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Solar cells consisting of photo sensitizer-reductant for generation of electrical energy

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ABSTRACT

We have constructed p-n heterojunction solar sandwich cells with photo sensitizer in a thin film of reductant placed between a conducting glass coated with indium oxide and a platinum foil. The current-voltage relations of the cells have been measured in the dark and light under both forward and reverse biases.

Key words: Power Point, Fill Factor, Conversion Effiency, Rose Bengal, Oxalic Acid, Ascorbic Acid.

INTRODUCTION

Solar cells convert sunlight directly to electricity with acceptable conversion efficiency. They are virtually free of pollution. There are few reports [1-3] on the construction of solar cells utilizing the semi conducting properties of dyes. The photovoltaic effect in a sandwich cell consisting of phenoSafranine in the solid polycrystalline state has been reported earlier; [4] the system generates a photo voltage of 90 mV within a few seconds. The dyes have characteristic properties of aggregation, which cause low efficiencies due to self-quenching. To increase the efficiency and overcome to this problem, we have constructed a sandwich cell with a thin film of phenosafranin in polyvinyl alcohol coated onto conducting glass (containing In_2O_3) and a platinum foil. The preliminary results [5] show that the cell on illumination generates a fairly large photo voltage of 515 mV. This interesting result has led us to make a detailed study of thin-film solar cells consisting of dye such as Rose Bengal and reductants such as ASCORBIC ACID and Oxalic Acid. The results are reported here. A detailed literature survey reveals that different photo sensitizers and reductants have been used in photo galvanic cell [9-35].

EXPERIMENTAL SECTION

The dyes such as Rose Bengal supplied by Loba Chemicals were twice re-crystallized from ethanol-water solutions. Ascorbic Acid and Oxalic Acid (Loba Chemical) were used without further purification. AR grade polyvinyl alcohol (Loba Chemical) was used without further purification. The solutions were prepared with doubly-distilled water. The conducting glass coated with In_2O_3 was supplied by Nesatron (PPG Industries). The thin films (20-30 μm thick) of dyes in polyvinyl alcohol were prepared by spreading the solution of dye of known concentration containing a definite amount of polyvinyl alcohol (~0.8 g/10 ml).

The experimental sandwich cell was constructed with semitransparent conducting glass containing a thin film of dye in. polyvinyl alcohol and a platinum foil by using spring clips. The construction of the sandwich cell and the experimental set-up were described in an earlier paper.[5] A tungsten lamp (220V, 300 W) served as light source and had an intensity of 30mW-cm^{-2}. The photo voltage and photocurrent were measured with a Keithley model 642 electrometer and a model 196 multimeter, respectively

