

Studies of Surfactant in Photogalvanic Cell for Solar Energy Conversion and Storage

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Abstract

The photogalvanic effect was studied in photogalvanic cell containing orange G as Photosensitizer, sodium lauryl sulphate and EDTA as reducing agent. The photo-outputs with EDTA are higher for Solar Energy Conversion and Storage. The current-voltage relations of the cell have been measured in the dark and light under both forward and reverse direction. The photo potential and photocurrent generated was found to be 960.0 mV and 350.0 μ A, respectively. The observed conversion efficiency was 1.52% fill factor and the maximum power of cell was 0.47 μ A and 158.9 μ W. The storage capacity of the cell was 80.0 minutes in dark. A mechanism was proposed for the generation of photocurrent in photo galvanic cell.

Keywords

Orange-G, NaLS (Surfactant), Photopotential, Photocurrent, Conversion Efficiency

1. Introduction

The worldwide demand for energy is expected to keep increasing at 5 percent each year [1]. Nowadays there are several major directions for solar technology development for photo galvanic that system directly converts the solar energy into electrical energy. Becquerel [2] first observed in 1839 the flow of current between two unsymmetrical illuminated metal electrodes in sunlight. Later, it was observed by Rideal [3] and Rabinowitch [4]. A dye sensitized solar cell (gratzed cell) which is based on a semiconductor formed between a photosensitized anode and on electrolyte systematic investigation was done [5]. And a metal based photo galvanic solar panel is the most commonly used solar technology

to generate electrical energy was studied [6]. Use of some reductant and photo sensitizer in photo galvanic cells for solar energy conversion and storage was investigated [7]. The studies of photo galvanic cell consisting various dyes with reductant and surfactant were done [8] [9]. Recently the photo galvanic effect in various interesting system were observed [10] [11]. The photo chemical conversion of solar energy into electrical energy was studied [12] [13].

A detailed literature [14]-[20] survey reveals that different photosensitize and EDTA have been used in photo galvanic cells, but no attention has been paid to use of the NaLS-orange G system in the photo galvanic cell for solar energy conversion and storage.

2. Experimental & Materials

The system contains orange G dye NaLS (surfactant), EDTA and water, used in the reported system is distilled twice in the laboratory only. All the Solutions were prepared in doubly distilled water and kept in amber colored containers to protect them from sunlight. A mixture of solution of NaLS, (Sodium Lauryl Sul-fate) orange G, EDTA and sodium hydroxide was taken in an H-shaped glass tube. A platinum electrode ($1.0 \times 1.0 \text{ cm}^2$) was immersed into one arm of the H-tube and a saturated calomel electrode (SCE) was kept in the others, the whole system was first placed in dark till a stable potential was obtained and then, the arm containing the SCE was kept in the dark and the platinum electrode was exposed to a 200 tungsten lamp. A water filter was used to cut off infrared radiations. The photochemical bleaching of orange G was studied potentiometrically. A digital pH meter (modal-III) and a microammeter were used to measure the potential and current generated by the system, respectively. The experimental set-up of photogalvanic cell is given in **Figure 1**.

