ V and ۰,۳۰٤۷, respectively.

Keywords: Dye-sensitized solar cells, Nanostructure, Photoanode, Photovoltaic, TiO_2/ZnO nanocomposite.

۱. Introduction

In the recent past, solar energy have attracted significant attention due to being sustainable and clean without carbon emotion. In ۱۹۹۱, O'Regan and Grätzel introduced first dye-sensitize solar cells (DSSCs) based on $TiO_۲$ [۱]. 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 [۲].

Semiconductor photoanode is the backbone of DSSCs and plays a vital role in the performance of DSSCs. $TiO_۲$ 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 [۳, ٤]. Besides $TiO_۲$, semiconductors such as ZnO, $SnO_۲$, $Fe_۲O_۳$, $Nb_۲O_٥$, $ZrO_۲$, $Al_۲O_۳$ and etc. have been studied. Among all semiconductor materials, ZnO showed better properties; however, its conversion efficiency is much lower than $TiO_۲$. In despite of $TiO_۲$, ZnO possess higher electron mobility but on the other hand it has lower stability [٥]. Subsequently, to use all benefits of these two materials, fabrication of $TiO_۲$/ZnO based DSSCs showed better performance compared with using one of them [٦-٨].

In this study, to fabricate composite based DSSC, first $TiO_۲$/ZnO composite paste was prepared as semiconductor film and then, the photovoltaic performance was evaluated.

۲. Experimental

۲,۱. Materials and chemicals

Titanium oxide nanopowders ($TiO_۲$-anatase, ۳۰-٥۰ nm), zinc acetate dehydrate ($Zn(CH_۳COO)_۲$,۲$H_۲O$, ۴۰ □□), □□□□□□□□ □□□□□□ (□۲□۶□۲), □□□□□□□□ (□□) isopropoxide ($Ti[OCH(CH_۳)_۲]_٤$), citric acid ($C_٦H_۸O_۷$). Acetonitrile ($C_۲H_۳N$), potassium iodide ($KIO_۳$) and iodine ($I_۲$) for preparing electrolyte solution. Ruthenium based dye (N۷۱۹), platinum (Pt), FTO conductive glass (sheet resistance ۱۵□/□□).

۲,۲. Preparation of $TiO_۲$ /ZnO paste

Ethylene glycol was heated at ٦۰ ºC then titanium (IV) isopropoxide was added and slowly stirred. Then, citric acid was added and the solution was stirred at a constant temperature of ٦۰˚C to get clear viscose solution. Zinc acetate dehydrate and $TiO_۲$ nanoparticles powder at the optimum weight ratio ($ZnO/TiO_۲$ = ۳/۹۷) [٦, ۹] along with prepared solution were ground well to the mortar to obtain a viscous paste [۱۰].

۲,۳. Preparation of electrolyte

For preparation of electrolyte solution, first, ۱۰ ml acetonitrile was added to ۲,٥ ml ethylene glycol under stirring. Subsequently, ۱,۰۳۷٥ g potassium iodide and ۰,۳۳۰۷ g iodine was added respectively. Prepared electrolyte was stirred until homogenous solution appeared [۱۱].

۲,۴. Fabrication of DSSC

For cleaning FTO glass substrate, it was sonicated with deionized water, hydrochloric acid, acetone and ethanol respectively and dried at ۷۰ ºC. To prepare the photoanode, $TiO_۲$/ZnO paste was deposited onto a conductive glass substrate using doctor blade method. This electrode first pre-heated at ۱۲۰ ºC, then calcined at ٤٥۰°C. For dye loading, the photoanode was immersed in ۰,۳ mM dye solution (N۷۱۹) in darkness for ۲٤ 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 ۰,٥ cm*۰,٥ cm. The photograph of the fabricated DSSC in laboratory scale is shown in Fig. ۱.

