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

ساحل هیربدی[1]، احمد جامه‌خورشید[1]، تهمینه جلالی[2] و شهریار عصفوری[1]

[1]گروه مهندسی شیمی، دانشگاه خلیج فارس، بوشهر، ایران؛ [2]گروه فیزیک، دانشگاه خلیج فارس، بوشهر، ایران

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 پر شدن نیز به ترتیب mA/cm^2 ۴/۸۴، V ۰/۷۰۴۵ 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

S. Hirbodi[1], A. Jamekhorshid[1,*], T. Jalali[2], and S. Osfouri[1]

[1]Department of Chemical Engineering, Persian Gulf University, Bushehr, Iran; [2]Department of Physics, Persian Gulf University, Bushehr, Iran; * jamekhorshid@pgu.ac.ir

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, ۴]. Besides $TiO_{۲}$, semiconductors such as ZnO, $SnO_{۲}$, $Fe_{۲}O_{۳}$, $Nb_{۲}O_{۵}$, $ZrO_{۲}$, $Al_{۲}O_{۳}$ 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 [۵]. 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 [۶-۸].

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, ۳۰-۵۰ nm), zinc acetate dehydrate ($Zn(CH_{۳}COO)_{۲}$,۲$H_{۲}O$, ۴۰ □□), □□□□□□□□ □□□□□□ (□۲□۶□۲), □□□□□□□□ (□□) isopropoxide ($Ti[OCH(CH_{۳})_{۲}]_{۴}$), citric acid ($C_{۶}H_{۸}O_{۷}$). Acetonitrile ($C_{۲}H_{۳}N$), 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 ۶۰ 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 ۶۰˚C to get clear viscose solution. Zinc acetate dehydrate and $TiO_{۲}$ nanoparticles powder at the optimum weight ratio (ZnO/$TiO_{۲}$ = ۳/۹۷) [۶, 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 ۲,۵ ml ethylene glycol under stirring. Subsequently, ۱,۰۳۷۵ 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.

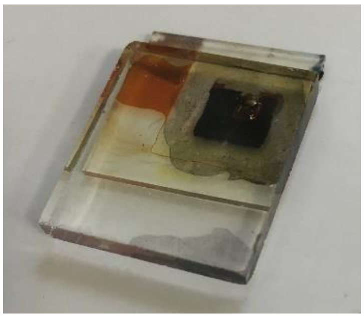

Fig. ۱: The fabricated DSSC

۳. Results and Discussion

The FT-IR spectroscopy was measured and given in Fig. ۲, which obviously revealed the formation of ZnO in TiO۲ 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 ٦٦۸,٦۹ cm⁻۱ are for O–Ti–O bonding in anatase morphology and ZnO. Similarly, Fig. ۳ shows the XRD pattern of TiO۲/ZnO powder to examine the phase and crystallinity of the as-prepared nanocomposite. Sharp peaks indicate high crystallinity of TiO۲ and ZnO in the nanocomposite. The XRD peaks in the range of ۲θ from ۲٥,۳٥, ۳۸,۰٥, ٤۸,۱٥, ٥٤,۱٥, ٥٥,۱٥, ۶۲,۸□, ۶۸,۹□, □□□ 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 TiO۲ and ZnO phases. The sharpness, as well as line widths of the peaks, were certified that the ZnO has a nanocrystalline structure.

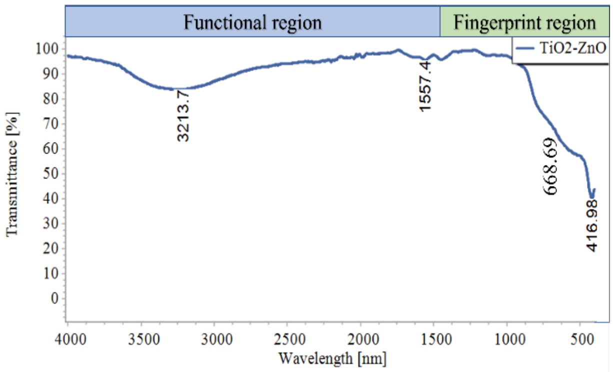

Fig. ۲: FTIR spectra of the TiO۲/ZnO nanocomposite

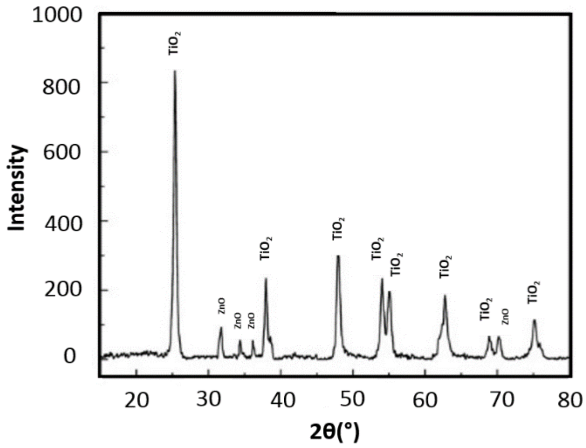

Fig. ۳: XRD pattern of the TiO۲/ZnO nanocomposite

The current-voltage (I-V) measurements under light sources of ۱۰۰ mW/cm۲ 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٪, ٤,۸٤ mA/cm۲, ۰,۷۰٤٥ V and ۰,۳۰۴۷, □□□□□□□□□□□□□□. □□□ □□□□□□□□ □□□□□□□□□□ □□□ existence of free carriers by light photons absorption.

