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DEVELOPMENT OF A SINGLE-LAYER TiO_2 PHOTOANODE FOR DYE-SENSITIZED SOLAR CELL (DSSC)

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Dye-sensitized solar cells (DSSC) are considered a promising low-cost and flexible alternative to conventional silicon-based photovoltaic technologies. This work reports the fabrication and analysis of DSSC based on a single-layer nanostructured TiO_2 photoanode. The proposed cell architecture is simplified by eliminating the conventional double-layer configuration, which reduces fabrication complexity and material consumption. The electrochemical and photovoltaic characteristics of the devices were systematically investigated. The energy conversion efficiency of the developed single-layer design is approximately twice that of a conventional two-layer cell. The performance enhancement is attributed to reduced internal resistance, improved electron transport, and suppressed charge recombination. The results demonstrate the potential of simplified single-layer DSSC architectures for transparent, flexible, and low-cost energy-harvesting applications.
Keywords: *Single-layer TiO_2 Photoanode, DSSC; Simplified architecture; Photovoltaic performance; Electrochemical impedance spectroscopy; Charge transport; TiO_2 nanoparticle morphology*
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INTRODUCTION

Dye-sensitized solar cells (DSSCs) have emerged as a promising third-generation photovoltaic technology, offering significant advantages over traditional silicon-based solar cells, including low production costs, mechanical flexibility, and efficient performance under low-intensity or diffuse-light conditions [1,2]. These features make DSSC attractive for diverse applications such as indoor energy harvesting, building-integrated photovoltaics (BIPV), and self-powered portable electronics.

At the core of a DSSC is the photoanode, traditionally composed of a bilayer titanium dioxide (TiO_2) structure. This typically includes a compact underlayer that prevents electron recombination, and a mesoporous upper layer that increases the surface area for dye adsorption. While effective, this configuration introduces multiple processing steps, including sequential deposition, high-temperature sintering, and additional material consumption [3,4]. Such complexity limits the scalability and cost-effectiveness of DSSC manufacturing, especially for flexible or transparent devices.

In recent years, there has been growing interest in simplifying DSSC architectures by implementing single-layer TiO_2 photoanodes. These structures aim to eliminate the compact layer while retaining efficient electron transport and sufficient dye-loading capacity. The anatase phase of TiO_2 is particularly favored for such applications due to its suitable bandgap (~3.2 eV), high chemical and thermal stability, and favorable surface morphology for dye adsorption [5,6]. Nanostructured TiO_2 pastes, spin-coating techniques, and low-temperature annealing have further enabled the development of uniform, thin, and reproducible films suitable for single-layer designs.

Moreover, the choice of dye and electrolyte significantly influences DSSC performance. Ruthenium-based dyes, such as Ruthenizer 535, offer broad spectral absorption and strong binding to TiO_2 surfaces. Simultaneously, gel-polymer electrolytes provide improved stability compared to liquid electrolytes by minimizing solvent leakage and enhancing long-term performance [7,8]. The integration of these components within a single-layer TiO_2 framework opens new opportunities for efficient, low-cost solar cell fabrication.

In this study, we propose and experimentally evaluate a simplified DSSC design based on a single nanostructured TiO_2 photoanode. The research focuses on three main objectives:

1. To fabricate and characterize single-layer TiO_2 films using spin-coating and anatase-phase nanoparticles;
2. To investigate the influence of photoanode morphology on interfacial charge-transfer and recombination processes;
3. To compare the photovoltaic performance and impedance characteristics of single-layer cell with conventional bilayer counterparts.

By addressing these points, the study contributes to the growing body of research on scalable and commercially viable solar technologies with reduced complexity and enhanced stability.

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1. MATERIALS AND METHODS

Dye-sensitized solar cell (DSSC) belongs to the class of thin-film photovoltaic devices based on wide-bandgap semiconductor photoanodes, most commonly TiO_2. A typical DSSC consists of a transparent conducting oxide substrate serving as the photoelectrode, a nanostructured semiconductor layer responsible for electron transport, a redox electrolyte that enables charge regeneration, and a counter electrode made of platinum or other conductive materials. The photoelectrochemical processes occurring at the semiconductor–electrolyte interface determines the overall photovoltaic performance of the device.

Optimization of liquid electrolytes (LEs).

