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THE BASIC DEVELOPMENT OF THE DYE SENSITIZED SOLAR CELL

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Abstract: The dye sensitized solar cells (DSSC) are the advancement in the existing technology. These cells are capable of converting the visible portion of the spectrum into a voltaic form. Semiconducting materials with wide band gap as naturally occurring extracts are used as Dyes. The properties of solar cells depend on the types of dyes used. In this paper we have studied the properties of solar cells designed by using TiO_2 as the semiconducting material and the extract of pomegranate and blueberries as the dye.

INTRODUCTION:

Owing to the limited availability of non renewable resources for energy generation, there has always been a quest for new renewable, environment friendly and natural alternatives for energy generation. In the last few years solar cell has immerged as an excellent alternative energy source [1-3]. The discoveries that led to the photovoltaic techniques are more than 100 years old. The advancement in the solar cells occurred as the time elapsed. The photovoltaic effect was discovered by one of the French scientist named Edmond Becquerel in 1839 (when he observed that the absorbed of light by a material generates electrical voltage). Thereafter in 1874, selenium photoconductivity was discovered by Willoughby Smith. Few years later it was found that electricity could be produced simply by using light without employing any heat or movable part. In 1883, Charles fritts designed the first solar cell by applying a thin layer of gold over selenium and successfully achieved an energy conversion with the rate of approximately 1-2%. Later on, Heinrich Hertz who was German physicist discovered photoelectric effect, where power was created by freeing electrons with the help of photo energy from solid materials (mostly metals). The number of electrons released increases as the incident visible light is replaced by ultraviolet radiations. Then in the mid of twentieth century scientists found that silicon is more efficient material to create solar power and solar cells were then produced commercially on the large scale. A majority of modifications and advancement were brought in this particular field of research. By the end of the century, NREL designed a solar cell using Indium gallium phosphide and reaches 30% energy conversion rate. These thin film cells transform one-third of the sun energy into usable form. The year 2005 marked the era of DIY solar panels which contributed in rising efficiency of the existing solar cells. A continuous research is still going on at present to bring out the possible changes in the solar cells that would make this energy conversion technique a major source of energy.

Dye-sensitized solar cell exhibit many advantages over other thin-film solar cells like the ratio of price to performance is quite good [4]. Dye-sensitized solar cells have the capability to absorb the photons well. This is because of their better depth within the nanostructure [5-7]. Hence, these cells are more efficient in creating free electrons by the absorption of photons. Although the dye sensitized solar cells are less efficient than existing photovoltaic cells but the ratio of price to performance is higher as compared to others. Further, the technique which is used to construct Dye-sensitized cell is very simple and can be designed under normal laboratory conditions. Meanwhile, the overall cost to manufacture these cells is also very low. No special apparatus or panels are required for their set-up. Dye-sensitized solar cells are capable to endure drastic environmental conditions and do not deteriorate overtime by the continuous effect of sunlight. This feature extends the life of these cells, unlike other solar cells. The dye which is present in Dye-sensitized solar cells is capable to absorb even the less intense solar light and thus make them suitable to operate even during cloudy weather conditions. Other cells have certain illumination range and do not work if this range is not in accordance. The commonly used cells are enclosed in a glass case and so there are chances that the cell may get burnt and having negative impact on the efficiency of the cell [8]. This drawback is depleted from Dye-sensitized solar cells as they are enclosed within the thin plastic layer. This thin layer assists in radiating the heat easily and hence maintaining a lower value of internal temperature. Dye-sensitized solar cells are constructed by using materials which are very lightweight and do not necessitate any extra care or protection from the rainfall or from any harsh object present in the environment. This ultimately reduces their maintenance cost to a greater level [9,10].

Finally, being highly dependent on the technology, people need energy for survival and for maintaining a sumptuous lifestyle. Thus, a search for energy resource with minimum disadvantages on the environment is growing. Dye-sensitized solar cells which are third generation photovoltaic cells are major energy convertor with overall efficiency greater than the existing solar cells [11-13].