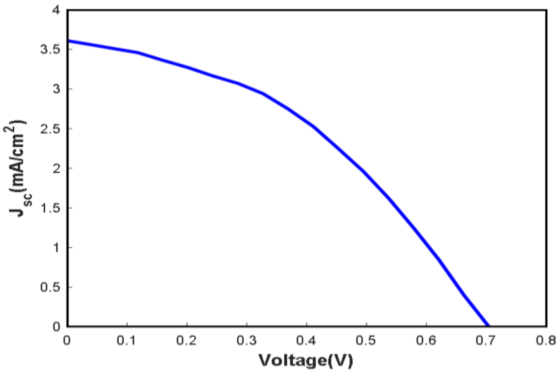

Fig. ٤: I-V curve of the fabricated DSSC

۴. Conclusion

DSSC based on TiO۲-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 TiO۲ and ZnO in high crystalline structure. Presence of ZnO contents on TiO۲ 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/cm۲, 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 TiO۲ 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.

References

[۱] B. O'regan and M. Grätzel, "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO ۲ films," *nature,* vol. ۳٥۳, no. ٦۳٤٦, pp. ۷۳۷-۷٤۰, ۱۹۹۱.

[۲] J. Gong, J. Liang, and K. Sumathy, "Review on dye-sensitized solar cells (DSSCs): Fundamental concepts and novel materials," *Renewable and Sustainable Energy Reviews,* vol. ۱٦, no. ٨, pp. ٥٨٤٨-٥٨٦۰, ۲۰۱۲/۱۰/۰۱/ ۲۰۱۲.

[۳] S. S. Kanmani and K. Ramachandran, "Synthesis and characterization of TiO۲/ZnO core/shell nanomaterials for solar cell applications," *Renewable Energy,* vol. ٤۳, pp. ۱٤۹-۱٥٦, ۲۰۱۲/۰۷/۰۱/ ۲۰۱۲.

[٤] S. Umale, V. Sudhakar, S. M. Sontakke, K. Krishnamoorthy, and A. B. Pandit, "Improved efficiency of DSSC using combustion synthesized TiO۲," *Materials Research Bulletin,* vol. ۱۰۹, pp. ۲۲۲-۲۲٦, ۲۰۱۹/۰۱/۰۱/ ۲۰۱۹.

[٥] Q. Zhang and C. J. N. Li, "TiO۲ coated ZnO nanorods by mist chemical vapor deposition for application as photoanodes for dye-sensitized solar cells," vol. ۹, no. ۹, p. ۱۳۳۹, ۲۰۱۹.

[٦] W. Ahmad *et al.*, "Synthesis of zinc oxide/titanium dioxide (ZnO/TiO۲) nanocomposites by wet incipient wetness impregnation method and preparation of ZnO/TiO۲ paste using poly (vinylpyrrolidone) for efficient dye-sensitized solar cells," vol. ۲۲۲, pp. ٤۷۳-٤٨۰, ۲۰۱٦.

[۷] M. Yang *et al.*, "TiO۲ nanoparticle/nanofiber–ZnO photoanode for the enhancement of the efficiency of dye-sensitized solar cells," vol. ۷, no. ٦٦, pp. ٤۱۷۳٨-٤۱۷٤٤, ۲۰۱۷.

[٨] A. M. Rheima, D. H. Hussain, and H. J. Abed, "Fabrication of a new photo-sensitized solar cell using TiO۲\ZnO Nanocomposite synthesized via a modified sol-gel Technique," in *IOP Conference Series: Materials Science and Engineering*, ۲۰۲۰, vol. ۹۲٨, no. ٥, p. ۰٥۲۰۳٦: IOP Publishing.

[۹] Y.-H. Nien *et al.*, "Investigation of Dye-Sensitized Solar Cell With Photoanode Modified by TiO_2-ZnO Nanofibers," vol. ۳۳, no. ۲, pp. ۲۹٥-۳۰۱, ۲۰۲۰.

[۱۰] S. K. Park, T. K. Yun, J. Y. J. J. o. n. Bae, and nanotechnology, "Combined Embedding of N/F-Doping and CaCO۳ Surface

Modification in the TiO_2 Photoanode for Dye-Sensitized Solar Cells," vol. ۱٦, no. ۳, pp. ۲٥۷۱-۲٥۷٥, ۲۰۱٦.

[۱۱] P. Gu *et al.*, "Influence of electrolyte proportion on the performance of dye-sensitized solar cells," vol. ۷, no. ۱۰, p. ۱۰٥۲۱۹, ۲۰۱۷.