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Research Article

PARAMETER OPTIMIZATION OF PRODIGIOSIN BASEDDYE-SENSITIZED SOLAR CELL

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ABSTRACT

"Prodigiosin", the naturally occurring red pigment in Serratia Marcescens NCIM 5246 was used as a photosensitizer in Dye-sensitized Solar cell. Prodigiosin was produced from Serratia Marcescens NCIM 5246 by solid culture in nutrient agar for 48 hours and then extracting the pigment by using ethanol. The performance of this pigment was observed by optimizing several parameters of DSSC like the surface area of TIO_2 film, Immersion time of TiO_2 electrode in Pigment extract, Prodigiosin concentration, and sun intensity. Maximum cell efficiency of 0.4597% was observed at 1002.38 W/m^2. It was found that the cell efficiency was maximum i.e., 0.5071% at a concentration of 4162.574µg/ml. Increase in TiO_2 surface area ameliorated the performance of Prodigiosin sensitized solar cell where it gave peak efficiency of 0.498% at highest TiO_2 film surface area of 7.5 cm^2. The immersion time was varied from 10mins to 60mins where the efficiency was maximum i.e., 0.5195% at 50 mins. The main purpose of this investigation is to evaluate the effect of various parameters like sun intensity, the concentration of the sensitizer (Prodigiosin), Surface area of semiconductor (TiO_2) and, Immersion time on the performance of dye-sensitized solar cell (DSSC).

Keywords: Prodigiosin, Dye-sensitized solar cell, DSSC, Serratia Marcescens NCIM 5246.

INTRODUCTION

Today utilization of solar energy because of its sustainability and ease of accessibility is considered to be a remarkable replacement to other energy sources like fossil fuels, coal etc., which are not only finite but also a menace to the environment in terms of global warming[1-3]. Dye-Sensitized Solar Cells (DSSC) is the third-generation photochemical device, which converts solar radiation into electrical energy[4-5]. Since there is no usage of fossil fuels or any high-priced material in this process, DSSC's are practically economical[6-7]. Low assembly cost [8], high power-conversion efficiency[9], simple fabrication process, use of environmentally friendly elements and usage of low purity material make DSSC's much more renowned among the researchers as compared to inorganic solar cells [10-12]. The DSSC involves (1) Anode (Working electrode) where conducting glass (ITO or FTO) is clad with TiO_2 toping with successive adsorption of dye or pigment molecule on it ;(2) Redox Couple (KI/I_2) solution as an electrolyte; (3) Conducting glass coated with carbon graphite as the cathode (Counter electrode) [13-14]. Conjugation (alternate single and double bond) is vital as far as the photoelectric conversion process is concerned and hence the reason why dye or pigment execute a crucial role as a photosensitizer [15-16] in DSSC by absorbing sunlight and transforming it into electricity [17-20].The absorption spectrum of the dye or pigment, its binding functional groups to TiO_2 that fosters productive electron inoculation into TiO_2 conduction band and energy levels are the three important factors that are responsible for amplifying the photoelectric conversion efficiency of DSSC [21-22].

An ideal sensitizer is a dye or pigment that possesses low manufacturing cost, the raw material used for producing it should be least hazardous and its power output must be exorbitant [23-24]. The anode is constructed by facing TiO_2 paste on conductive glass, which further acts as a mediator of electrons ejected from dye or pigment adsorbed on TiO_2 film [25]. Painless manufacturing, low cost, high rate of conversion efficiency and illustrating stability towards the illumination in multiple environmental patterns-are the four factors which make TiO_2 as most commonly used semiconductor to construct a working electrode for DSSC [26-27]. The freshly constructed working electrode is further immersed into the dye solution or pigment extract to get the colourant molecule adsorbed on to porous TiO_2film, which enhances photoelectric conversion largely[28]. As like other natural colourants, prodigiosin[29]also can function as photosensitizer[30]

Working Principle of Dye-Sensitized Solar Cell: When a photon hits the pigment molecule, an electron receives sufficient amount of energy to escape from the pigment molecule i.e. It goes in the excited state and then escape from the pigment molecule via TiO_2 semiconductor. When this happens a vacancy of an electron (hole) is generated in the pigment molecule. A mediator I^- in liquid electrolyte fills the hole with the electron, which it carries, and become I^-_3, which is then reduced further at the counter electrode or cathode. In this way, electrons travel in a circle from anode to cathode and create an external circuit, which powers the electrical devices (Figure 1)[31-34].

In the present research work, the optimization of significant parameters of Prodigiosin based Dye-Sensitized Solar Cell (DSSC) like Sun Intensity, the concentration of prodigiosin, Surface area of TiO_2 and, Immersion time in pigment (prodigiosin) extract, has been studied in terms of efficiency.