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Nano-technology

The energy demand is augmenting day by day and the energy resources like coal, petroleum and natural gases are consumed in a non-sustainable manner which in turn will lead to the problems that will arise because of the shortage of resources. Thus, the inclination towards the renewable sources of energy is rising and alternatives are being developed in order to meet the crucial future demands. Scientists are working really hard in order to discover and develop new ways to get rid of these challenges. Developing new techniques of energy generation harnessing Nano-technology has been argued as one of the potential areas of research as the behavior of materials at Nano level is very captivating.

The solar cells are the photovoltaic devices which absorb photons and produce the flow of charge carriers which in turn lead to the generation of electric current. They are playing great role in meeting the high energy demands throughout the world. In 2016 about 98.4% of solar power is generated by photovoltaic technology and 1.6% is generated by CSP (concentrating solar cell) technology. The photo-voltaic solar cells are basically the solar panels made of semiconductor materials like Si, Ga etc. These semiconductor materials are not abundant in nature and at the same time they are quiet expensive. Another category of solar cells are the Dye sensitized solar cells. They make use of the two electrodes, one of which has a coated semiconductor material on one side and a Dye which serves as sensitizers. A number of metal complexes and organic dyes have been extracted and served as sensitizers such as porphyrin, platinum complex, anthocyanin etc. The most widely used sensitizers are Ru-based complexes as they are highly efficient and durable but they are very expensive and exhibit degradation in the presence of water.

Natural dyes are preferred because they are easily accessible, easy to prepare, cheap and environmental friendly. Fruits and vegetables such as blueberries, blackberries, cherries, black grapes, red cabbage, red beans, plums, purple cabbage etc. contain anthocyanin which is capable of attaching a TiO_2 surface and release electrons into the conduction band and conduct electricity.

There are several semiconductors materials that can be used for coating the glass plate but TiO_2 has gained a lot attention nowadays because of its potential in generating cost effective and environmental friendly energy.

Operating principle

The principle of operation of DSSC is based on the complex process of photosynthesis. In photosynthesis the effective absorption of the photons is carried out by the green color pigment present in the leaves of the plant that is chlorophyll. This further converts this energy into more usable form like carbohydrates and oxygen and is used to generate ATP and NADPH. The existing natural apparatus through which photosynthesis occurs is very complicated and difficult to design. It comprises of designed sets of nanostructures capable of carrying out the energy conversion process in three major steps. The antenna, the reaction center and the charged membrane are the nanostructures which are involved in the photosynthesis process. A greater number of light absorbing centers are present on the antennas which are capable of absorbing the sunlight. Before arriving to the next nanostructure that is the reaction centre, the energy is passed into a collecting station. The energy in the collecting station is made suitable to transfer by exchanging that energy among the rings present within the station. The reaction centre is the spot where separation of charges takes place by exploiting this energy. Then in the end the complex membrane allows the recombination of the charges that forms ATP which is a biological molecule capable to store and carry energy. Innumerable efforts have been made by the scientists to imitate this natural process of photosynthesis and generate a major renewable source of energy. This would reduce the detrimental effects on the environment to a greater extent which arises because of the continuous burning of the fossil fuels. Simultaneously, the energy needs of the larger population will also get fulfilled.

In Dye Sensitized Solar Cell, the function of chlorophyll is replaced by the utilization of effective dye. The electrons present within the dye absorbs the photon and gets excited from low energy level to high energy level, which then become mobile enough to flow and carry out the electric effect in the circuit. The resulting voltage leads to the electrical current when the circuit is completed.

Experimental set-up

- Materials and chemicals required

1. Conductive glass plates with one side of the plate coated with Indium Tin Oxide.
2. Nano TiO_2 powder.
3. Solution of Labolene for cleaning the conducting electrodes before carrying out the experiment.
4. Dilute solution of Acetic acid.
5. An electrolytic solution of Iodine which contains ethylene glycol.
6. Hot plate for the heat treatment of TiO_2 coated ITO glass plate.
7. A multimeter, alligator clips, thin glass rod, and the filter paper respectively.