Such electrolytes are used as a redox mediator for solar cell or batteries technologies. Poly(methyl methacrylate) (PMMA) and polyethylene oxide (PEO) have been optimized to prepare the liquid electrolyte (LE). Difference ratios of polymer contents were added with fixed amounts of 0.25 ml ethylene carbonate (EC), 0.25 g propylene carbonate (PC), 1 ml dimethylformamide (DMF), 0.2 g tetrapropylammoniodide (TPAI). All electrolytes mixer are dried out at room temperature and 0.02 g iodine (I_2) were added with every electrolytes [9,10].

Table 1. Composition of liquid electrolyte

No. samples	PEO	PMMA	DMF	EC	PC	TPAI	I_2
	g	g	ml	ml	g	g	g
1	1	0	1	0.25	0.25	0.2	0.02
2	0.8	0.2	1	0.25	0.25	0.2	0.02
3	0.6	0.4	1	0.25	0.25	0.2	0.02
4	0.5	0.5	1	0.25	0.25	0.2	0.02
5	0.4	0.6	1	0.25	0.25	0.2	0.02
6	0.2	0.8	1	0.25	0.25	0.2	0.02
7	0	1	1	0.25	0.25	0.2	0.02

Prior to weighing the chemicals, the working table was cleaned, the balance was calibrated, and all glassware was washed and dried to avoid contamination of the electrolyte mixture. Polyethylene oxide (PEO), poly(methyl methacrylate) (PMMA), ethylene carbonate (EC), and propylene carbonate (PC) were dissolved in a predefined amount of N,N-dimethylformamide (DMF). The compositions of the gel-based electrolytes used in this study are summarized in Table 1. After each component was added, the mixture was stirred for 30 min using a Stuart SB 162-3 hotplate magnetic stirrer. Subsequently, tetrapropylammonium iodide (TPAI) was added in the specified amounts, and the mixture was further stirred at 70 °C until a homogeneous gel electrolyte was obtained [11].

After the mixture was cooled to room temperature, iodine crystal (I_2) was added to it in the amount of 10% tetrapropylammonium iodide (TPAI) and mixed in an IKA C-MAG apparatus until homogeneous and kept for 24 hours in a place protected from sunlight. After this, the liquid electrolyte (LE) is ready to use and assemble DSSC.

Receiving photocatalytic layer TiO_2

To construct a single-layer TiO_2, a paste was prepared from 0.5 g TiO_2 grade P25, 2 ml HNO_3, 0.4 ml polyethyleneglycol and 2 drops of Triton X-100. After ultrasonic dispersion, the paste was spin-coated onto the FTO substrate to ensure a uniform layer. Drying was carried out at 450°C.

Application of TiO_2

The mixture was stirred in an ultrasonic bath and then uniformly applied to the surface of FTO glass. The thickness of the layer was controlled using adhesive tape spacers with a predefined thickness, which ensured the uniformity and reproducibility of the TiO_2 film across the substrate. To create a single-layer TiO_2 structure, the spin-coating method was employed. The TiO_2 solution (nano paste) was evenly distributed over the FTO substrate at a rotation speed of 3000 rpm and subsequently annealed at 450°C for 30 minutes to enhance crystallinity and improve adhesion. Titanium dioxide grade P25 was selected due to its suitable physicochemical properties and widespread use in DSSC fabrication.

Dye adsorption

The prepared single-layer TiO_2 photoanodes were immersed in a 0.3 mM solution of a standard ruthenium-based dye in an ethanol–acetonitrile mixture (volume ratio 1:1) at 40 °C for 24 hours to form the photosensitive layer. After sensitization, the photoanodes were gently rinsed with ethanol to remove weakly bound dye molecules and dried under ambient conditions prior to cell assembly.

Measurement of photovoltaic characteristics

To analyze the photovoltaic performance of the fabricated solar cell, current–voltage (I–V) measurements were carried out under simulated AM1.5G illumination with a light intensity of 100 mW/cm². A Metrohm AUTOLAB PGSTAT128N potentiostat–galvanostat was used in combination with a Newport Oriel LCS-100 solar simulator to ensure accurate evaluation of the operating parameters. Particular attention was paid to the influence of the TiO_2 layer thickness, as this parameter critically affects charge generation and transport processes.

Under these conditions, the representative single-layer device exhibited an open-circuit voltage (Voc) of 0.69 V, a short-circuit current density (Jsc) of 9.53 mA/cm², a fill factor (FF) of 0.54, and an energy conversion efficiency of approximately 3.56%. The maximum efficiency achieved for optimized single-layer TiO_2 devices reached 6.5%, demonstrating the performance potential of the proposed photoanode architecture.