EXPERIMENTAL

MATERIALS

"Serratia Marcescens" NCIM Accession No: 5246, was ordered from, National Collection of Industrial Microorganisms (NCIM), National Chemical Laboratory, Pune, Maharashtra, India. FTO (conducting) glass slides (dimensions of 5cm*5cm*2.2 mm, 7 ohm) supplied by Global Nanotech Company, Mumbai, Maharashtra, India, was used for this experiment. All chemicals were purchased from Thomas Baker Co.

Identification of conducting side

Conducting side of FTO glass is identified by multimeter where it displays resistance of zero ohm, as shown in Figure 2a and 2b.

Preparation of Pigment extract

Serratia Marcescens NCIM 5246 strain was grown on nutrient agar for 48 hours at 26^0C and then it was scraped and added to the centrifuge tube. To prepare an appropriate sample to measure absorbance, an equal volume of ethanol (95%) was added further to the cell pellets and Prodigiosin was extracted by heating the mixture of pigmented cells and ethanol (95%) at $90\text{-}95^0C$ for 1-1.5 hour with successive filtration of the mixture (Figure 3a and 3b).

Concentration Calculation

The absorbance of the prepared sample was measured at 530nm by using a colorimeter. The concentration of Prodigiosin was calculated by using the formula mentioned in the literature [35]. It can be seen from Figure 4,as the concentration goes on increasing the absorbance also goes on rising. The graph is linear.

Preparation of working electrode

All four sides of FTO glass were sealed with tape. TiO_2 paste was applied on the same (conducting) side of the FTO glass followed by heating the TiO_2coated FTO glass over the open flame. Further, it was simply submerged in the pigment extract for a few minutes and was subsequently allowed to dry (Figure 5a to 5e).

Preparation of Counter Electrode

Coat another FTO slide (conducting side) with graphite layer by scratching pencil on it. It serves as a counter electrode (Figure 5f and 5g).

Preparation of solar cell

Both the electrodes (both FTO glass slide's conducting side) were placed facing each other with the help of binder clips. The redox couple (0.5 M KI and 0.05 M I_2) was added dropwise between them (Figure 5h).

Testing the solar cell

The test was performed outdoors on a sunny day with an average temperature of 35^0C in Mumbai city, Maharashtra with sun intensity. Efficiency was calculated as per the formulae mentioned in literature [36] (Figure 5i).

RESULTS AND DISCUSSION

Intensity Optimization

The intensity of the light may upshoot the electrical parameters of DSSC and therefore experiments were performed at a different time in a day to observe the consequences of light intensity on electrical out-turn of the prepared cell (Figure 6). The efficiency of DSSC shows an upward drift with the augmentation of light intensity since strengthening the intensity of light hikes the photons per unit area[37-38]. As the intensity of sunlight went on rising from 963 W/m^2 to 1002 W/m^2 efficiency of cell also increased from 0.2873 % to 0.4597 %. However, as the intensity rise further with time there was sudden deep in the efficiency.

Concentration optimization

In the above experiment, the concentration of Prodigiosin pigment was varied from 2836.039μg/ml to 4208.316 μg/ml. This experiment was carried out at Sun intensity of 1002.38 W/m^2 (Figure 7).It was observed that as the concentration went on increasing, the efficiency of DSSC intensified gradually up to the concentration 4162.574 μg/ml. This happens because the coating of pigment on TiO_2 surface involves dissemination of sensitizer molecules into the permeable nanostructure of TiO_2, leading to pigment-TiO_2 bond formation. Now as the sensitizer concentration goes on rising, the quantity of sensitizer molecules also goes up [39], which not only proliferates the possibility of sensitizer-TiO_2 bond formation but also have a remarkable impact on the performance of DSSC. When the photons hit the pigment molecule, the electrons go into an excited state and are injected through TiO_2 and this process of electron injection depends on the number of Pigment-TiO_2 bonds. Therefore, this bond formation is critical as far as the performance of DSSC is concerned [40]. Another phenomenon that was observed was the sudden dip in the efficiency after the concentration 4162.574 μg/ml and it is because at a certain concentration point the adsorption sites of $TiO_2$are saturated by pigment molecules[41]. When the concentration is increased beyond that point the free pigment molecules in the solution gets attached to sensitizer molecules adsorbed on TiO_2 surface leading to a stockpile of sensitizer molecules on TiO_2 [42]. Consequently, this stockpile functions as an interior sieve for the incident radiation and restrict necessary light intensity to reach TiO_2.

TiO_2Surface area optimization

In this experiment, the surface area of TiO_2 coated on FTO glass was varied, 1.5cm^2, 3 cm^2, 7.5 cm^2 respectively(at sun intensity=1002.38 W/m^2 and Pigment Concentration = 4162.574 μg/ml)and it was observed that as the surface area of semiconductor went on increasing, the efficiency of DSSC also went on rising gradually (Figure 8). As the surface area of TiO_2 was increased, the amount of sensitizer (Prodigiosin) molecules adsorbed to it also incremented leading to growth in the electron inoculation through TiO_2 consequently amplifying efficiency of the cell [43].