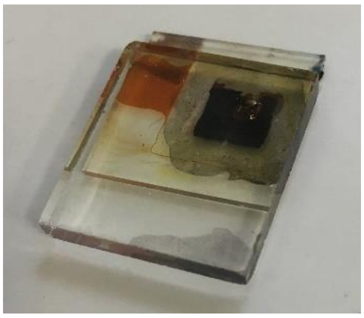

Fig. ۱: The fabricated DSSC

۳. Results and Discussion

The FT-IR spectroscopy was measured and given in Fig. ۲, which obviously revealed the formation of ZnO in $TiO_۲$ nanoparticles. The broad IR transmittance peak is in the ۳۰۰۰–۳٥۰۰ $cm^{-۱}$ range which indicated high amount of alcohol based component in prepared nanocomposite. In this curve, peaks at ٤۱٦,۹۸ $cm^{-۱}$ and ٦٦٨,٦۹ $cm^{-۱}$ are for O–Ti–O bonding in anatase morphology and ZnO. Similarly, Fig. ۳ shows the XRD pattern of $TiO_۲$/ZnO powder to examine the phase and crystallinity of the as-prepared nanocomposite. Sharp peaks indicate high crystallinity of $TiO_۲$ and ZnO in the nanocomposite. The XRD peaks in the range of ۲θ from ۲٥,۳٥, ۳٨,۰٥, ٤٨,۱٥, ٥٤,۱٥, ٥٥,۱٥, ۶۲,٨□, ۶٨,۹□, □□□ ۷۵,۲□, □□□□□ □□□ attributed □□ □□□ (۱۰۱), (۰۰٤), (۲۰۰), (۱۰٥), (۲۱۱), (۲۰٤), (۱۱٦), and (۲۱٥) crystalline structures of anatase. As well, several slight diffraction peaks at ۲θ value of ۳۱,۷٥ (۱۰۰), ۳۴,۴□ (۰۰۲), ۳۶,۳□ (۱۰۱), □□□ ۷۰,۰□ (۲۰۱) □□□ □□□□ observed which was known as hexagonal ZnO nanoparticles.

These XRD results further confirmed the successful preparation of the nanocomposites consisting of both $TiO_۲$ and ZnO phases. The sharpness, as well as line widths of the peaks, were certified that the ZnO has a nanocrystalline structure.

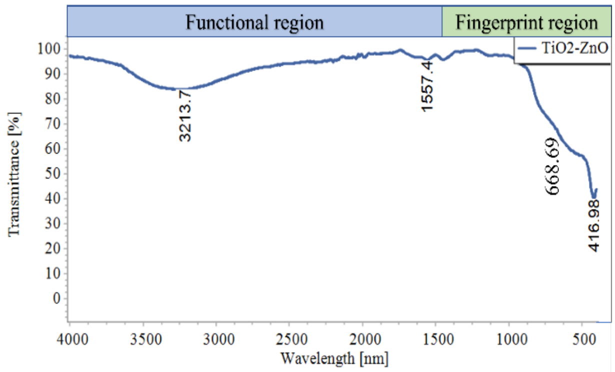

Fig. ۲: FTIR spectra of the $TiO_۲$/ZnO nanocomposite

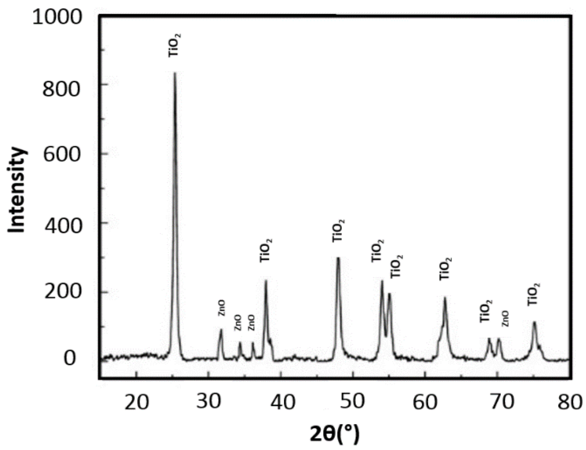

Fig. ۳: XRD pattern of the $TiO_۲$/ZnO nanocomposite

The current-voltage (I-V) measurements under light sources of ۱۰۰ mW/$cm^۲$ and ۱,٥ air mass (AM) is represented in Fig. ۴. □□□ □□□□□□□ □□□□□□□□□ □□□□ PCE and other photovoltaic parameters include I_{SC}, V_{OC} and FF are ۱,۰٤٪, ٤,٨٤ mA/$cm^۲$, ۰,۷۰٤٥ V and ۰,۳۰۴۷, □□□□□□□□□□□□. □□□ □□□□□□□ □□□□□□□□□ □□□ existence of free carriers by light photons absorption.

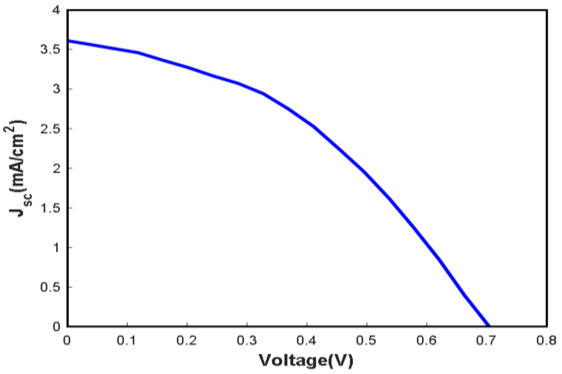

Fig. ٤: I-V curve of the fabricated DSSC

۴. Conclusion

DSSC based on $TiO_۲$-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 $TiO_۲$ and ZnO in high crystalline structure. Presence of ZnO contents on $TiO_۲$ 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 ٤,٨٤ mA/cm^۲, open-circuit voltage of ۰,۷۰٤٥ V and fill factor of ۰,۳۰٤۷ represented photoelectric conversion efficiency of ۱,۰٤٪. The gained results were attributed to the nanocrystalline $TiO_۲$ 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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