2. EXPERIMENTAL RESULTS AND DISCUSSIONS

Morphology and structure of TiO_2

SEM (scanning electron microscopy) analysis revealed that the fabricated single-layer TiO_2 photoanode exhibits a uniform nanostructured surface. Compared with conventional bilayer TiO_2 photoanodes, the single-layer structure exhibits lower macroporosity but higher nanoparticle packing density. The TiO_2 nanoparticle size ranges from 20 to 30 nm, ensuring homogeneous surface coverage and continuous electron transport pathways.

Atomic force microscopy (AFM) measurements indicate a root-mean-square (RMS) surface roughness of approximately 8 nm, which is suitable for effective dye adsorption. While previous studies have reported that high specific surface area TiO_2 nanostructures promote enhanced dye adsorption [9], the present single-layer photoanode demonstrates improved charge transport properties and reduced internal resistance despite its reduced porosity. This combination contributes to the enhanced photovoltaic performance observed in the fabricated devices.

Characteristics of a single-layered semiconductor solar cell

The current-voltage characteristics (I-V) of a solar cell were measured using the Metrohm Autolab Potentiostat / Galvanostat PGSTAT 128N" device at a light power density of (100 mW/cm²) emitted by the solar simulator with an active area of 0.2 cm². As a result of the experiment, the I-V characteristics of highly sensitive dye- sensitized solar cell (DSSC) was obtained. One of the graphs of these characteristics is shown in Figure 1. Similar measurement approaches have been reported in the literature [12].

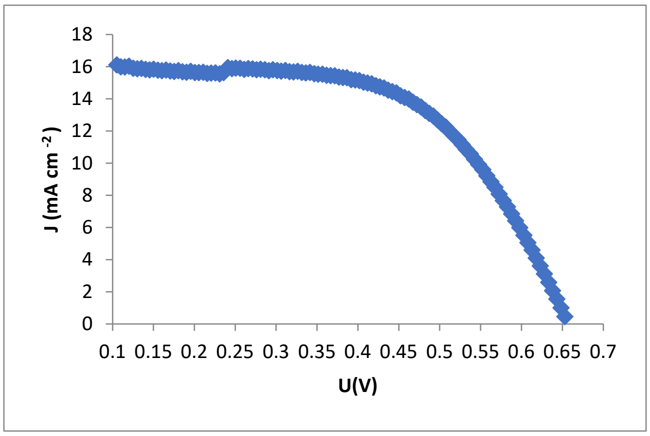

Figure 1. Photovoltaic current characteristic (I-V) of a single-layered semiconductor, highly sensitive dye-sensitized solar cell (DSSC)

Electrochemical impedance spectroscopy

The efficiency of highly sensitive dye-sensitized solar cell (DSSC) largely depends on the electrochemical parameters of the electrolyte used. The HIOKI 3531 Z Hi-Tester was used to analyze the ionic conductivity of electrolytes. The measurements were carried out using electrochemical impedance spectroscopy at an alternating voltage of 10 mV in the frequency range from 50 Hz to 100 kHz. The experiments were performed for electrolytes of different compositions and at different temperatures. This method allows one to reliably estimate the ionic conductivity of liquid electrolytes, condensed salts, ion-conducting polymers and glasses, which is important for increasing the efficiency of DSSC solar cell.

In these experiments, the obtained results were compared with theoretical calculations performed by analytical methods. Figure 2 shows a graph demonstrating the results obtained by electrochemical impedance spectroscopy (EIS) for one of the electrolyte samples. It is known that the electrolyte resistance (impedance) consists of real and imaginary parts, which are expressed by the following formulas [11] :

$$Z_r = R + \frac{\cos\left(\frac{\pi p}{2}\right)}{k^{-1}\omega^p}, \tag{2.1}$$

and

$$Z_i = \frac{sin\left(\frac{\pi p}{2}\right)}{k^{-1}\omega^p} \tag{2.2}$$

here $Z_r$andZ_i respectively represent the real and imaginary parts of the impedance, ω is the frequency. The parameter p is determined from Figure 2 using the following formula $p = \frac{2tg\alpha}{\pi}$.