Immersion time optimization

The immersion time of TiO_2 electrode in the sensitizer solution is a crucial variable as far as the productivity of DSSC is concerned [44]. In this experiment (Figure 9), the cell gave maximum efficiency 0.5195%at the immersion time of 50 mins and the efficiency decreased after 50 mins (at sun Intensity = 1002.38 W/m^2; Pigment concentration= 4162.574 μ g/ml; TiO_2Surface Area= 7.5cm^2). The reason behind this decrease in performance of DSSC can be the re-dissolution of prodigiosin pigment molecule adsorbed on TiO_2 surface, in the solvent of the pigment solution in which this TiO_2 electrode is immersed. Because of the re-dissolution of the pigment in the solvent, the pigment molecules adsorbed on TiO_2 surface decreases and hence the efficiency comes down[45-46].

CONCLUSION

In the contemporary research, it was discovered that in Prodigiosin sensitized solar cell the maximum efficiency 0.4597% was at the sun intensity of 1002.38 W/m^2, efficiency 0.5071% was the maximum at concentration 4162.574 μg/ml, efficiency 0.498% was the maximum at TiO_2 surface area of 7.5 cm^2 and efficiency 0.5195% was maximum at immersion time of 50 mins. Based onthe above results we concluded the fact that the Prodigiosin pigment procured from Serratia Marcescens NCIM 5246 bacteria can be used as a photosensitizing material for DSSC. The incorporation of biodegradable Prodigiosin into the solar cells will make a complete environmentally friendly electricity generation system.