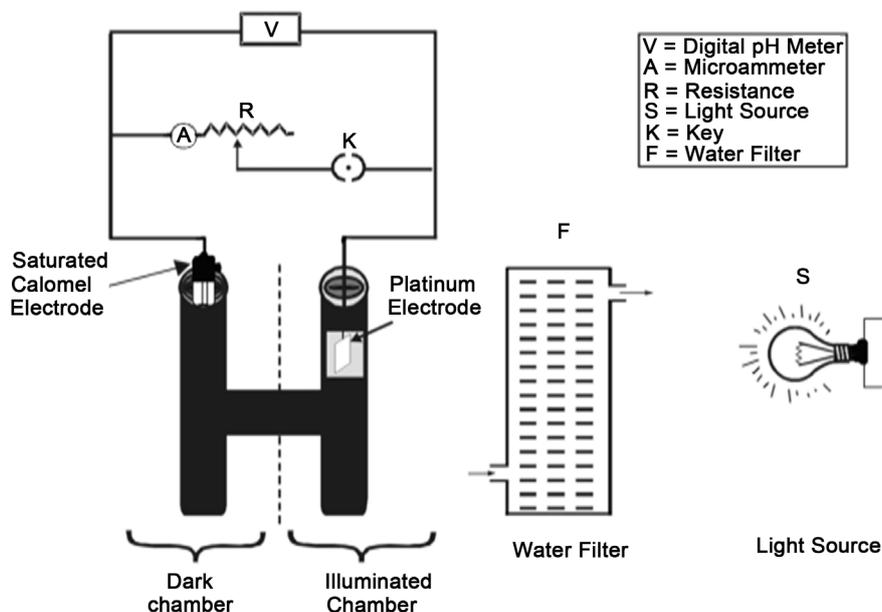
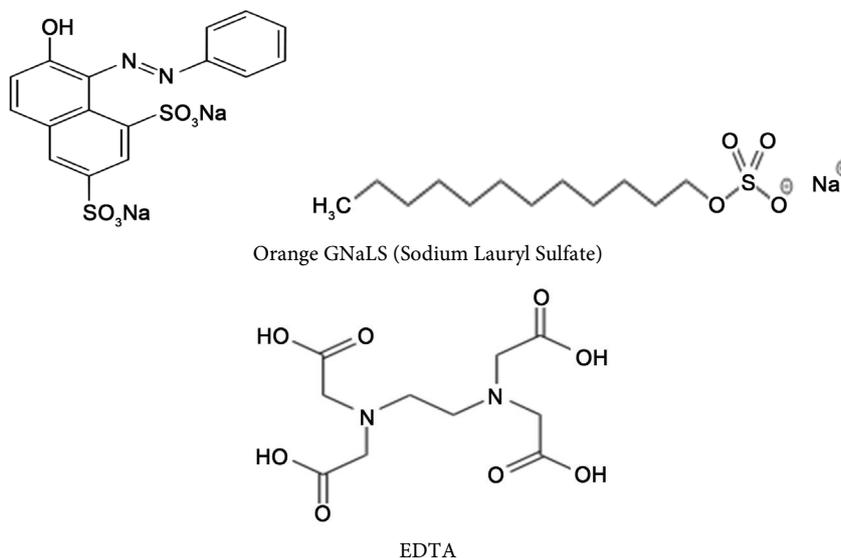


Figure 1. Experimental set-up of photo galvanic cell.



3. Result and Discussion

3.1. Effect of Variation of Surfactant [NaLS] Concentration

The photo galvanic cell having orange G-EDTA-NaLS system, the photo potential and photocurrent were increased with the increase in concentration of the surfactant. A maximum was found for a particular value of NaLS concentration, above which decrease in electrical output of photo galvanic cell was obtained. All observed results are reported in **Figure 2**. The reason of the change in electrical output is that micelles solublize the dye molecules up to highest extend at or around their micelles concentration upon increase in NaLS concentration to a value higher than CMC a charge transfer complex between dye and surfactant which is hydrophobic in nature so a fall in electrical output was observed.

3.2. Effect of Variation of Reductant Concentration

The electrical outputs of these electrochemical cells were found to increase with the increase in the concentration of the reducing agent till it reaches an optimum value. Then there was a decrease in photo potential and photo current both on further increase in the concentration of the reductant. The fall in the concentration of reductant also resulted into fall in power output due to less number of molecules available for electron donation to the cationic form of the dyes. On the other hand, higher concentration of the reductant will hinder the movement of dyes molecules to reach, the electrode in the desired time limit. The observed result are given in **Figure 3**.

3.3. Effect of Variation of Photo Sensitizer (Dyes) Concentration

The effect of variation of photosensitizer (dyes) concentration has been studied. It was observed that there was an increase in photopotential and photocurrent on increasing the concentration of photosensitizer. It was felt necessary to keep the concentration of photosensitizer (dyes) for effective results in electrical output. On the lower side of concentration range of photosensitizer, there will be

