Journal of Applied Science and Education, 2023,
Vol. 03, Iss. 01, S. No. 040, pp. 1-13
ISSN (Online): 2583-1372

Study of Photoactive Materials Used in Photo Electrochemical Cell for Solar Energy Conversion and Storage

Shanker Lal Meena*[1], Ravi Kumar Bhupesh[2], Lal Chand Yadav[3]

Department of Chemistry, JNV University, Jodhpur, Rajasthan, India
[1]slmeena.jnvu@gmail.com, [2]ravikumarbhupesh1955@gmail.com, [3]lalchand71yadav@gmail.com

How to cite this paper: S. L. Meena, R. K. Bhupesh and L. C. Yadav, "Study of Photoactive Materials Used in Photo Electrochemical Cell for Solar Energy Conversion and Storage," *Journal of Applied Science and Education (JASE)*, Vol. 03, Iss. 01, S. No. 040, pp 1-13, 2023.

https://doi.org/10.54060/jase.v3i1.40

Received: 27/01/2023
Accepted: 20/04/2023
Published: 25/04/2023

Abstract

Photoelectrochemical Cell is a device that absorbs light with a high-absorption electrolyte solution and provides energy for photo chemical reactions. Ponceau-S was used as a photosensitizer and EDTA served as a reducing agent in the study of photo-electron-chemical cells. The photocurrent and photo potential were 1047.0 mV and 390.0 µA respectively. The highest power of the cell was 84.0 µW, with a conversion efficiency of 1.61%. The fill factor of the cell was 0.20. The photoelectric cell can function at this power level for 240.0 minutes in storage (performance). The effects of various parameters on the cell's electrical output were observed. In this study, a mechanism for photocurrent generation in Photoelectrochemical cells is proposed.

Keywords

Photo potential, Photocurrent, Fill factor, Conversion efficiency, Storage capacity of cell.

1. Introduction

Solar energy can be converted and stored through photoelectrical cells, which are sensitive solar cells based on dyes. Only photoelectric solar cells can produce and store solar energy. A photon stimulates a molecule in anon-synchronous photochemical reaction, which results in the production of highly energy-intensive species. The species returns to its basic state after losing its energy. The photogalvanic effect was first discovered in 1839 by A.E. Becequeral. The Photoelectrochemical cells, there are four types (a) metal electrodes submerged in the electrolytic solution. (b) The inorganic substance is covered on the metal electrode. (c) The surface of the platinum electrode has additives with adsorbed dyes. (d) The metal electrode of the photogalvanic cell is submerged in an organic solution. Another form of photoelectric cell is (a) their reversible photo-chemical reaction, which is one-sided and has very low free energy changes, leading to very low conversion efficiency. (b) Reversible photochemical reactions are bidirectional and have very high conversion efficiency due to a significant change in free energy.

Rideal and Williams [1] describe the photogalvanic phenomenon, while Rabin Witch [2-3] analyses its symmetry. There is a study on the absorption of phogalvanic cells [4–8]. Hoffman and Lichtin [9] have taken into account a number of problems that have arisen as this field has expanded. The use of several photosensitizers and reducing agents in photogalvanic cells has been historically documented [10–14]. In recent years, photogalvanic effects have been observed in photoelectrochemical cells containing dyes and reduction agents [15–26]. Meena et. al [27-29] has shown the performance results of Cell of the previous work for ponceau-s dye with different reductants and surfactants the increase in cell efficiency (CE= 0.45%,0.85%,0.99%), photopotential 1080 mV ,890 mV,900 mV and photocurrent (120 μA,240 μA). It is reported in the journals of Int. J. Chemical Science, Int. Chem. Science and J. Chem. and Pharm. Research (Meena et. al 2010, 2011, 2012) that the Ponceau-S dye as a photosensitizer with Glucose and Mannitol reductant. Thus, the increase in CE in present work on the use of Ponceau-S dye as a photosensitizer with EDTA reductant is expected and justified. EDTA and several photosensitizers have been used in photogalavinc Cells [30–34], but detailed discussions and literature analysis indicate that the use of Ponceau-S dye with EDTA in photogalavinic cells is not considered for solar energy conversion and storage. We have investigated the conversion and storage of solar energy using the Ponceau-S -EDTA system in the Photoelectrochemical Cell.

2. Experimental Setup of the Photoelectrochmical Cell

The photosensitizer (dye), the reducing agent, and the solution of sodium hydroxide and double-distilled water are placed in an H-shaped glass tube, with a total volume of 30.0 ml. One of the H tubes was filled with saturated calomel (SCE) electrodes and the other was filled with platinum electrodes. When the cell reaches a static current, the photocurrent is measured in darkness. The chamber containing the platinum electrode was subsequently exposed to a 200W tungsten lamp. We can use different power lamps to change the intensity of light. In order to block infrared radiation, water filters are placed between the working electrode and light sources as shown in Figure 1.