- *Dye preparation*

Fruits and flowers containing organic dyes such as porphyrin, platinum complex, anthocyanin, etc. are used as a dye in Dye Sensitized Solar Cells. Here, we have used fruits rich in anthocyanin such as blueberry and pomegranate, as a dye. Fresh fruit juice must be extracted while preparing the electrode. This can be done in two ways, by crushing or grinding the fruit. The juice thus obtained will be used as the dye.

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- *Electrodes preparation*

➢ Preparation of TiO_2 Electrode:

1. Prepare the solution of the particles of TiO_2 by adding dilute acetic acid solution into it and make a thin paste.
2. Take the glass plate which is conductive on one side and non-conductive on the other side.
3. Clean the plate with acetone or labolene or with any cleaning liquid.
4. Tape the edges of the plate.
5. Now take the TiO_2 paste and put it on the plate. Dry it and then peel off the tape carefully.

➢ Heating Process:

1. Heat the plate to 300℃ for 30 minutes till the coating turn yellow.
2. The plate is now allowed to cool down.

➢ Preparation of second Electrode:

1. Now the second electrode is prepared. The conducting side of the plate is used.
2. A small amount of carbon soot is deposited to the second electrode on the conducting side which acts as a catalyst to reduce tri-iodide to iodide respectively.

- DSSC accumulation

1. The plate with the oxide layer is immersed in the dye solution for several hours.
2. The dye-coated electrode is then put together with another conducting glass electrode and the space between them is filled with an electrolyte solution.
3. Join the two electrodes in such a manner that the coated side of both the electrodes faces each other.
4. The two electrodes should be hold together by clippers from both the sides.
5. The cell is ready for testing.

Working mechanism

The working of dye sensitized solar cells has employed the high band-gap materials and open several avenues for their utilization. A high band gap semiconducting material TiO_2 is utilized in the construction of the cell. Natural dye of pomegranate is used which contains anthocyanin. It is a pigment which easily gets attached with TiO_2 particles and electrons gets transfer to the high energy levels that is conduction band. When the cell is exposed to light source, the electrons in the dye absorbs the photons and gets excited from low level of energies to high energy level. Dye works as a transition metal complex which has the capability of transferring the electron to TiO_2 semiconductor. The excited electrons then moves to the conduction band of the TiO_2 semiconductor. The circuit is completed by connecting the negative terminal to the TiO_2 and positive terminal to the scounter electrode. The electron is now available at the counter electrode. As soon as the electron moves to the conduction band, the dye acquires a slightly positive charge. The positive charge is compensated by the iodine electrolyte. The iodine electrolyte acts as the mediator to transfer electron from counter electrode to reduce the dye as dye is not in physical contact with the electrode.

$$\text{Dye} + \text{photons} \rightarrow \text{Excited Dye}$$

$$\text{Excited Dye} \rightarrow \text{Dye}^{+}$$ (when electrons get transferred to the conduction band of TiO_2)

$$\text{Dye}^{+} + I^{-} \rightarrow \text{Dye} + I_3^{-}$$

The positively charged dye obtain electron from iodine and become neutral again and iodine get converted to I^-. It obtain electron from counter electrode and become I_3^-.