ACKNOWLEDGEMENT

Nil.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

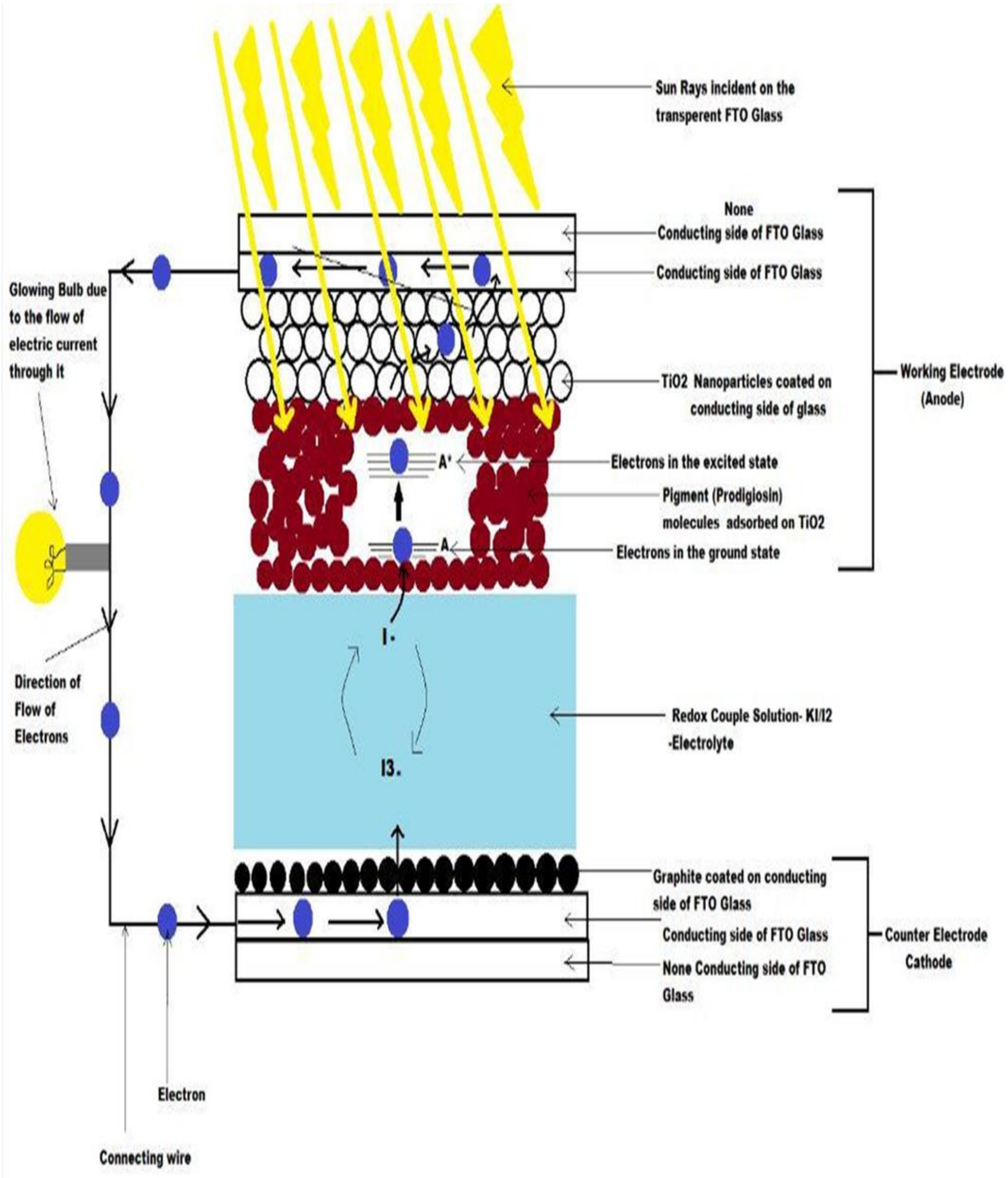

Fig. 1: Mechanism of working of Dye-Sensitized Solar Cell

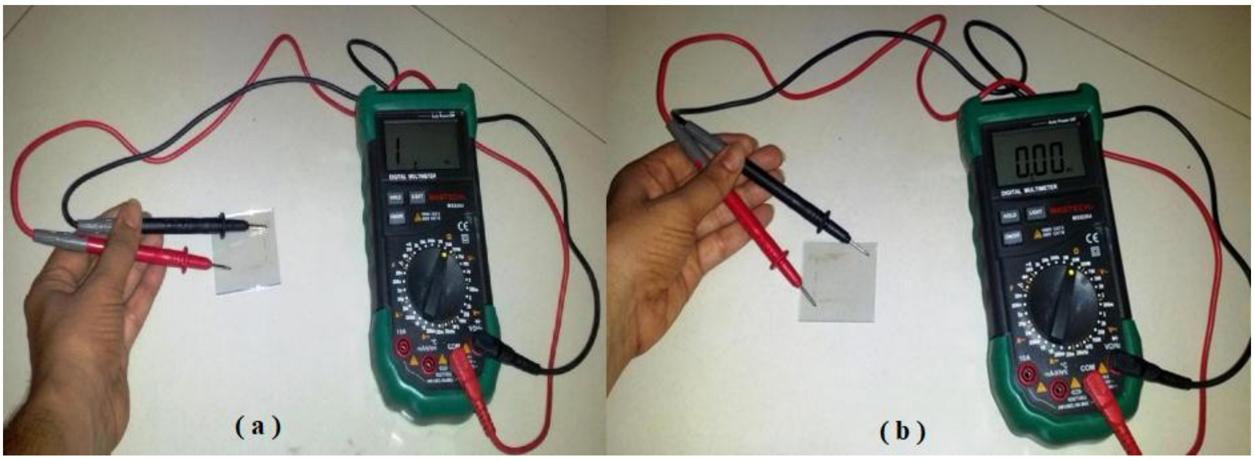