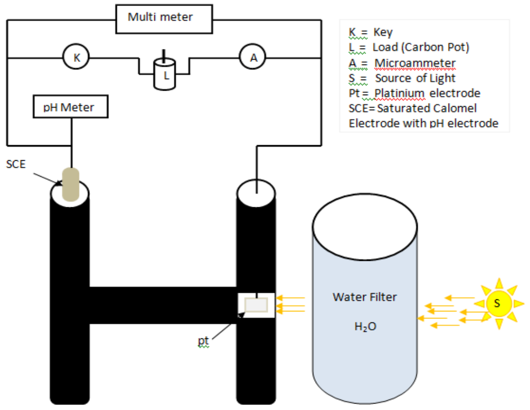

Figure 1. Circuit diagram of Photoelectrochemical solar cell set-up

3. Material Used

Table 1: Used chemical name

S.No.	Chemical name	Specification
1.	Ponceau-S dye	Loba chemical
2.	EDTA disodium salt	ASES Chemical
3.	Sodium hydroxide	Loba chemical

3.1. Structures of the used compound

3.1.1. Ponceau-S Dye

Chemical formula- $C_{22}H_{16}N_4O_{13}S_4$
Molecular weight- 760.56 g/m,
λ_{max} - 517-523nm

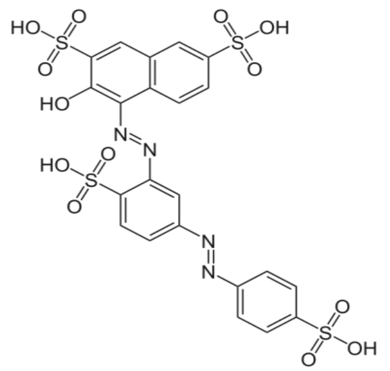

Figure 2. Structure of ponceau-S dye

3.1.2. EDTA disodium Salt

Molecular formula- $C_{10}H_{14}N_2Na_2O_8$ and Molecular weight- 336.1g/m

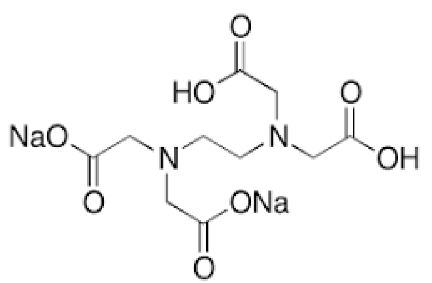

Figure 3. Structure of EDTA disodium Salt

4. Results and Discussions

4.1. Variation of photopotential with time

In photoelectrochemical cells, during the charging of Cell the graphs of different quantity of dye solution with EDTA reductant are created with time, the cell leaves light, and the voltage is measured in the zero-time (V_{dark}=295mV), and the light is turned off, the maximum voltage is reached at the maximum time, called the maximum voltage ($V_{max.}$=1047mV), The changes in photopotential with time of Ponceau-S -EDTA systems are shown in graphic form in Figure 4 and observed data are summarized in Table 2.

Table 2. Variation of photopotential with time

[Ponceau-S] = 6.7×10^{-3}M Light intensity = 10.4 $mWcm^{-2}$

[EDTA] = 3.7×10^{-4} M Temperature = 303 K

Time(Min.)	Dye-5ml + EDTA-5ml Potential (mV)	Dye- 5.2ml + EDTA-5ml Potential (mV)	Dye 4.8ml + EDTA 5ml Potential (mV)
0	295 (V_{Dark})	631	531
10	315	728	595
20	336	729	674
30	378	730	682
40	420	731	698
50	448	732	711
60	512	733	721
70	538	734	730
80	557	735	733
90	620	736	734
100	658	737	735
110	802	735	730
120	843	733	725
130	882	732	720
140	912	730	715
150	942	728	710
160	992	726	705
170	1007	724	700
180	1017	722	695
190	1025	720	690
200	1039	718	685
210	1047 ($V_{MAX.}$)	716	680
220	1047	716	680
230	1045.	712	675
240	1042	710	670
250	1040	708	667
260	1038	705	658
270	1035	702	655
280	1032	698	652
290	1030	695	648
300	1027	692	645
310	1025	690	642