$$I_3^{-} + \text{Electron} \rightarrow I^{-}$$

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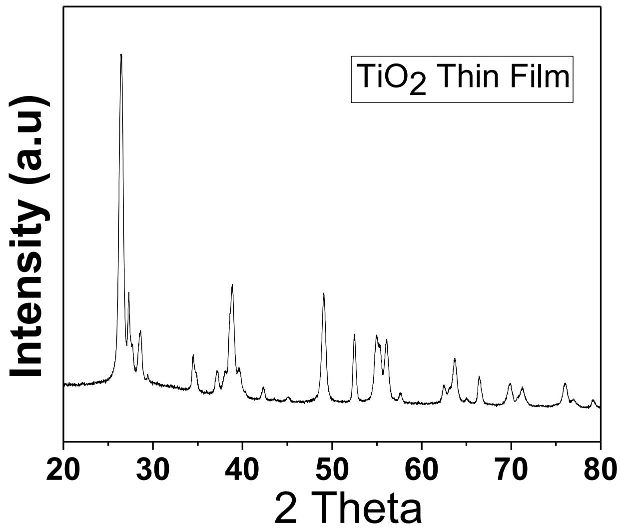
The counter electrode is coated with carbon soot which catalysis the above reaction. This way the circuit gets completed. A multimeter is connected in between the terminals in order to obtain the values of current and potential difference.

Observations

The structure of the sample has been studied by X-Ray Diffraction (XRD). The XRD of the coated TiO_2 glass plate is shown below. It is similar to the X-Ray diffraction curve of the original sample.



The reading of current and voltage have been recorded daily (almost 10 values). Here, we have studied the cell for seven consecutive days, but were able to record the observations for first five days as the reading were not stable for the following days.

A. Average value of current for Five days

The values of current for five days are observed. One set of current values is taken without light source and another set is taken with light source and their corresponding graphs are plotted which shows variation of current with the consecutive days.

- **Without Light Source**

Day	**Average Current (mA)**
1	0.0023
2	0.0022
3	0.0012
4	0.0001
5	0.0010

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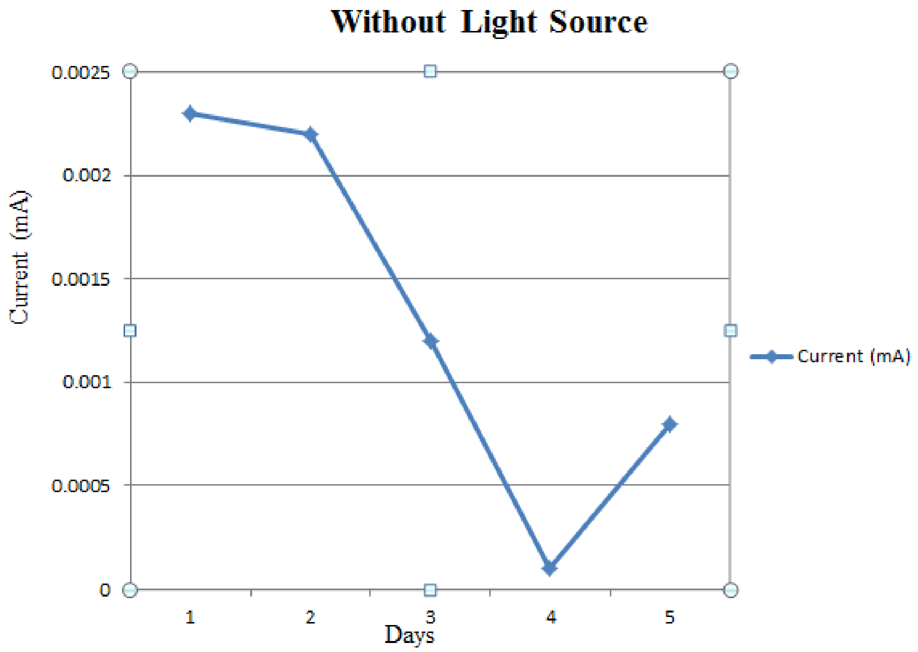
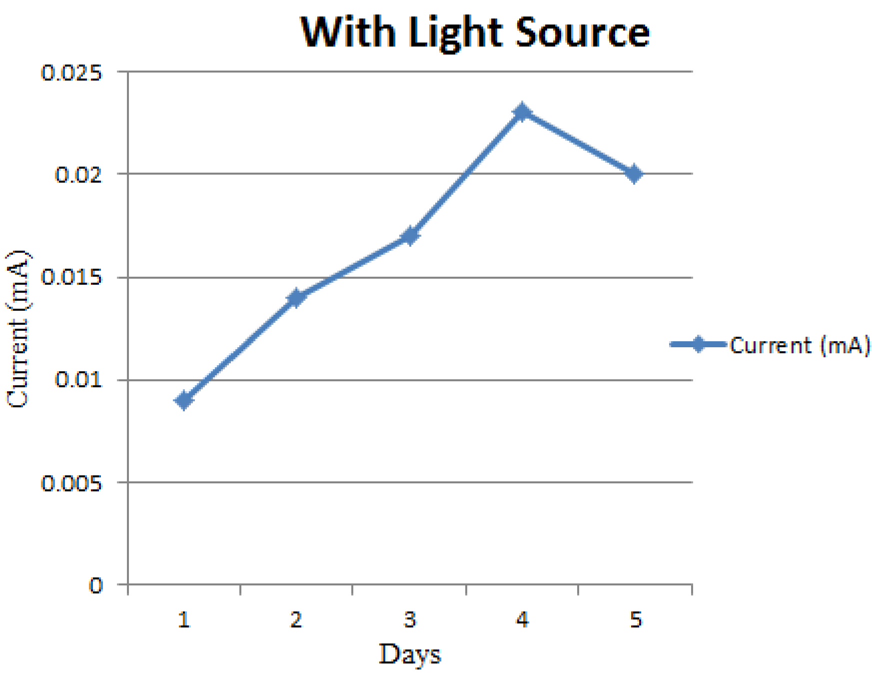