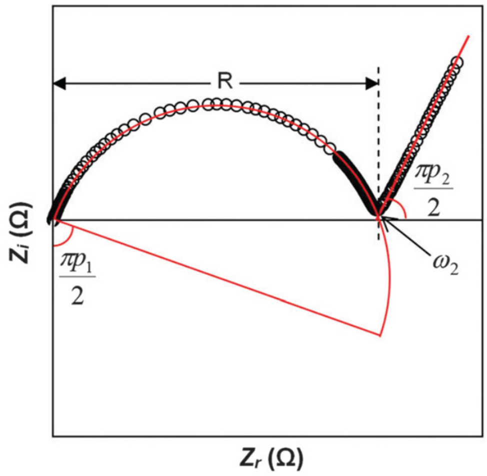

Figure 2. Electrochemical impedance spectroscopy (EIS) graph of an electrolyte [11]

The real part of the impedance is equal to the active resistance, that is, $Z_r = R$, This value is determined from the graph of electrochemical impedance spectroscopy of the electrolyte. *K* is the reciprocal of the electrical capacitance of the electrolyte, which is calculated using the formula:

$$C = k^{-1} = \frac{\varepsilon_r \varepsilon_0 S}{d} \tag{2.3}$$

where, is ε_r the relative permittivity of the electrolyte, ε_0- electric constant, S is the contact area between the electrolyte and the electrode, d −the thickness of the electrolyte layer. The ionic conductivity of the sample σ is calculated using the following formula:

$$\sigma = \frac{l}{RS} \tag{2.4}$$

where *l is* the thickness of the electrolyte layer, R is the active resistance of the electrolyte, S is the surface area of the electrolyte.

3. PHOTOVOLTAIC CHARACTERISTICS

Measurements of solar cell efficiency showed:

Double layer TiO_2: efficiency (η) = 2.8%
Single layer TiO_2: efficiency (η) = 6.5%

Additionally, an analysis of the photoelectric characteristics was carried out when illuminated by a sunlight simulator:

Maximum output voltage (Voc): 0.69 V
Short-circuit current density (Jsc): 9.53 mA/cm²
Fill Factor (FF): 0.54
Energy Conversion Efficiency (η): 3.56%

The increased efficiency of single-layer TiO_2 is explained by the reduction of charge carrier recombination and improved contact with the electrodes. The thickness of the TiO_2 layer plays a key role in the efficiency of the cell: the optimal thickness range ensures maximum light absorption with minimal resistance to charge carrier transfer [13].

Comparison with a two-layer structure

Despite the reduction in the contact area between the dye molecules and the porous TiO_2 surface (typically decreased by 20–30% compared to a mesoporous upper layer), the absence of a compact blocking layer (usually formed from dense TiO_2 to prevent electron backflow) has led to a decrease in internal resistance and improved charge transport within the photovoltaic cell. Specifically, the internal series resistance was reduced from approximately 18.2 Ω·cm² in the two-layer structure to 11.5 Ω·cm² in the single-layer configuration, indicating better charge mobility and reduced recombination losses.

Additionally, using only one TiO_2 layer significantly reduces the cost of DSSC production by minimizing the number of processing steps, materials, and thermal treatment stages. Titanium dioxide (grade P25), used in this technology, making the approach economically viable and attractive for industrial-scale implementation.

CONCLUSIONS

In this study, dye-sensitized solar cell based on a single-layer nanostructured TiO_2 photoanode were developed and systematically investigated. The approach used to create the anode focused on simplifying the photoanode architecture by eliminating the traditional two-layer configuration while maintaining efficient charge generation and transport within the active layer.

The fabricated single-layer TiO_2 photoanode demonstrated approximately twice the energy conversion efficiency compared to traditional bilayer structures under identical measurement conditions. The performance improvement is associated with reduced internal resistance, suppressed charge recombination, and optimized active layer thickness, as confirmed by photovoltaic and electrochemical impedance spectroscopy measurements.

Unlike traditional DSSC designs that rely on multilayer photoanodes to balance light absorption and electron transport, the proposed single-layer architecture provides efficient charge transport pathways due to its dense and uniform nanoparticle morphology. This structural simplification reduces interfacial losses and enhances electron mobility without increasing fabrication complexity.

The obtained results indicate that single-layer TiO_2 photoanodes represent a promising strategy for the development of cost-effective, flexible, and transparent DSSC. The simplified fabrication process and stable photovoltaic performance make this approach attractive for practical applications, such as building-integrated photovoltaics, indoor energy-harvesting systems, and flexible electronic devices.