Fig. 2: (a) Non-conducting side, (b) Conducting Side

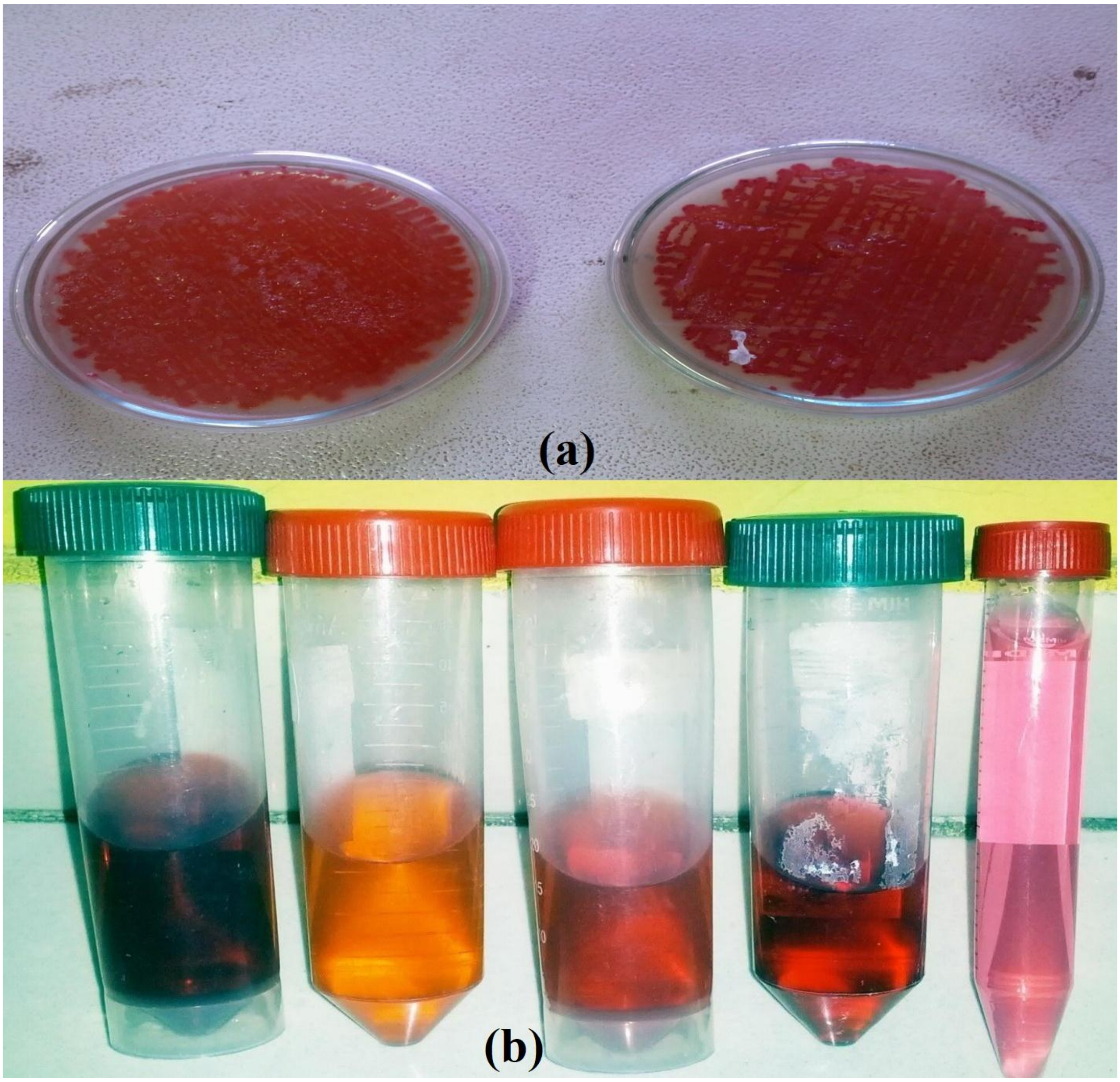

Fig. 3: (a) Solid culture of Serratia Marcescens NCIM 5246 to produce Prodigiosin Pigment, (b) Extraction of Prodigiosin from Serratia Marcescens by ethanol (95%)