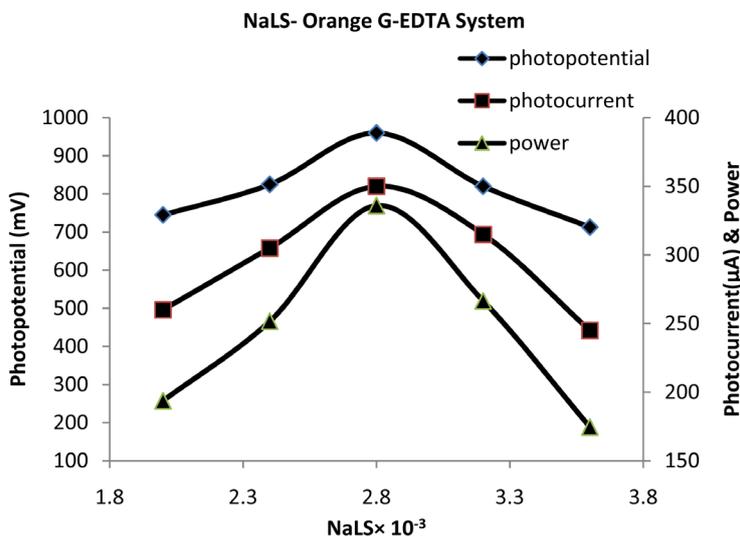


Figure 2. Variation of photopotential, photocurrent and power with NaLS concentration.

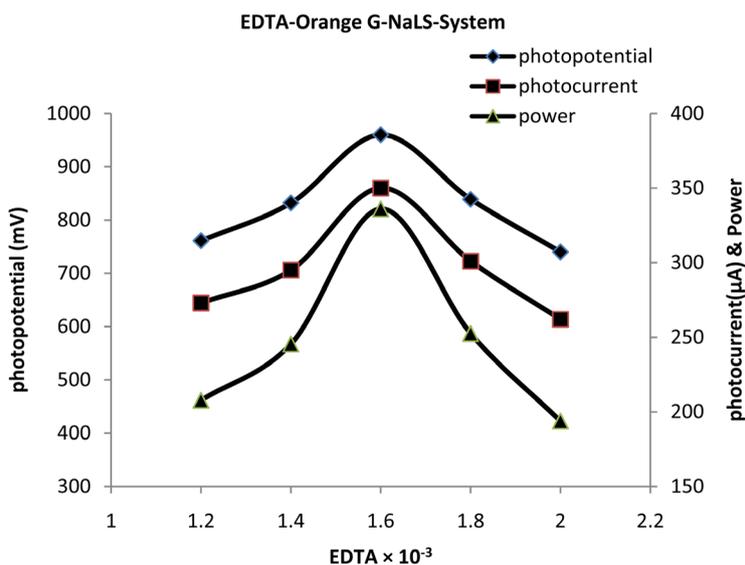


Figure 3. Variation of photopotential, photocurrent and power with EDTA concentration.

limited number of photosensitizer molecule to absorb the solar light in cell and, therefore, there is low electrical output whereas higher concentrations of photo sensitizer will not permit the desired light intensity to reach the photosensitizer molecules near the electrodes and hence, there will be a corresponding fall in the power of the cell.

1. On the lower concentration range of orange G, there is a limited number of photosensitized molecules to absorb the major portion of the light and therefore, a few number of electrons can reach the platinum electrode and a low electrical output was obtained;
2. Higher concentration of the dye does not permit the desired light intensity to reach the molecules near the electrodes and hence, there is a corresponding fall in the power of the cell;

3. Due to the high concentration, there are short lived excited dye states therefore; an excited dye molecule must reach Pt within its short life for electron donation. Give these, only dye molecules that exist and absorb photons near Pt have greater chance of electron donation to Pt electrode;
4. The increased concentration of dye under operational conditions may also lead to be accelerated recombination between the injected electrons and dye accompanied by losses of photocurrent and photovoltage and reduced conversion efficiencies.

The effects of variation of photosensitizer are reported in **Figure 4**.

3.4. Effect of PH

The electrical output of the cell was affected by the variation in pH of the system. That there is an increase in electrical output of the cell with the increase in pH values. At pH 12.8 a maxima was obtained. Further increase in pH, a decrease in photo potential and photocurrent was observed. Thus, photo galvanic cell containing the orange G-EDTA and NaLS system were found to be quite sensitive to the pH of the solution. The effect of variation of PH on photo potential and photocurrent are given in **Figure 5**.

3.5. Effect of Diffusion Length

Conversion of solar energy into electrical energy of the cell is also affected by the diffusion length of the cell. With the increase in the diffusion length the current also increases. Maximum current of the cell is observed to increase first with increase in diffusion length and then decrease on further increase in the diffusion length whereas equilibrium current i_{eq} and rate of generation of current are found to increase slightly. The results are shown as below in **Table 1**.