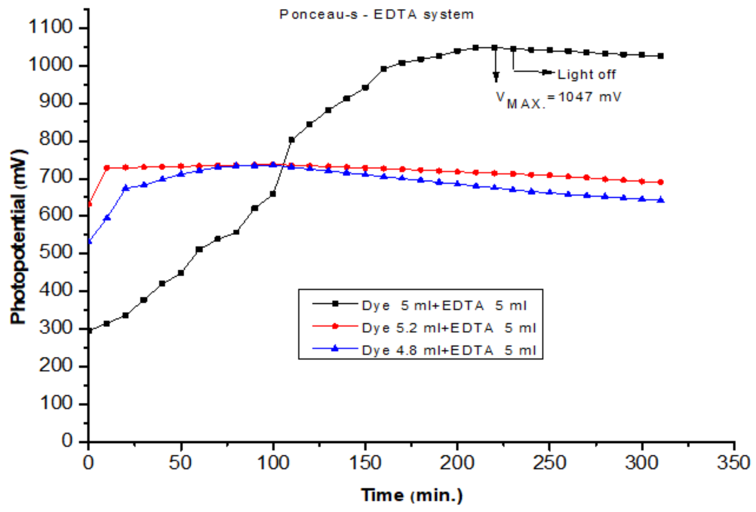

Figure 4. The photopotential changes with time during the charging of the cell

4.2. Characteristics of current voltage (i-v) during cell charging

Electrical parameters (open circuit voltage (V_{OC}) and short circuit current (i_{SC}) characteristics were observed when cells were placed under direct light sources. Digital multimeters are used to measure photocurrent and photocurrent, and from this digital multimeter we measure short-circuit currents (i_{SC}=390μA) and open-circuit voltages (V_{OC}=1047mV). By using carbon-linked circuits in digital multimeter circuits to supply external loads, the photocurrent and photopotential are noted between the two extreme values. The current voltage (i-v) characteristics of a photoelectrochemical cell with the maximum power of the Ponceau-S-EDTA system at power point (P_{PP}=84μW) are shown in Figure 5 and observed data are summarized in Table 3.

Table 3. Current - voltage (i-v) characteristics of the cell

[Ponceau-S] = 6.7×10^{-3}M　　Light intensity = 10.4 mWcm^{-2}

[EDTA] = 3.7×10^{-4}M　　Temperature = 303 K

Photocurrent(μA)	Dye-5ml + EDTA-5ml Potential (mV)	Dye- 5.2ml + EDTA-5ml Potential (mV)	Dye- 4.8ml + EDTA 5ml Potential (mV)
390(i_{SC})	30	25	20
360	39	36	28
330	49	48	42
300	68	64	58
270	107	120	92
240	290	280	132
210	360	350	185
180	443	432	230
150	560	522	310
120	686	610	420
90	787	672	480
60	878	720	532
30	967	785	592
0	1047(V_{OC})	850	750

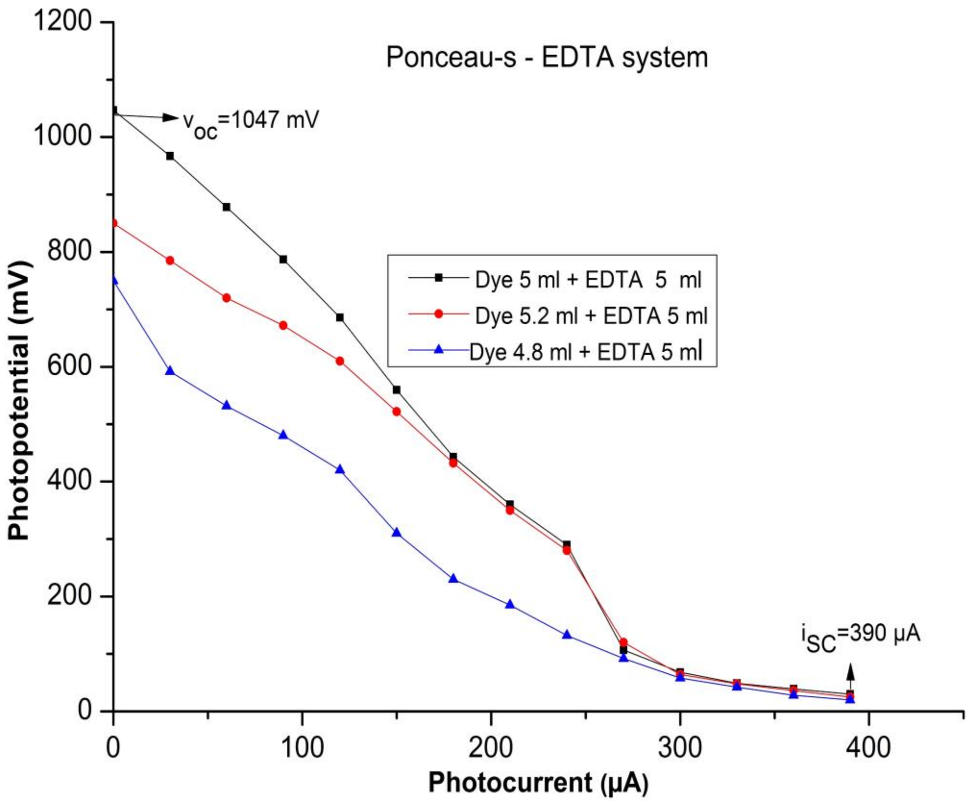

Figure 5. The photopotential and photocurrent (i-v) characteristics curve for Ponceau-S dye and EDTA systems

Fill factor

From the (i-v) curve, we get the highest values of open circuit voltage (V_{OC}) and short circuit current (i_{SC}), and from this (i-v) curve, the value of the fill factor was determined to be 0.20, which comes out of this formula-

$$\text{Fill Factor} = \frac{V_{PP} \times i_{PP}}{V_{OC} \times i_{SC}}$$

In this formula, i_{PP} and V_{PP} are current and potential at the power point, V_{OC} is open circuit voltage, and i_{SC} is short circuit current, respectively.