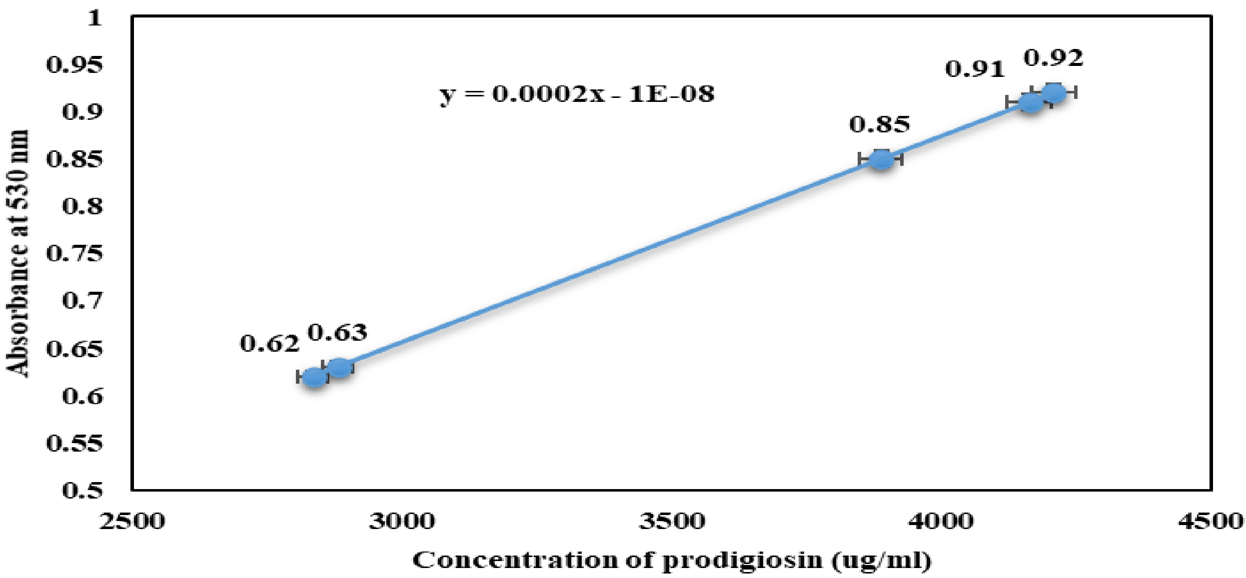

Fig. 4: Absorbance v/s concentration of Prodigiosin at 530 nm

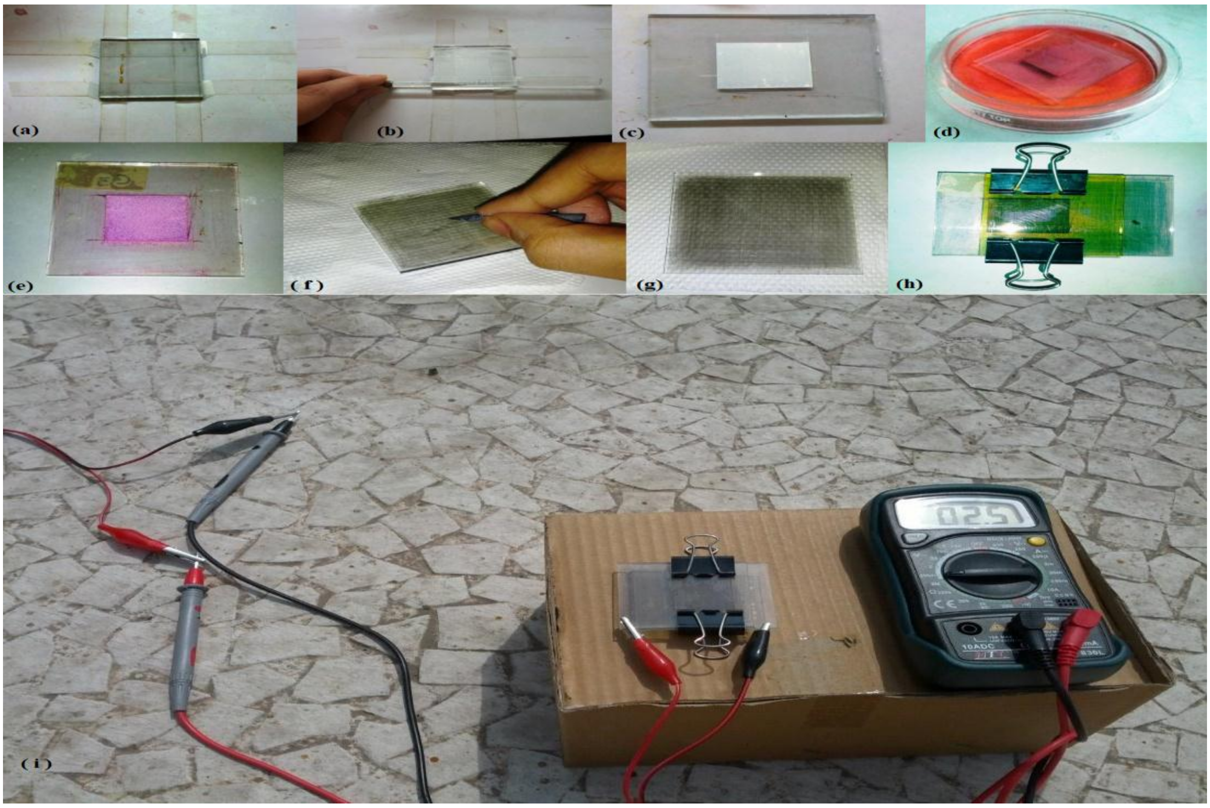

Fig. 5: (a) Tapping the slides, (b) Spreading TiO_2 paste on the non-taped surface of conducting side, (c) After removal of tapes and heating, (d) FTO slide submerged in pigment extract, (e) Prodigiosin pigment particles adsorbed on TiO_2 surface of electrode, (f and g) Coating of graphite on conductive side of glass by scratching pencil led on it, (h) the complete Dye sensitized solar cell, (i) Working solar cell.