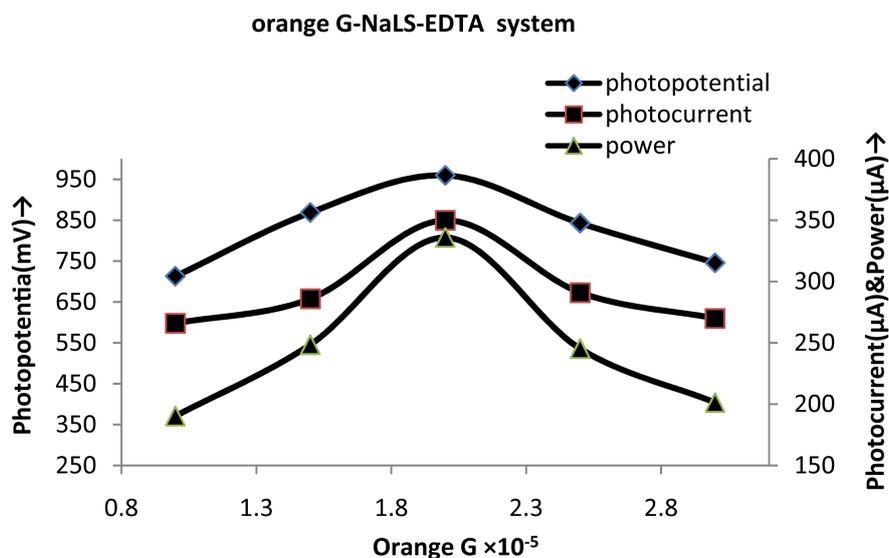


Figure 4. Variation of photopotential, photocurrent and power with orange g concentration.

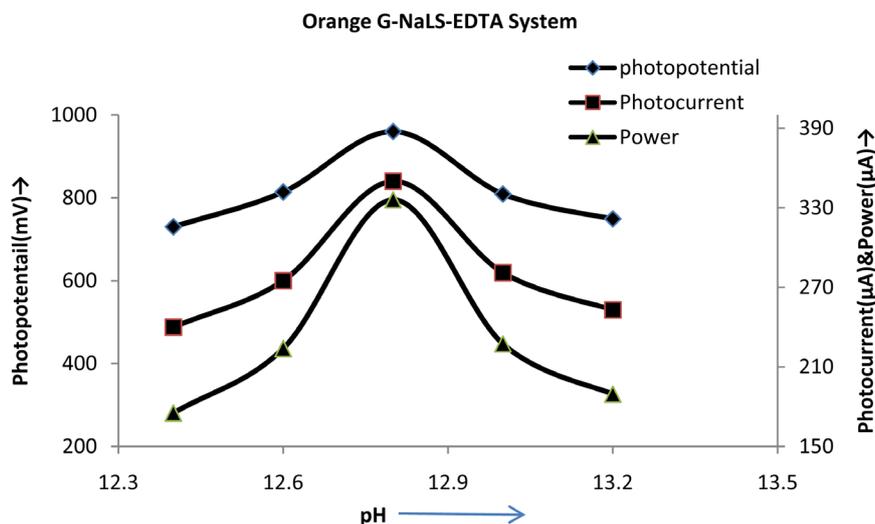


Figure 5. Variation of photopotential, photocurrent and power with pH.

Table 1. Effect of diffusion length.

Orange G + EDTA + NaLS System Orange G = 5.9×10^{-5} pH = 12.8 Temp. = 303 K Light intensity = $10.4 \text{ mW}\cdot\text{cm}^{-2}$ EDTA = 2.2×10^{-3} NaLS = 1.4×10^{-3}			
Diffusion path length D_L (mm)	Maximum photocurrent I_{max} (µA)	Equivalent photocurrent I_{eq} (µA)	Rate of initial generation of current ($\mu\text{A}\cdot\text{Min}^{-1}$)
35.0	280	240	12.55
40.0	304	276	14.87
45.0	385	350	20.99
50.0	320	290	19.50
55.0	270	255	16.90

3.6. Light Intensity and Temperature

Photo galvanic effect is a light induced phenomenon and depends upon the intensity of light. Intensity of light increases photo potential and photocurrent both increases. Tungsten bulbs of various watts were used to vary light intensity and the result is as tabulated in **Table 2**.

3.7. Effect of Electrode Area

The effect of electrode area on the current parameters of the cell has also been studied. It was observed that with the increase in the electrode area the value of photopotential is found to increase. All observed results with respect to effect of electrode area are summarized in **Table 3**.