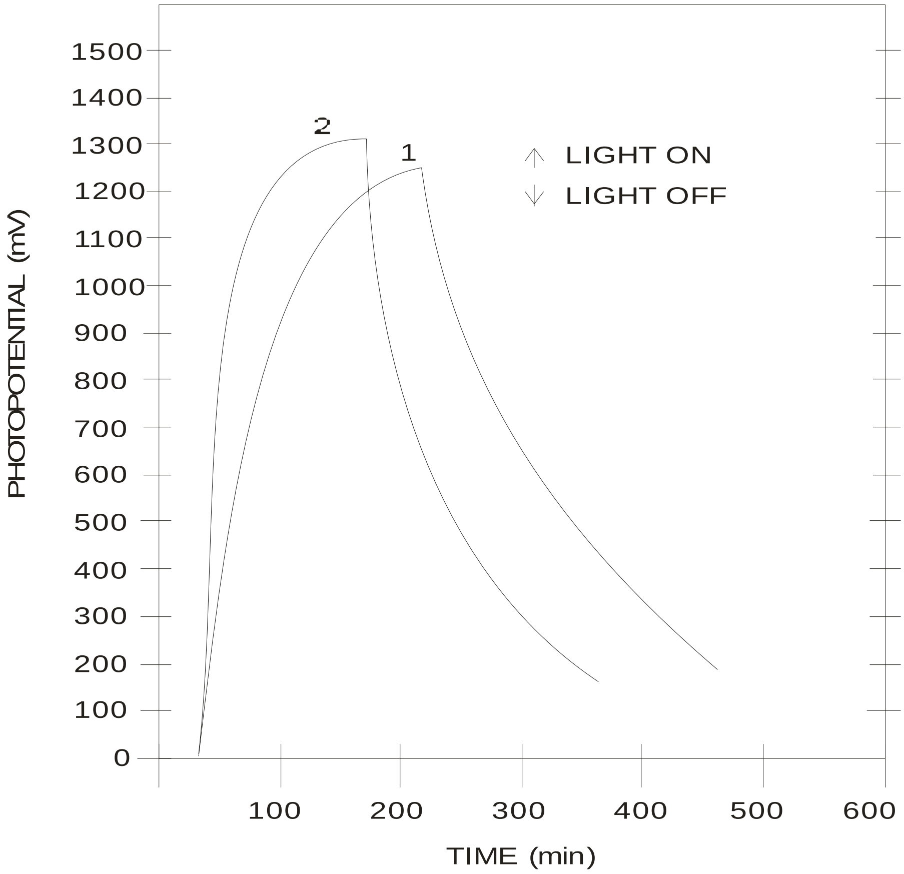

Fig.1 The effect of light on photo voltage generation for solar cells containing dye-reductants mixtures in the thin film. The dyes reductant mixtures are: (1) Rose Bengal-Ascorbic Acid (2) Rose Bengal-Oxalic Acid

RESULTS AND DISCUSSION

On illuminating the conducting glass of the sandwich cell containing the photo sensitizer dye, a photo voltage develops, which attains a maximum value within a few minutes. This photo voltage decays gradually in the dark. The growth and decay of the cell photo voltages using different dyes of different concentrations in the thin film are shown in Fig.1. The open-circuit photo voltage (V_{oc}) increases with increase inµ concentration (C) of dye till it reaches a maximum for effective conversion of light in electrical energy and follows a relation that is similar to the Freundlich adsorption isotherm, i.e. $V_{oc} = KC^{1/m}$, where K is a constant and m is a number greater than one.

Table – 1

Observations	Rose Bengal - Ascorbic Acid system	Rose Bengal - Oxalic Acid System
Open Circuit voltage (V_{oc})	1239.0 mV	1302.0 mV
Photopotential (V)	1137.0 mV	1185.0 mV
Equilibrium Photocurrent (i_{eq})	160.0 μA	175.0 μA
Maximum Photocurrent (i_{max})	180.0 μA	210.0 μA
Short circuit current (i_{sc})	160.0 μA	175.0 μA
Current at power point (i_{pp})	100.0 μA	135.0 μA
Potential at power point (V_{pp})	1022.0 μA	962.0 μA
Power at power point	64.0 μA/min	68.8 μA/min
Rate of Generation	56.0 μA/min	62.4 μA/min
Conversion Efficiency	0.981%	1.248%
Charging Time	180.0 min	180.0 min
t1/2	90.0 min	75.0 min
Fill factor (n)	0.51	0.56

Power Conversion Effiency of Photo galvanic Cell

One of the important characteristics of any electrochemical cell is its power conversion effiency. The i-V characteristics of Rose Bengal– Ascorbic Acid and Rose Bengal-Oxalic Acid. Photo galvanic cells have been investigated to estimate the power conversion efficiency of the cell. The possible power output from the cell can be obtained from the rectangle of maximum area which can be draw under i-V curve. The power point (appoint on the curve where the product of potential and current was maximum) in i-V curves were determined and their fill factorswere also calculated. These data are summarized in table 2. The efficiency of the Rose Bengal-Oxalic Acid photo galvanic cell has been calculated to be 1.248 percent, comparable to that of andRose Bengal – Ascorbic Acid photo galvanic cell has been calculated to be 0.981 percent.Power point (A point where the product of photocurrent and photo potential is maximum) is determined by using i-V curve. Where the fill factor and Conversion effiency of the cell is calculated by using following formula.