4.3. Photopotential and photocurrent studies are carried out at the power points of the cell

The shunt is adjusted at 30µA of photocurrent, with a differential between photocurrent and photo potential that is continuously rising. The cell's maximum output is 84µW, with a power point at potential of 560 mV and a power point at current of 150 µA. Figure 6 shown graphically and observed data are summarized in Table 4, represents the study of photo potential and power with the photocurrent of the cell.

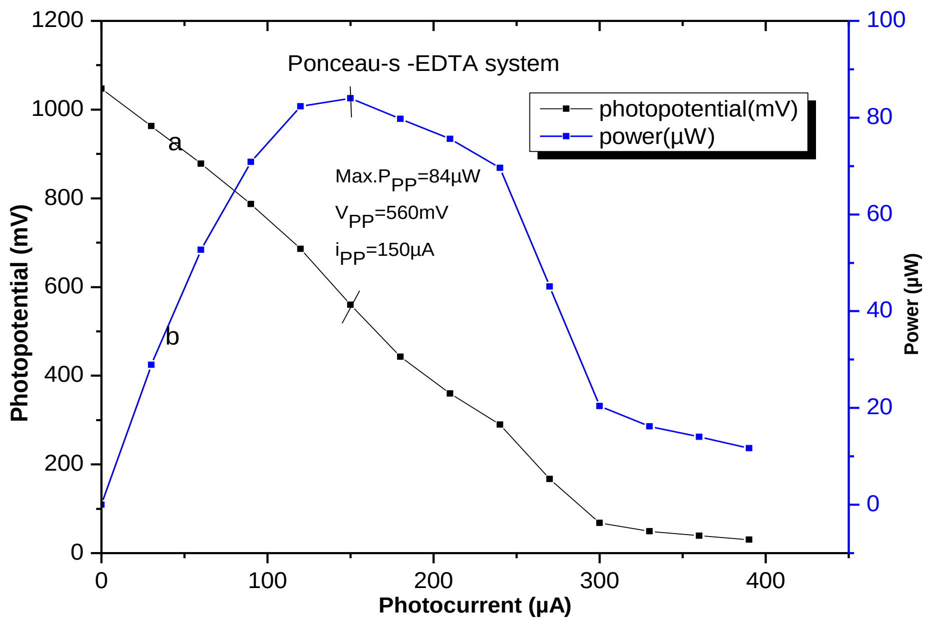

Figure 6. The change of the potential and current with the power

Table 4. Variation of potential and power with currant

[Ponceau-S] = 6.7×10^{-3}M Light intensity = 10.4 $mWcm^{-2}$

[EDTA] = 3.7×10^{-4}M Temperature = 303 K

Photocurrent(µA)	Photopotential (mV)	Power (µW)
390	30	11.7
360	39	14.04
330	49	16.17
300	68	20.4
270	107	45.09
240	290	69.6
210	360	75.6
180	443	79.74
150 (i_{pp})	560 (V_{PP})	84 (Max.P_{PP})
120	686	82.32
90	787	70.83
60	878	52.68
30	967	28.89
0	1047	0

4.4. The cell capability for storage

Applying a load from outside as soon as the potential reaches a consistent value after turning off the illumination allows for the observation of the Performance of the cell. The time it takes for maximum power (P_{PP}) to drop to half in the dark is known as t1/2, and it is used to calculate storage capacity. The half-life of a cell has been observed to be 240 minutes. Figure 7 shows the performance of the cell and observed data are summarized in Table 5.

Table 5. Storage capacity of the cell

[Ponceau-S] = 6.7×10^{-3}M   Light intensity = 10.4 mWcm^{-2}

[EDTA] = 3.7×10^{-4}M   Temperature = 303 K

Time (Min)	Power (μW)
0	0
10	84
20	78.19
30	75.97
40	74.06
50	72.83
60	71.76
70	70.69
80	69.9
90	68.85
100	68.07
110	66.89
120	65.06
130	63.57
140	60.7
150	56.12
160	51.83
170	49.68
180	46.73
190	45.87
200	43.01
210	44.38
220	43.76
230	43.14
240 ($t_{1/2}$)	42.12
250	41.4