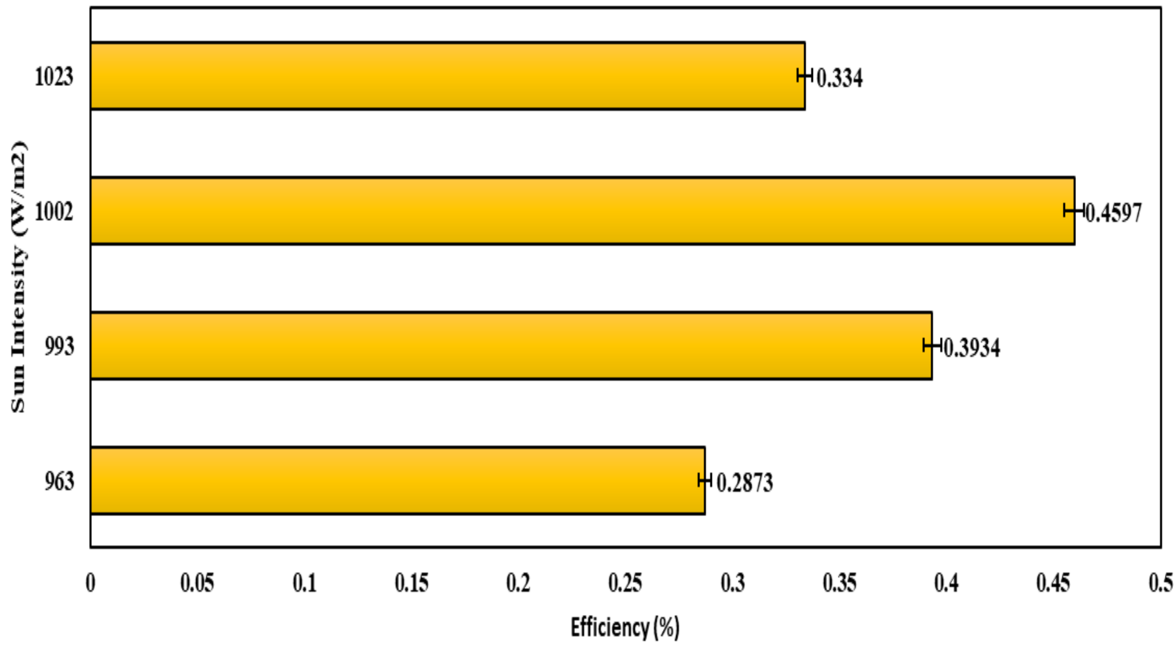

Fig. 6: Sun Intensity optimization

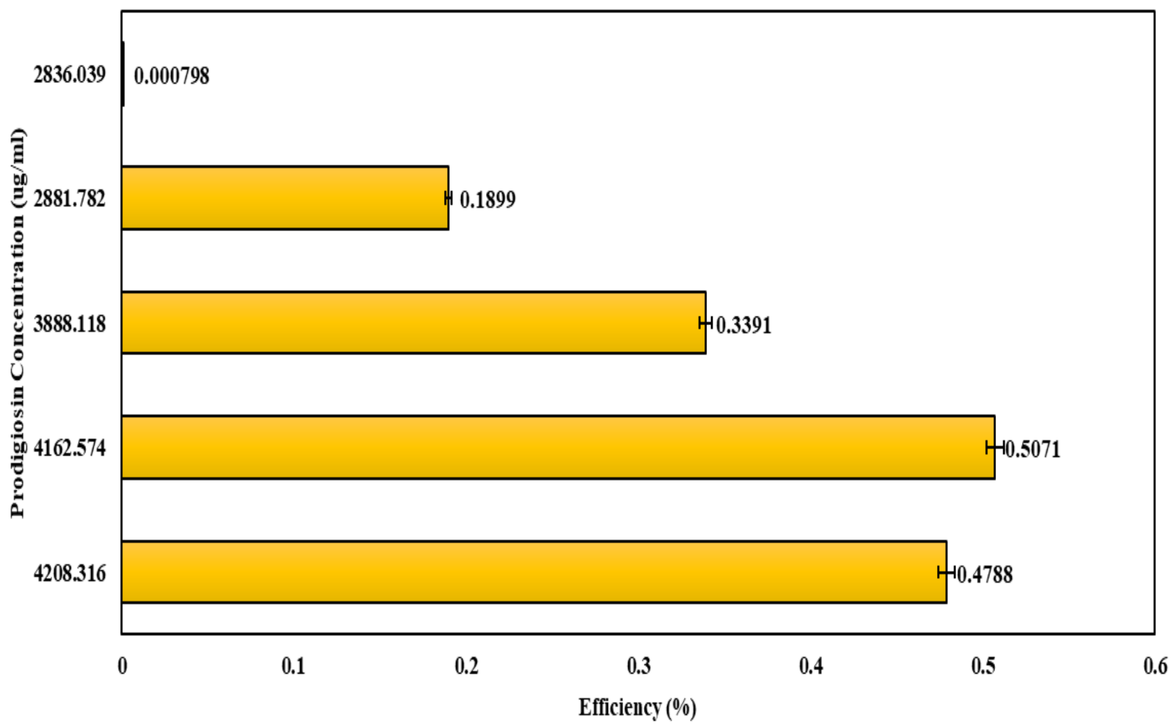

Fig. 7: Performance of DSSC with increasing concentration (Sun intensity = 1002.38 W/m²)

