Assembly of biosolar cells by using N719-bacteriorhodopsin complex

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ABSTRACT

Today, using new and renewable energy sources to replace fossil fuels is greatly expanded. The solar cells are devices that convert solar energy to electrical energy. Solar cells based on organic materials, especially proteins, are one of these solar cells. For example, bacteriorhodopsin (bR) which is one of the membrane proteins in halobacterium salinarum could be used in solar cells and participate in the liberation and transfer of the electrons. In this study, the effort has been to add a chemical dye (N719) to protein and develop a new hybrid bR/Dye complex to increase efficiency of solar cells based on protein. The formed hybrid complex was tested by using of FTIR and other spectroscopy. Current and voltage of bacteriorhodopsin-based photocell was increased in new complex-based photocell. The results of AFM, FTIR and UV-Visible spectroscopy showed a smooth deposition of bR-Dye N719; stable complex of bR-Dye N719 was also formed.

Keywords: Solar Cell; Bacteriorhodopsin (bR); Dye N719; FTIR; Immobilization

INTRODUCTION

Prohibitive prices and toxicity are from among difficulties of using the chemical dyes in solar cells and photovoltaic cells. The introduction of dye-sensitized solar cells (DSSCs) by O'Regan and Gratzel in 1991 has revolutionized the scope and efficiency of solar cell applications [1-3]. Because of simple manufacturing used in its production, dye-sensitized solar cell (DSSC) has been significantly studied and developed in the last decade [4]. DSSCs are composed of a mesoporous TiO_2 film that is sensitized with a monolayer of photosensitizer molecules, filled with an iodide/triiodide-based electrolyte and capped with a platinum counter electrode. This way, fast electron transfer from the photo-excited photosensitizer into the conduction band (CB) of the TiO_2 takes place [5].In recent years, the use of biosolar cells based on biomacromolecules such as proteins and aptamers have been increased and broadly accepted. However, immobilization of proteins on different solid substrates for biosolar cell construction is one of the protocols that constitute a crucial process in many biotechnological and bioengineering approaches [6]. For example, monolayer films of proteins on substrates have attracted considerable attention for some applications, such as biosensor [7], biofuel cell [8], implant [9] and biophotovoltaic cells [10]. Among a number of proteins used for bioelectronics applications, the photoactive membrane protein (bacteriorhodopsin (bR)) is the most appealing one [11]. BR is a photoactive protein found in the purple membrane (PM) of Halobacterium. Monolayer thin films of bR have been studied extensively because of its importance in biotechnology [12]. Various techniques have been demonstrated for controlled immobilization of oriented monolayers, such as Langmuir–Blodgett (LB) [13], electrostatic sedimentation [14], chemisorption [15], antigen–antibody interactions [16], and electrostatic layer-by-layer assembly [17]. However, in biosolar cells based on biomacromolecules, efficiency and capability of cells in power density has been decreased. To overcome these difficulties, coupling of biomacromolecules and chemical dyes such as N719 have been used. Therefore, solar cell is biodegradable as chemical dyes can increase the efficiency and coincident of the case.

In this study, we have focused on increasing the bR-based photocell efficiency and power density by coupling the ruthenium (N719) and bR on TiO2 surface. Our results show that electron transfer and efficiency of new complex-based photocell and ultimately power density of biophotovoltaic cell have been improved.

MATERIALS AND APPARATUS

Transparent-conductive-oxide-coated glass (fluorine-doped tin oxide, FTO) was purchased from Solaronix (Aubonne, Switzerland). The electrolyte and TiO_2 paste were provided by Sharifsolar, Tehran, Iran. All other materials were obtained from Sigma-Aldrich (St. Louis, MO, USA) and Merck.

Spectroscopy, AFM and Electrochemical measurements

A Unicam UV 300 spectrophotometer was used for the evaluation of the UV-Visible spectra of bR, dye N719 and the complex of bR-Dye N719 solution in the range of 250 to 700 nm. The surface morphology of TiO2 film was examined using atomic force microscopy (AFM). The AFM studies could provide comprehensive information about the surface morphology of TiO2 coated on the FTO. FTIR spectroscopy has been used to survey the alteration of functional groups before and after immobilization. After creating the bio-solar cells via bR-Dye N719 and bR, the current–voltage curve was obtained through applying an external bias to the cell and measuring the generated photocurrent under simulated sunlight (Luzchem) irradiation by using of Drop Sens potentio-galvanostate.