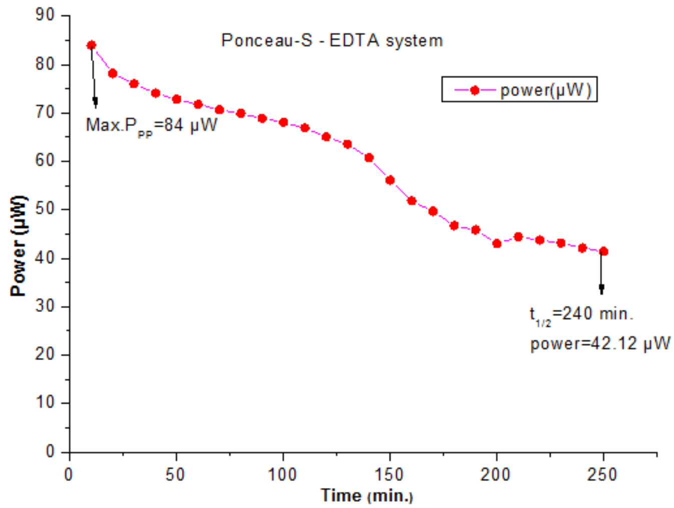

Figure 7. Cell capacity (performance) curve for during cell discharge

Solar Cell efficiency

The function of energy incident, which is transformed into electrical energy and is defined as determining the conversion efficiency of a solar cell

$$\text{Conversion efficiency} = \frac{V_{PP} \times i_{PP}}{A \times P} \times 100\%$$

Where V_{PP} and i_{pp} are the power point at potential and current respectively, and A is the area of platinum electrode (cm^2). Solar efficiency of this Ponceau-S – EDTA system is 1.61%.

4.5. The performance of the cell

All parameters are observed result in performance of the cell such as Open circuit voltage (V_{oc})= 1047 mV, Short circuit current (i_{SC})= 390 µA, Storage capacity ($t_{1/2}$)= 240 min., Conversion efficiency=1.61%, Fill factor (F_r)= 0.20, Potential at power point (V_{PP})= 560 mV, Current at power point (i_{pp})= 150 µA, Maximum power=84 µW and Photopotential(Δv)= 752 mV, respectively and the result are presented in table 6.

Table 6. Observed results of all parameters for performance of the cell

Paramaters	Observed result
Open circuit voltage (V_{oc})	1047 mV
Short circuit current (i_{SC})	390 µA
Storage capacity ($t_{1/2}$)	240 min.
Conversion effeciency	1.61%
Fill factor (F_r)	0.205
Potential at power point (V_{PP})	560 mV
Current at power point (i_{pp})	150 µA
Maximum power	84 µW
Photopotential (Δv)	752 mV

4.6. Effect of change in EDTA concentration

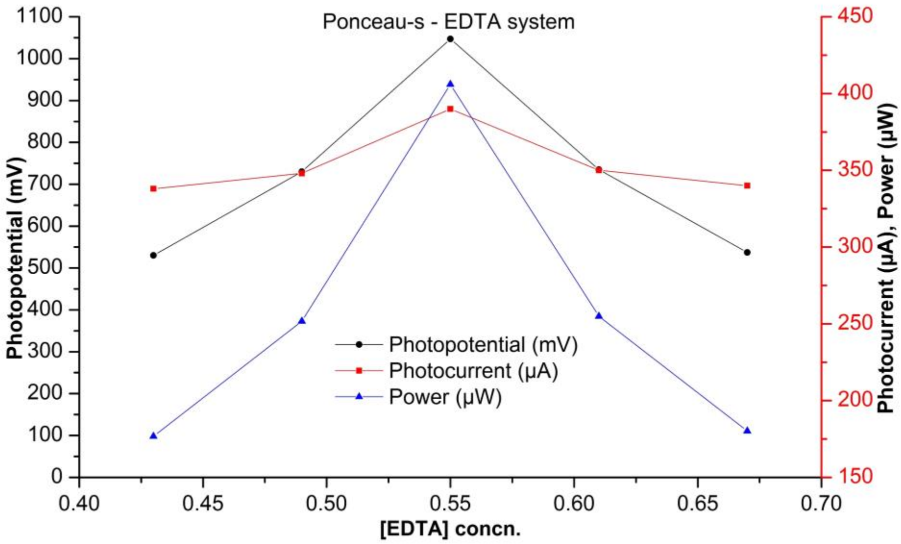

Figure 8. Changes in the concentration of reductant [EDTA] with potential and power with current

The study and its results examined the relationship between photopotential and photocurrent and reductant concentrations. EDTA is present in a quantity of [0.55 ×10^{-4}M], the photopotential and photocurrent reach their maximum levels. Five Photo-electrochemical cells were built together to investigate the effects of varying EDTA reductant concentrations on cell performance. The optimum cell performance in terms of the electrical parameters was observed at optimal EDTA reductant concentration to [0.55 ×10^{-4}M], (Fig. 8).

The particle nature of matter and sunlight, which both consist of distinct particles called photons and molecules, can both be used to explain this finding. At EDTA reductant concentration below the [0.55 ×10^{-4}M], the number of available EDTA reductant molecules shall be less in number for donating electrons to the dye molecules leading to the reduced cell current and power. At EDTA reductant concentration above the [0.55 ×10^{-4}M], the increased back electron combination reaction (electron coming back from dye to reductant) coupled with the increased hindrance by the reductant molecules in the diffusion path of the dye molecules may be the reason for lowering of the cell power and current.