4. Performance of the Cell and Conversion Efficiency

The open-circuit voltage (V_{oc}) and short-circuit current (i_{sc}) of the photo galvanic cell were measured by means of a digital multimeter (keeping the cir-

Table 2. Effect of Light intensity and temperature.

Orange G + EDTA + NaLS System Orange G = 5.9×10^{-5} pH = 12.8 Temp. = 303 K Light intensity = $10.4 \text{ mW}\cdot\text{cm}^{-2}$ EDTA = 2.2×10^{-3} NaLS = 1.4×10^{-3}			
Intensity of Light $\text{mW}\cdot\text{cm}^{-2}$	Photo Potential (mV)	Photo Current (μA)	Log V
3.1	892	265	2.37
5.2	918	280	2.41
10.4	960	350	2.52
15.6	980	385	2.57
26.0	998	390	2.59

Table 3. Effect of electrode area.

Orange G + EDTA + NaLS System Orange G = 5.9×10^{-5} pH = 12.8 Temp. = 303 K Light intensity = $10.4 \text{ mW}\cdot\text{cm}^{-2}$ EDTA = 2.2×10^{-3} NaLS = 1.4×10^{-3}		
Electrode Area (cm^{-2})	Maximum Photocurrent(μA)	Equilibrium Photocurrent(μA)
0.25	280	265
0.49	305	280
1.00	380	350
1.44	405	385
1.69	420	390

cuit closed). The current and potential between two extreme values (V_{oc}) and (i_{sc}) were recorded with the assistance of a carbon pot (linear 470 K) that was connected in the circuit of the multimeter and through which an external load was applied. The i-V characteristics of the cell containing Orange G EDTA-NaLS System are shown graphically in **Figure 6**. And cell performance in **Figure 7**.

Rectangular shape. A point in the i-V curve, called the power point (pp), was determined where the product of photocurrent and photo potential is maximum. The potential and the current at the power point are represented by (V_{pp}) and (i_{pp}) respectively. With the help of the (i-V) curve, the Fill Factor and Conversion Efficiency of the cell are found to be 0.47% and 1.52% respectively, using the formulae.

$$\text{Fill Factor} = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}}$$

$$\text{Conversion Efficiency} = \frac{V_{pp} \times i_{pp}}{10.4 \text{ mW}\cdot\text{cm}^{-2}} \times 100\%$$

10.4 $\text{mW}\cdot\text{cm}^{-2}$ Artificial Illumination intensity.

The performance of the cell was studied by applying the external load that was

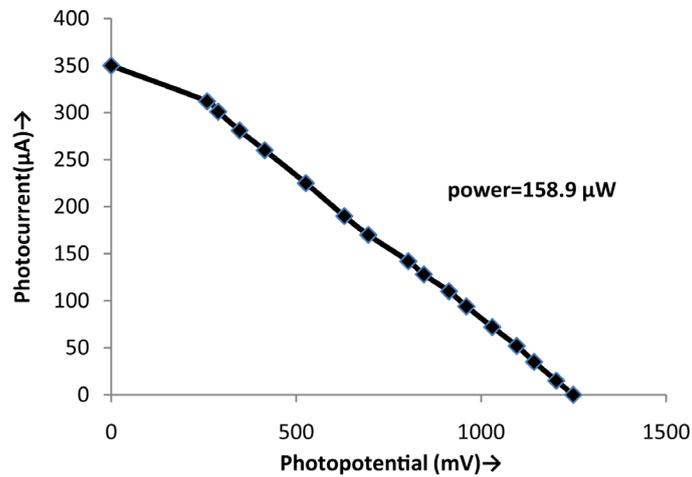


Figure 6. Current-voltage (i-v) curve of the cell.