Fabrication of nanoporous TiO2 electrodes

The FTO conductive glasses as working electrode were first cleaned in a detergent solution using an ultrasonic bath for 15 Min, washed with ethanol and distilled water, and then dried overnight at room temperature. Titanium dioxide paste was deposited on FTO glasses by the doctor blade method. The thickness of the coated TiO_2 film was about 9 μm, and the active area of the resulting cells exposed to light was approximately 0.25 cm^2 (0.5 cm × 0.5 cm). The TiO_2 electrodes were gradually heated under an air flow at 325 ˚C for 5 Min, at 375 ˚C for 5 Min, at 450 ˚C for 15 Min, and finally at 500 ˚C for 15 Min. The annealed TiO_2 films were treated with 40 mM TiCl4 aqueous solution at 70 ˚C for 30 Min, and then washed with pure water and ethanol, and sintered again at 500 ˚C for 30 Min. After being cooled to 22 ˚C, the TiO_2 electrodes were immersed in 100 μl of 0.05 mg/mL of bR and 50 μM of Dye N719 complex for 2 hour at 25 ˚C [18].

Preparation of bio-sensitized solar cells

FTO/TiO2/Br + Dye N719

Platinum-coated FTO sheets were used as counter electrode in this research. After cutting the FTO glasses into the dimension of 20 mm × 20 mm, two holes were drilled into it by a drill press (Fig1).

Figure 1. Production of a hole on FTO glass by using of drill press

The perforated sheets were cleaned by ultrasound in an ethanol bath for 10 Min. The platinum catalyst was deposited on the FTO glass by coating with a drop of H_2PtCl_6 solution (2 mg Pt in 1 mL ethanol), and heat treatment was carried out at 400 ˚C for 15 Min. The pigment-adsorbed TiO_2 electrode and counter electrod were assembled into a sealed sandwich solar cell with hot-melt Surlyn film (30 μm thickness) as spacer between the electrodes. A drop of the electrolyte solution was placed on the drilled hole in the counter electrode of the assembled cell and was

driven into the cell via vacuum backfilling (Fig 2). Finally, the hole was sealed using extra Surlyn [19].

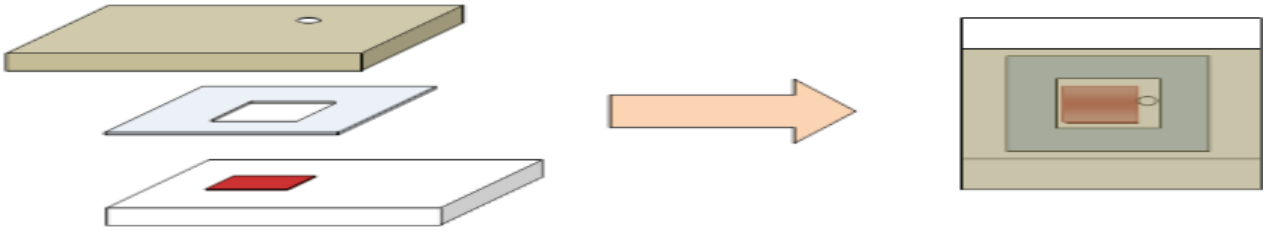

Figure 2. Fabrication of photovoltaic cell

RESULTS

Ultraviolet–visible spectrophotometry

The optical spectra of bR and dye N719 were measured between 250 and 700 nm. Figure 3 shows the absorption spectra of the bR-DyeN719 complex. The maximum absorbance of bR was found at 568 nm, which is related to the absorptions of the protonated Schiff-base retinal. DyeN719 exhibited a major peak at 300 nm, and two minor peaks at 370 and 500 nm [20]. According to the results, absorbance peak in 500 nm for Dye N719 shows the photocurrent generation capacity of dye in immobilization with bR in increasing the efficiency and output of photocell.