4.7. The effect of changes of the [Ponceau-S] dye concentration

During the observations, it was observed that the photopotential increased with the increase in dye concentra-tion (Ponceau-S) until it reached the maximum value, and that the electrical output of the cells decreased with the increase in dye concentration. The photopotential and photocurrent depend on the concentration of photosernsitizer (Ponceau-S). When the concentration of ponceau-S increases, photopotential and photocurrent increase to the maximum to [1.11×10^{-3}M], after which both properties decrease (figure-9).

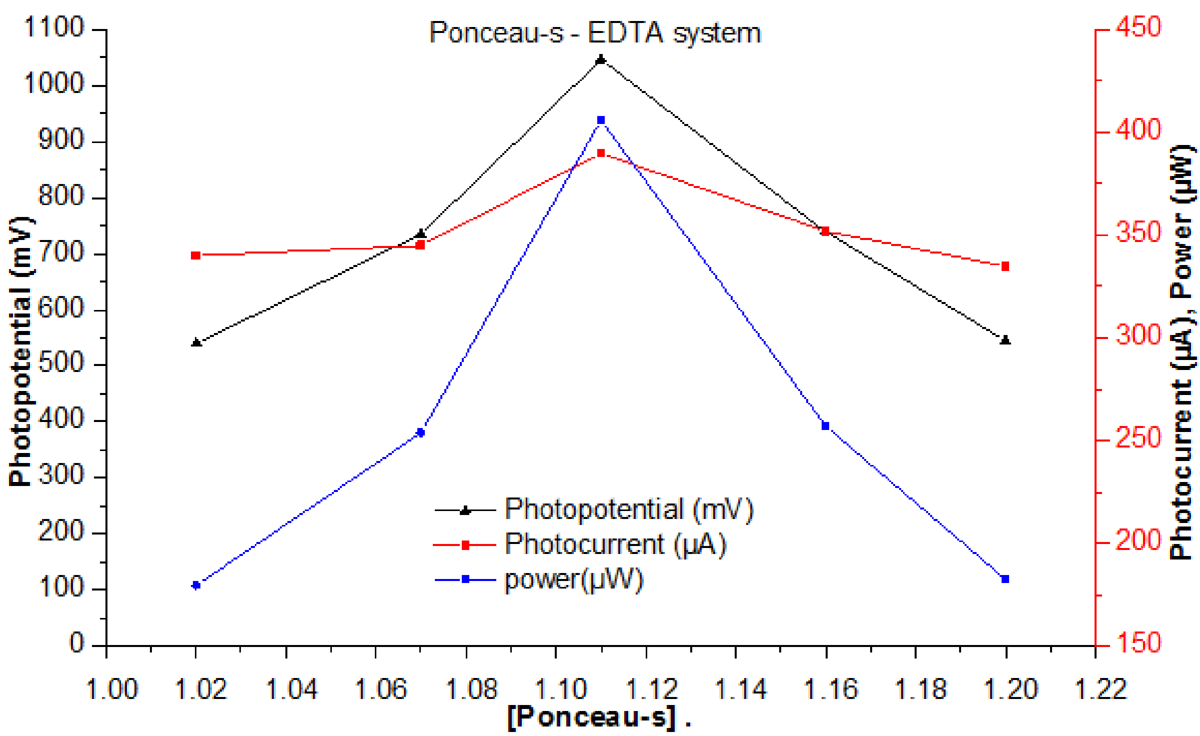

Figure 9. The Effect of variation of dye concentrations [Ponceau-s] with potential and power with current

5. Mechanism

The photosensitizer (Ponceau-S) and EDTA do not show reactions when it is in dark, It could be a factor that EDTA has a considerably larger redox potential than Ponceau-S. When the platinum electrode is lit, a rapid potential reduction is noticed. Over a certain period of time, the potential increases to a fixed value. Notwithstanding the fact that the direction of the possible change is back on, turn off the light source. The potential falls short of its accepted worth. This indicates that a secondary reversible reaction is present in addition to the first reversible photochemical process. The following diagram (10) illustrates how photocurrent is produced in a photoelectrochemical Cell:

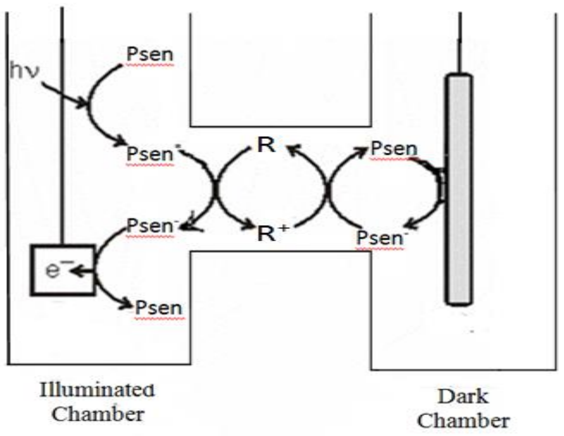

Figure 10. Scheme of mechanism of current generation

SCE = Saturated calomel electrode

Psen = Photosensitizer

$Psen^*$ = Excited state of Photosensitizer

$Psen^-$ = Reduced state of Photosensitizer

R = Reluctant

R^+ = Oxidized form of Reluctant

e^- = Electron

Illuminated chamber

Photo-processes occurring in the illuminated chamber containing.