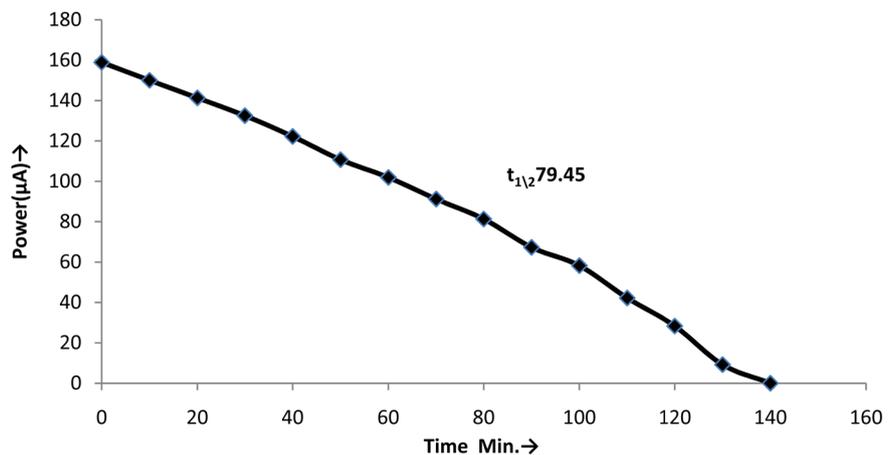


Figure 7. Performance of the cell.

necessary to have the current and the potential at the power point after removing the source of light. The cell can be used in the dark at its power point for 80.0 min. Thus, whereas photovoltaic cell cannot be used in the dark even for a second, a photo galvanic system has the advantage of being used in the dark, but at lower conversion efficiency.

5. Role of Surfactant

The utility of surfactants in photogalvanic cells with respect to their nature has been investigated and found to follow the order anionic surfactants, neutral surfactants and cationic surfactants. Alkalis *et al.* have studied the photo ejection of electrons from dye-surfactant systems, suggesting the tunneling photoelectrons from the surfactants phase to the aqueous phase, whereas Mukhopadhaya and Bhowmik [21] have suggested the probability of some charge transfer between surfactant and dye. The used NaLS solubilise the dye more easily and stabilizes the system and may increase the probability of charge transfer between surfactant and the dye in the system.

6. Mechanism

As no reaction is observed between the orange G and EDTA in the dark, it may be concluded that the redox potential of EDTA is much higher than that of Orange G. A rapid fall in potential is observed when the platinum electrode is illuminated. The potential reaches a steady value after certain period of exposure. Although the direction the change of potential does not returns to its initial value. This means that the main reversible photochemical reaction is also accompanied by some side irreversible reactions. The electro active species in this photo galvanic system is thus different from that of the well-studied Orange G-EDTA system. In the present case, the leuco- or semi-reduced dye is considered to be the electrode active species in the illuminated chamber, and the dye itself in dark chamber.

On the basis of the above investigations the mechanism of the photocurrent generation in the photogalvanic cell can be proposed as follows.

Illuminated chamber

Bulk solution

$h\nu$

Orange G \rightarrow Orange G-B*, (1)

Orange G-B* + R \rightarrow Orange G-B- + R +, (2)

At electrode

Orange G-B- \rightarrow Orange G-B + e^- , (3)

Dark chamber

At electrode

Orange G-B + $e^- \rightarrow$ Orange G-B- (4) *Bulk solution*

Orange G-B - R + \rightarrow Orange G-B

Where B + B-, R and R+ are Orange G, its semi or leuco form, reductant and its oxidized form, respectively.

7. Conclusion

On the basis of above results, it is concluded that orange G can be used successfully as photosensitizer in a photogalvanic cell. The conversion efficiency of the cell is 1.52% and the cell can be used in dark at its power point for 80.0 min. Photogalvanic cells have the added advantage of having in-built storage capacity. The time is not far off when the conversion efficiency of these cells will be comparable with that of existing solar cells. Thus, photo galvanic cells show good prospects of becoming commercially viable.

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Nomenclature

I_{eg} = photocurrent at equilibrium

i_{max} = maximum photocurrent

i_{pp} = photocurrent at power point

i_{sc} = short circuit current

mv = millivolt

m = molarity

pp = power point

$t_{1/2}$ = storage capacity of cell

Dv = observed photopotential

Ocv = open circuit voltage

Vpp = photopotential at the power point

n = fill factor

mA = microampere

mW = microwatt

S.N Parameter Observed value

1.	Dark potential	289 mV
2.	Open circuit voltage	1249 mV
3.	Photopotential (Dv)	960 mV
4.	Equilibrium photocurrent	350 μ A
5.	Maximum photocurrent	385 μ A
6.	IGP	25.5 MA min ⁻¹
7.	Times of illumination	130.0 min
8.	Storage capacity ($t_{1/2}$)	80.0 min
9.	% of storage capacity	57.14%
10.	Conversation efficiency	1.52 %
11.	Fill Factor (n)	0.47 μ A



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