$$\text{Fill-factor (n)} = \frac{V_{pp} \text{ x } i_{pp}}{V_{oc} \text{ x } i_{sc}}$$

Where V_{pp}= photo potential at power point.
i_{pp}= Current at power point.
V_{oc} =potential in open circuit.
i_{sc}= Current in short circuit.

$$\text{Conversion efficiency} = \frac{V_{pp} \text{ x } i_{pp}}{10.4 \text{ Mw /}} \text{ x } 100\%$$

Table – 2i- V Characteristics of the Photogalvanic Cells

Systems	V_{oc} (mV)	i_{sc} (μA)	V_{pp} (mV)	i_{pp} (μA)	n
Rose Bengal and Ascorbic Acid	1239	160.0	1022.0	100.0	0.51
Rose Bengal and Oxalic Acid	1302	175.0	962.0	135.0	0.56

The conversion efficiency and sunlight conversion data for these two systems are reported in table 3.

Table – 3Conversion Efficiency and Sunlight Conversion Data

System	Fill Factor (n)	Conversion Efficiency (%)	Sunlight Conversion Data	
			Photopotential (mV)	Photocurrent (μA)
Rose Bengal and Ascorbic Acid	0.51	0.981	1239	180
Rose Bengal and Oxalic Acid	0.56	1.24	1302	210

On the basis of these observations, the highest conversion efficiency was found in Rose Bengal – Oxalic Acid system followed by Rose Bengal – Ascorbic Acid system

Performance of the photogalvanic cell

All the two systems were studied by applying the desired external load to have the potential and current corresponding to power point. The time t1\2 was determined after removing the source of light. It is the time taken in reaching half the value of power. The performance of cells was studied and comparative values are summarized in table 4.

Table – 4 Performance of the Photogalvanic Cells in Dark

System	**Power (μ W)**	**$t_{1/2}$ (min)**
Rose Bengal and Oxalic Acid	64.0	90.0
Rose Bengal and Ascorbic Acid	68.8	75.0

On the basis of the observed data, the Rose Bengal –Ascorbic Acid is most efficient from power point of view (Electrochemical Studies of Photosensitizers)

Electro active Species

The various probable processes may be considered for photocurrent generation in photo galvanic cells. The results of diffusion length on current parameters were utilized to know more about the electro active species. The possible combinations of electro active species in photo galvanic cell are tabulated in table in-5

Table – 5 The Probable Electro active Species

In Illuminated Chamber	**In Dark Chamber**
Rose Bengal Dyes	Oxidized form of the Reductant (R^+)
Leuco or Semi dye$^-$	Oxidized form of the Reductant (R^+)
Leuco or Semi dye$^-$	Dyes

The value of *K* is 3.16 V, The current-voltage relation of the *p-n* heterojunction cell in the dark is $I = I_0[1-(V/V_{bi})]\ [\exp(eV/kT)-1]$, where V_{bi} is the total electrostatic potential for the two semiconductors [6] and *k* is Boltzmann's constant.

When the junction is forward biased, i.e. V >> (kT/e), then $I = I_0[1-(V/V_{bi})]\ [\exp(eV/kT)-1]$, when it is biased in reverse, i.e. V << (kT/e), then $I = I_0(V/V_{bi})-I_0$, where I_0 is the dark current for the system. On the other hand, the photocurrent I_L develops when these systems are illuminated and the current-voltage relation becomes $I = I_L+ I_0\ [1-(V/V_{bi})]\ [\exp\ (eV/kT)-1]$, When the illuminated cell is biased forward and in reverse, then $I = I_L+ I_0\ [1-(V/V_{bi})] \exp\ (eV/kT)$ and $I=I_L+I_0\ (V/V_{bi})-I_0$, respectively. Linear and semilog plots of the current-voltage relations of the systems are shown in Figs. 2 and 3 for the dark and with light when the junctions are biased both forward and in reverse. All of the parameters are calculated from these plots.