As can be seen in the graph, the current decreases with increase in the number of days.

- **With Light Source**

Day	Average Current (mA)
1	0.009
2	0.014
3	0.017
4	0.023
5	0.002



As can be seen in the graph, the current first increases with increase in number of days and then finally decreases on the fifth day.

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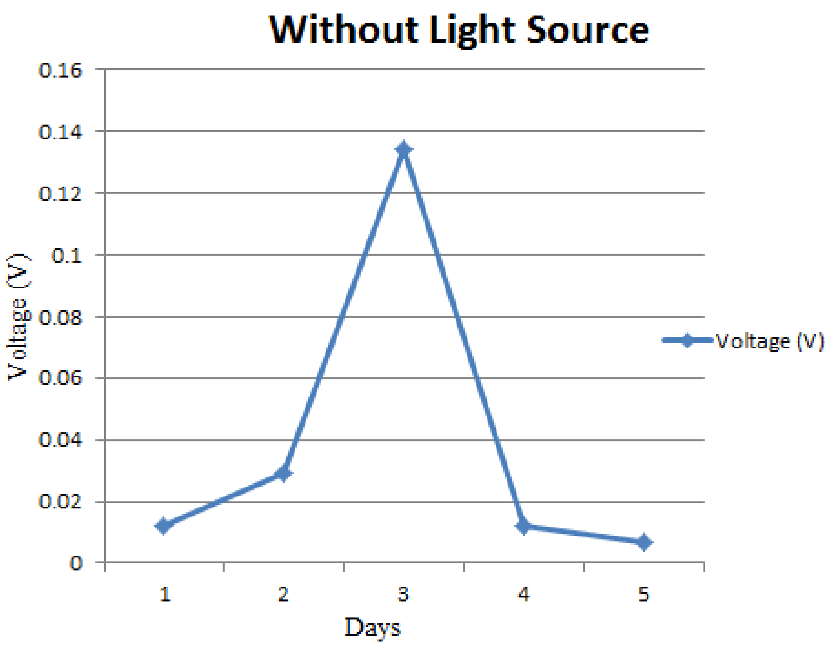
B. Average value of voltage for Five days

The values of Voltage for five days are observed. One set of voltage values are taken without light source and another set is taken with light source and their corresponding graphs are plotted which shows variation of voltage with the consecutive days.