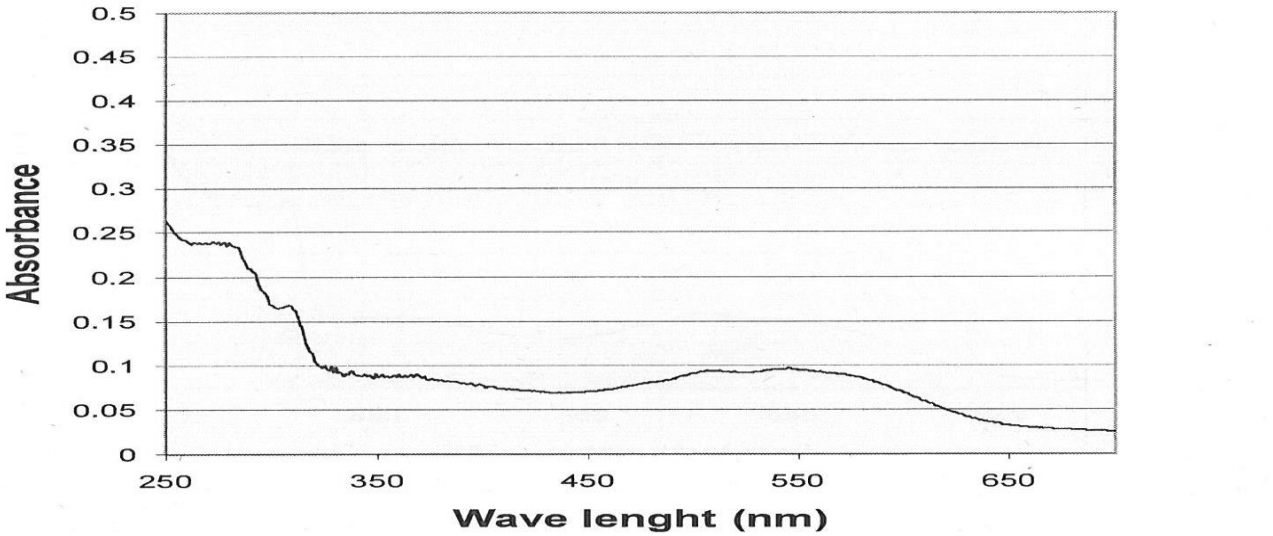

Figure 3. UV-visible spectra of compelex of bR-DyeN719

TiO_2 morphology

Atomic force microscopy was used to investigate the surface of the nanocrystalline TiO_2 morphologically. The AFM image (2 μm × 2 μm surface plots) of the sintered TiO_2 nanoparticles is shown in Fig. 4. The film porosity is in the range of 10 nm, which is suitable for photovoltaic applications. Moreover, analysis of the AFM images show that the morphology of samples is very rough and may be advantageous to enhancing the adsorption of pigments because of its immense surface roughness and high surface area (Fig. 4). AFM results show that more than 80 percent of TiO_2 nanoparticles has been agglomerated in 300 nm^2 of electrode base.

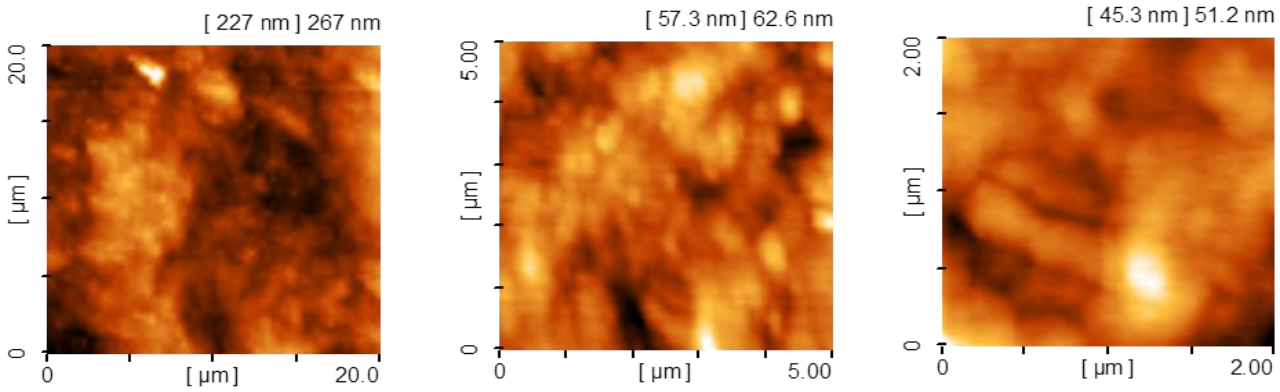

Figure 4. AFM image of film porosity of TiO_2 nanoparticle in our photovoltaic cell

Photoelectrochemical properties of DSSC

The photovoltaic performance of DSSCs using bacterial pigments was investigated by measuring the current–voltage (I–V) curves under irradiation with white light AM1.5 (100mWcm−2) from a solar simulator lamp. Short circuit current (Jsc), open circuit voltage (Voc), fill factor, and energy conversion efficiency were measured to investigate the performance of bR-Dye N719 complex and bR as sensitizer in DSSCs.

CONCLUSION

The results of the present study reveals that immobilization of bR-DyeN719 complex on TiO2 nanoparticle in solar cell fabrication is a suitable procedure to overcome the chemical dye difficulties. Therefore, complex production of Dye-biomacromolecules such as proteins is an appropriate option to make organic solar cells for photovoltaic cells in future.

"The authors declare no conflict of interest"

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