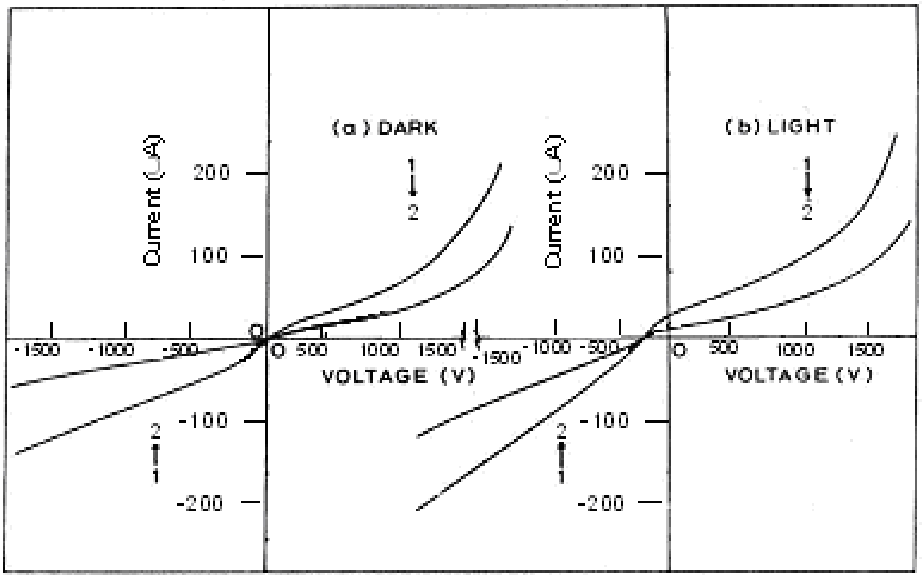

Fig.2. Linear plots of the current-voltage characteristics are shown for the cells in the dark (a) and with light (b) when the junctions are both forward and in reversed biased. The curves 1-2 represent Rose Bengal-Ascorbic Acid and Rose Bengal-Oxalic Acid respectively. The low resistivity of Rose Bengal-Ascorbic Acid compared to that of other dye-reductant films results in relatively higher currents at various voltages.