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REFERENCES

[1] M. Grätzel, "Recent advances in sensitized mesoscopic solar cells," *Accounts of Chemical Research*, 42 (11), 1788–1798 (2009). https://doi.org/10.1021/ar900141y
[2] K. Hong, R. Song, and H. Chen, "Nature-inspired hierarchical nanostructures as optimal photoanode in dye-sensitized solar cells," *Materials Today Energy*, 54, 102099 (2025). https://doi.org/10.1016/j.mtener.2025.102099
[3] L. Wei, X. Xu, L. Zhao, J. Liu, R. Wang, and X. Zhang, "Design and fabrication of layered TiO_2/rGO composited photoanode and its photovoltaic performance regulation for dye-sensitized solar cells," *Optical Materials*, 154, 115709 (2024). https://doi.org/10.1016/j.optmat.2024.115709
[4] B. O'Regan, and M. Grätzel, "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films," Nature, **353**, 737–740 (1991). https://doi.org/10.1038/353737a0
[5] A. Hagfeldt, G. Boschloo, L. Sun, L. Kloo, and H. Pettersson, "Dye-sensitized solar cells," Chemical Reviews, **110**, 6595–6663 (2010). https://doi.org/10.1021/cr900356p
[6] M. Grätzel, "Dye-sensitized solar cells," Journal of Photochemistry and Photobiology C: Photochemistry Reviews, **4**, 145–153 (2003). https://doi.org/10.1016/S1389-5567(03)00026-1
[7] O.O. Mamatkarimov, B. Uktamaliyev, and A.A. Abdukarimov, "Determination of ionic conductivity of polymer electrolytes in Li-ion batteries using electrochemical impedance spectroscopy," An International Multidisciplinary Research Journal, **11**(7), 141–146 (2021). https://doi.org/10.5958/2249-7137.2021.01735.3
[8] N. Sharibaev, and A. Ergashov, "Mathematical modeling of processes in a dye-sensitized photocell," Journal of Physics: Conference Series, **2373**(7), 072044 (2022). https://doi.org/10.1088/1742-6596/2373/7/072044
[9] N.Y. Sharibayev, M.M. Kakharov, S.S. Kakharov, and A.Q. Ergashev, "Determination of the characteristics of polymer-containing electronic elements using a mobile device," Turkish Journal of Computer and Mathematics Education, **12**(4), 61–68 (2021).
[10] Q. Zhang, and G. Cao, "Nanostructured photoelectrodes for dye-sensitized solar cells," Nano Today, **6**(1), 91–109 (2011). https://doi.org/10.1016/j.nantod.2010.12.007
[11] A.K. Arof, S. Amirudin, S.Z. Yusof, and I.M. Noor, "A method based on impedance spectroscopy to determine transport properties of polymer electrolytes," Physical Chemistry Chemical Physics, **16**, 1856–1867 (2014). https://doi.org/10.1039/C3CP53830C
[12] E Aram, M Ehsani, and H.A. Khonakdar, "Improvement of ionic conductivity and performance of quasi-solid-state dye sensitized solar cells using PEO/PMMA gel electrolyte," Thermochimica Acta, **615**, 61–67 (2015). https://doi.org/10.1016/j.tca.2015.07.006
[13] F. Azeez, and P.S. Fedkiw, "Conductivity of LiBOB-based electrolyte for lithium-ion batteries," Journal of Power Sources, **195**, 7627–7633 (2010). https://doi.org/10.1016/j.jpowsour.2010.06.021

РОЗРОБКА ОДНОШАРОВОГО TiO_2 ФОТОАНОДА ДЛЯ СОНЯЧНИХ ЕЛЕМЕНТІВ, СЕНСИБІЛІЗОВАНИХ БАРВНИКОМ (DSSC)

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Сонячні елементи, сенсибілізовані барвником (DSSC), вважаються перспективною недорогою та гнучкою альтернативою традиційним фотоелектричним технологіям на основі кремнію. У цій роботі представлено виготовлення та аналіз DSSC на основі одношарового наноструктурованого TiO_2 фотоанода. Запропонована архітектура елемента спрощена шляхом виключення традиційної двошарової конфігурації, що зменшує складність виготовлення та витрату матеріалів. Були систематично досліджені електрохімічні та фотоелектричні характеристики пристроїв. Ефективність перетворення енергії розробленої одношарової конструкції приблизно вдвічі вища, ніж у звичайної двошарової комірки. Підвищення продуктивності пояснюється зниженням внутрішнього опору, покращеним транспортом електронів та пригніченням рекомбінації зарядів. Результати демонструють потенціал спрощених одношарових архітектур DSSC для прозорих, гнучких та недорогих застосувань збору енергії.

Ключові слова: *одношаровий TiO_2 фотоанод; DSSC; спрощена архітектура; фотоелектричні характеристики; електрохімічна імпедансна спектроскопія; транспорт заряду; морфологія наночастинок TiO_2*