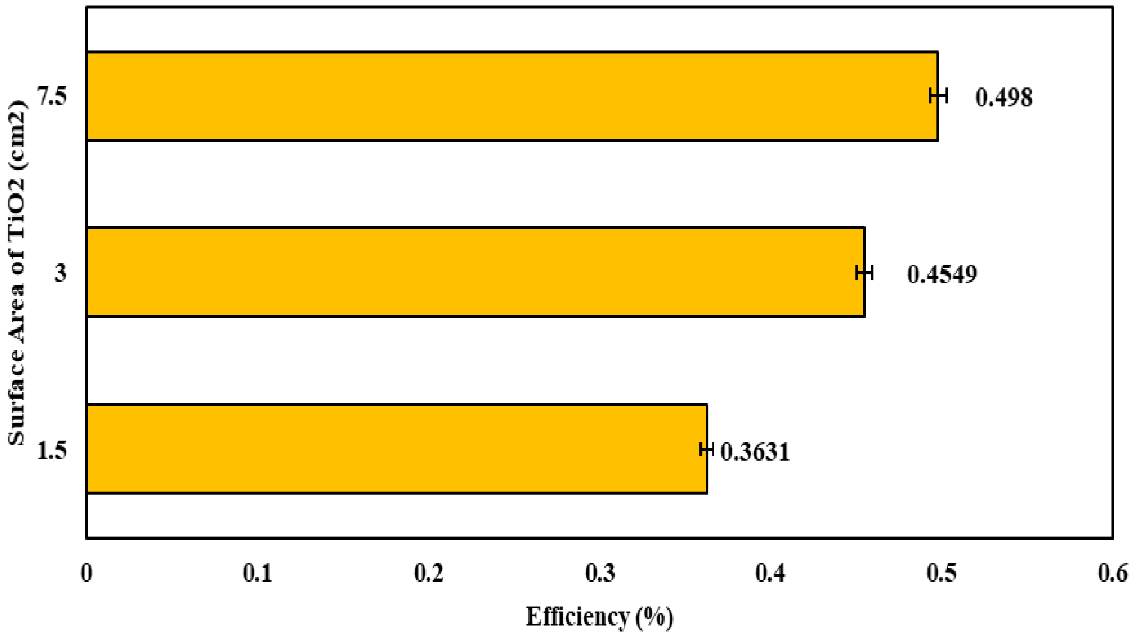

Fig. 8: Performance of DSSC with increasing surface area of TiO_2 (Sun intensity= 1002.38 W / m^2; Pigment concentration = 4162.574 µg/ml)

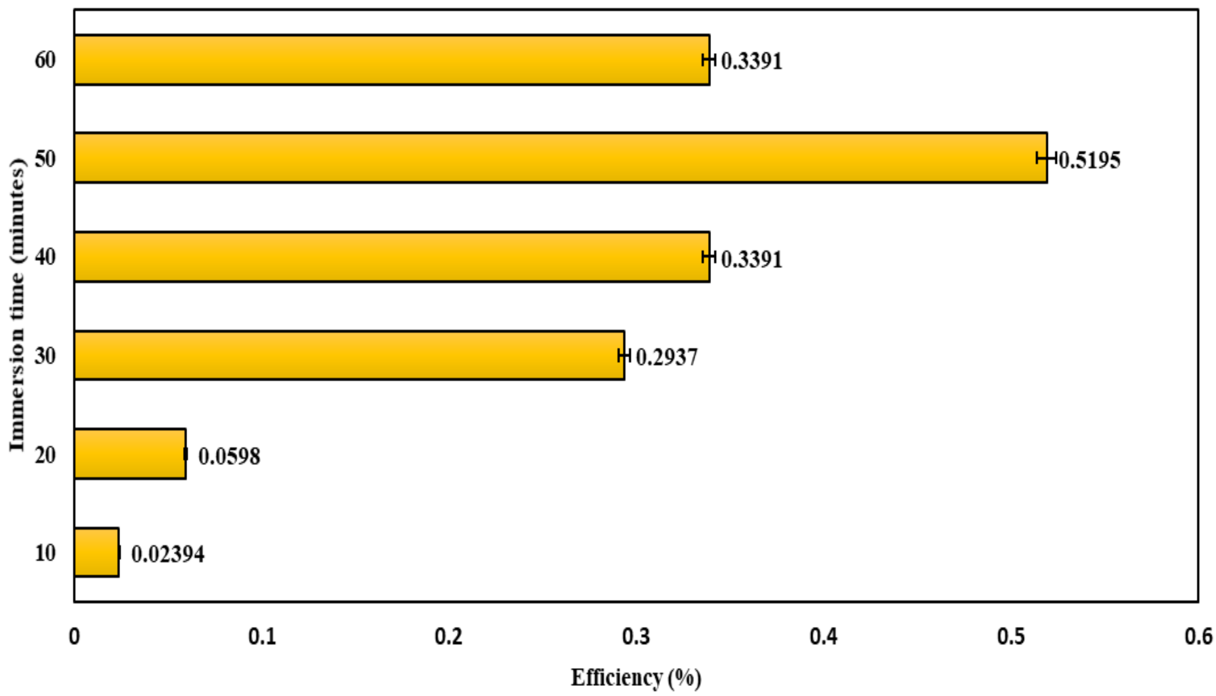

Fig. 9: Performance of DSSC with increasing immersion time (Sun intensity= 1002.38 W / m^2; Pigment concentration = 4162.574 µg/ml; TiO_2 Surface Area = 7.5 cm ^{2})

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