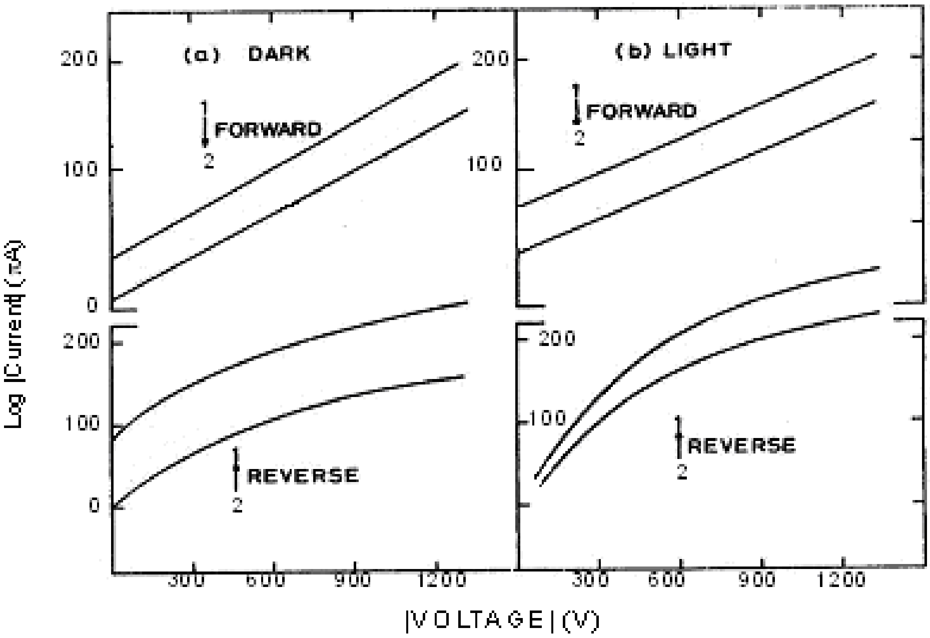

Fig.3. Semilog plots of current vs voltage for cells in the dark (a) and with light (b). The curves 1-2 represent Rose Bengal-Ascorbic Acid and Rose Bengal-Oxalic Acid respectively.

The ln_2O_3-coated glass is an n-type semiconductor with a band gap [7] of 3.6eV, whereas phenosafranin behaves as a p-type semiconductor. The reported band gap [8] for phenosafranin is 2.17 eV. Platinum is used only for ohmic contact. The formation of a *p-n* heterojunction solar cell is initiated on absorption of visible light by the dye molecules. When visible light is incident on these *p-n* heterojunctions, an excess of electron-hole pairs is generated and the electrons diffuse to the n-region while the holes diffuse to the p-region. In the absence of an externally applied field, the light-induced current develops a photovoltage across the *p-n* heterojunction.

The conductivities of semiconductor dyes in thin films of reductant increase exponentially with temperature according to the relation[6] $\sigma(T) = \sigma_0 \exp(-E/2kT)$, where E is the band gap for the process and σ_0 is the extrapolated conductivity at infinite temperature. The band gaps of dyes in a thin film of reductant have been determined directly from conductivity measurements and plotting $\ln\sigma$ as a function of 1/T. The results for Rose Bengal-Oxalic Acid and Rose Bengal-Ascorbic Acid are 1302.0, and 1239.0 mV, respectively. There is an interesting correlation between the activation energies of the dyes and the photo voltages generated in the film containing dyes. The lower the band gap of the dye, the greater is the photo voltage generated in the solar cell containing dye. Lower activation energy means that less energy is required to generate charge carriers in the semiconductors.

The use of dyes in the film increases the efficiency of photo voltage generation by decreasing self-quenching caused by aggregation. This type of solar cell using a polymer of low resistivity is important since its preparation is simple and the cost is low compared to that of other solar cells.

Mechanism:
On the basis of these observations, a mechanism is suggested for the generation of photocurrent in the photo galvanic cell as:

Illuminated Chamber

$$\text{Dye} \longrightarrow \text{Dye}^* \qquad (6.1)$$

$$\text{Dye}^* + \text{R} \longrightarrow \text{Dye}^-\text{(semi or leuco)} + \text{R}^+ \qquad (6.2)$$

At Platinum Electrode

$$\text{Dye}^- \longrightarrow \text{Dye} + e^- \qquad (6.3)$$

Dark Chamber

$$\text{Dye} + e^- \longrightarrow \text{Dye}^-\text{ (semi or leuco)} \qquad (6.4)$$

$$\text{Dye}^- + \text{R}^+ \longrightarrow \text{Dye} + \text{R} \qquad (6.5)$$

Where Dye, Dye*, Dye^-, R and R+ are the excited form of dye, semi or leuco dye, reductant and oxidized form of the reductant, respectively.

CONCLUSION

Photo galvanic cells are low cost due to the use of a dye, which are cheap and used in minute quantities reductant like Ascorbic Acid, is also not that very expensive. So overall working with a photo galvanic cell has lot of scope for its development.

On the basis of observation in the whole study it is concluded that photogalvanic cells are better option for solar energy conversion and storage. Also this systems with better electrical out put good performance and storage capacity may be used in near future. According to observed photo galvanic effect in all these two systems, Rose Bengal-Oxalic Acid system was the most efficient in all the ways.

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