At Anode **(**Pt electrode)

$$Dye \xrightarrow{h\nu} Dye^* \quad (1)$$

$$Dye^* + R \longrightarrow Dye^- + R^+ \quad (2)$$

$$Dye^- \longrightarrow Dye + e^- \text{ (at pt electrode)} \quad (3)$$

Photo-processes occurring in the dark chamber containing

At Cathode (SCE electrode)

$$Dye + e^- \longrightarrow Dye^- \text{ (at calomel electrode)} \quad (4)$$

$$Dye^- + R^+ \longrightarrow Dye + R \quad (5)$$

Where SCE stands for Saturated calomel electrode;

D = dye molecule;

D* = oxidised form of dye molecule;

R^+ = oxidised form of the reductant;

R = reduced state of the reductant;

e- = electron, respectively

6. Conclusion

The results indicate that Ponceau-S can be used successfully in a Photoelectrochemical cell as a photosensitivity agent. The cell is converted to 1.61% efficiency and operates in total darkness at maximum power for 240 minutes. Photoelectrochemical cells have the advantage of having an integrated circuit for storage of power.

Acknowledgements

Authors are grateful to the Head of the Department of chemistry, Jai Narian Vyas University, Jodhpur, for Re-search facilities.

References

[1]. E. K. Rideal & D. C. Williams, “The action on the ferrous iodine iodide equilibrium,” J. Chem Soc, vol.127, pp.258-269, 1925.

[2]. E. Rabinowitch & L. F. Epstein, “Polymerization of Dyestuffs in Solution Thionine and Methylene Blue,” J. Chem. Phy, vol.63, no.1, pp.69-78, 1941.

[3]. E. Rabinowitch, L. F. Epstein, F. Karush, “A spectrophotometric study of thionine,” JOSA, vol.31, no.1, pp.77-84, 1941.

[4]. R. Gomar, “Photogalvanic cells,” Electochim Acta, vol.20, no.1, pp.13-20, 1975.

[5]. J. G. Calvert, A. M. Zarem, D. D. Erway, “Photochemical process for utilization of solar energy,” McGraw Hill New York, 1964.

[6]. W. D. K. Clark & J. A. Eckert, “Photogalvanic cells,” Sol. Energy, vol.17, no.3, pp.147-150, 1975.

[7]. M. Kaneko & A. Yamada, “Photopotential and photocurrent induced by a tolusafranine ethylenediaminetetraacetic acid system," The Journal of Physical Chemistry, vol.81, no.12, pp. 1213-1215, 1977.

[8]. A. S. N. Murthy, K. S. Reddy, “Studies on photogalvanic effect in systems containing toluidine blue,” Solar Energy, vol.30, no.1, pp.39-43, 1983.

[9]. M. Z. Hoffman, N. N. Lichtin, R. R. Hantala, et al., “Use of reductant and photosensitizer in photogalvanic cells for solar energy conversion and storage: oxalic acid–methylene blue system,” Solar Energy, N.N.Publisher, New Jersey,vol.141, no.2-3, pp. 175-177, 2001.

[10]. A.S. N. Murthy, H. C. Dark, K. S. Reddy, “Photogalvanic effect in riboflavin—ethylenediaminetetraacetic acid system." International Journal of Energy Research, vol.4, no.4, pp.339-343, 1980.

[11]. S. C. Amcta, S. Khamcsra, S. Lodha, et al., “Studies on photogalvanic effect in systems containing toluidine blue,” J. Photochem Photobiol, vol.81, 1989.

[12]. S. C. Ameta, S. Khamesra, M. Bala, et al., Use of Micelles in Photogalvanic Cell for Solar Energy Conversion and Stor-age,” The Philippine Journal of Science, vol.119, pp.371-373, 1990.

[13]. M. Mukhopadhyaya & B. B. Bhowmik, “Kinetics of photoinduced electron transfer in a photoelectrochemical cell consisting of thiazine dyes and Triton X-100 surfactant,” J. Photochem. Photobiol, vol.69, no.2, pp.223-227, 1992.

[14]. K. M. Gangotri, O. P. Regar, C. Lal, et al., “Role of an Anionic Surfactant and Reductant in Photo Galvanic Cell for So-lar Energy Conversion and Storage,” Int. J. Energy Res., vol.20, pp.581-585, 1996.

[15]. K. M. Gangotri, C. Lal, "Studies in Photogalvanic Effect and Mixed Dyes System: EDTA-Methylene Blue Toluidine Blue System," International Journal of Energy Research, vol.24, pp.365-371, 2000.

[16]. K. M. Gangotri, C. Lal, "Use of Mixed Dyes in Photogalvanic Cells for Solar Energy Conversion and Storage: EDTA-Methylene Blue and Azur-B System," Energy Sources, vol.23, no.3, pp.267-273, 2001.

[17]. K. M. Gangotri, R. C. Meena, "Use of reductant and photosensitizer in photogalvanic cells for solar energy conversion and storage: oxalic acid–methylene blue system," J. Photochem Photobiol., vol.141, no.2-3, pp.175-177, 2001.

[18]. K. M. Gangotri, R. C. Meena, "Role of reductant and photosensitizer in solar energy conversion and storage: ascorbic acid-eiosin system," J. Ind. Chem. Soc., vol.81, pp.576-578, 2004.

[19]. K. M. Gangotri & C. Lal, "Use of mixed dyes in photogalvanic cells for solar energy conversion and storage: EDTA-methylene blue and thionine system," J. Power and Energy, vol.219, no.5, pp. 315-320, 2005.

[20]. R. C. Meena & R. S. Sindal, "USE OF SURFACTANT IN PHOTOGALVANIC CELL FOR. SOLAR ENERGY CONVERSION AND STORAGE: TWEEN-80-OXALIC ACID-TOLUIDINE BLUE SYSTEM," Int. J.Chem. Sci., vol.2, no.3, pp.321-330, 2004.

[21]. R. C. Meena & G. Singh, "Role of reductant and photosensitizers in solar energy conversion and storage: Oxalic acid - Brilliant Cresyl system," Int.J. Chem. Sci., vol.31, pp.463-470, 2006.

[22]. A.Chauhan, M. Genwa, I. Prakash, et al., "Study of photogalvanic effect in photogalvanic cell containing Azur B-NaLS-Ascorbic acid system," J.Ind. Chem. Soc., vol.83, no.8, pp.799-802, 2006.

[23]. C.Lal, "Use of mixed dyes in a photogalvanic cell for solar energy conversion and storage: EDTA–thionine–azur-B sys-tem," J. Power Sources, vol.164, no.2, pp.926-930, 2007.

[24]. K. R. Genwa & M. Genwa, "Photogalvanic cell: A new approach for green and sustainable chemistry," Original Re-search Article Solar Energy Materials and Solar Cells, vol.92, no.5, pp.522-529, 2008.

[25]. K. R. Gemwa, A. Kumar, A. Sonel, "The Role of Ascorbic Acid in a Photogalvanic Solar Cell Containing a Crystal Vio-let-diocyle Sulphosuccinate System and to Study the Energy Efficiency of the Cell," Original Research Article Applied Energy, pp.1431-1436, 2009.

[26]. K. M. Gangotri, V. Indora, "Studies in the photogalvanic effect in mixed reductants system for solar energy conversion and storage: Dextrose and Ethylenediaminetetraacetic acid–Azur A system," Original Research Article Solar Energy, vol.84, no.2, pp.271-276, 2010.

[27]. M. Chandra, R. C. Meena, "Role of Ponceau-S-Mannitol System for Generation of Electrical Energy in Photogalvanic Cell," Int. J. Chemical Science, vol.26, pp.1447-1456, 2010.

[28]. M. Chandra, R. C. Meena, "Role of reductant for generation of solar energy in photogalvanic cell," J. Chem. And Pharm. Research, pp.264-270, 2011.

[29]. M. Chandra, A. Singh, R. C. Meena, "Role of Rose Bengal-Mannitol system for generation of electrical energy in photo galvanic cell," Int. Chem. Sci., vol.7, no.42, pp.5642-5647, 2012.

[30]. R. C. Meena, Neelakshi, Manju, "Photochemical Study for Solar Energy Conversion & Storage in Solar Cell: Yellow 5GN-EDTA System," Int. J. Chem. Pharmaceu. Sci., vol.18, pp.612-616, 2014.

[31]. N. Kumar, P. K. Meena, S. L. Meena, "Use of Photosensitizer in a Photoelectrochemical Cell for Solar Energy Conver-sion and Storage," Journal of applicable chemistry, vol.7, no.6, pp.1682-1690, 2018.

[32]. K. Meena, S. R. Saini and R. C. Meena, "Studies of Surfactant in Photogalvanic Cell for Solar Energy Conversion and Storage," Chemical Science international journal, vol.18, no.2, 2017.

[33]. S. R. Saini, S. L. Meena and R. C. Meena, "Studies of Surfactant in Photogalvanic Cell for Solar Energy Conversion and Storage," Advance in Chemical Engineering and Science, vol.7, pp.125-136, 2017.

[34]. S. L. Meena, P. K. Meena, R. C. Meena, et al., "USE OF ACID RED-36 DYE AS PHOTOSENSITIZER IN PHOTOGALVANIC CELL FOR SOLAR ENERGY CONVERSION AND STORAGE," Journal of Advance Scientific Research, vol.12, no.2, pp.110-116.