- **Without Light Source**

Day	Average Voltage (V)
1	0.012
2	0.029
3	0.134
4	0.012
5	0.007



As can be seen in the graph, the voltage shows a peak like behavior that is it first increases with increase in number of days, attains a maximum value on third day and then decreases with increase in number of days.

- **With Light Source**

Day	Average Voltage (V)
1	0.06
2	0.11
3	0.16
4	0.13
5	0.11

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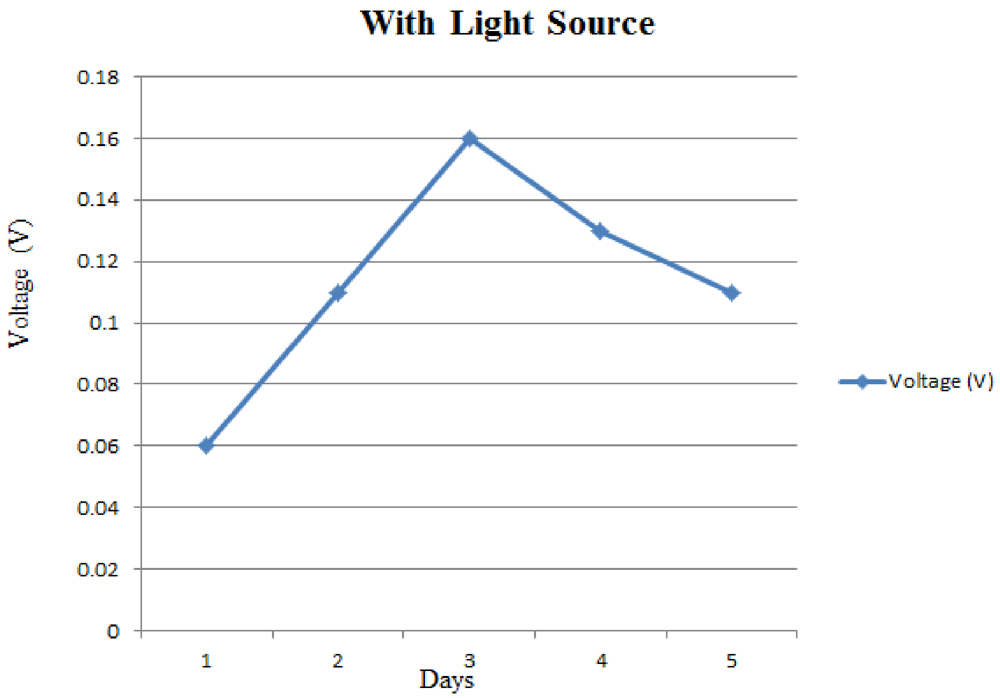

As can be seen in the graph, the voltage first increases with increase in number of days, attains a maximum value on third day and then decreases with increase in number of days. The magnitude of the voltage obtained in this case is more than the value without light source.

C. Variation of Current with Distance from the light source

The variation of current is observed with distance from the light source for the consecutive four days. It can be clearly seen that when distance between light source and the solar cell is minimum, the values of current obtained is maximum and as the distance between the cell and light source increases the current starts to decrease. It is also displayed through the plots. Thus, cell is more efficient when light source lie near to the cell.

Distance from Light Source (cm)	**Current (mA)**			
	First Observation	**Second Observation**	**Third Observation**	**Fourth Observation**
100	0.004	0.0004	0.006	0.009
90	0.005	0.003	0.010	0.011
80	0.006	0.007	0.017	0.013
70	0.005	0.009	0.019	0.016
60	0.007	0.012	0.022	0.017
50	0.007	0.015	0.024	0.021
40	0.009	0.017	0.025	0.021
30	0.012	0.021	0.029	0.023
20	0.015	0.034	0.032	0.032
10	0.016	0.047	0.039	0.033

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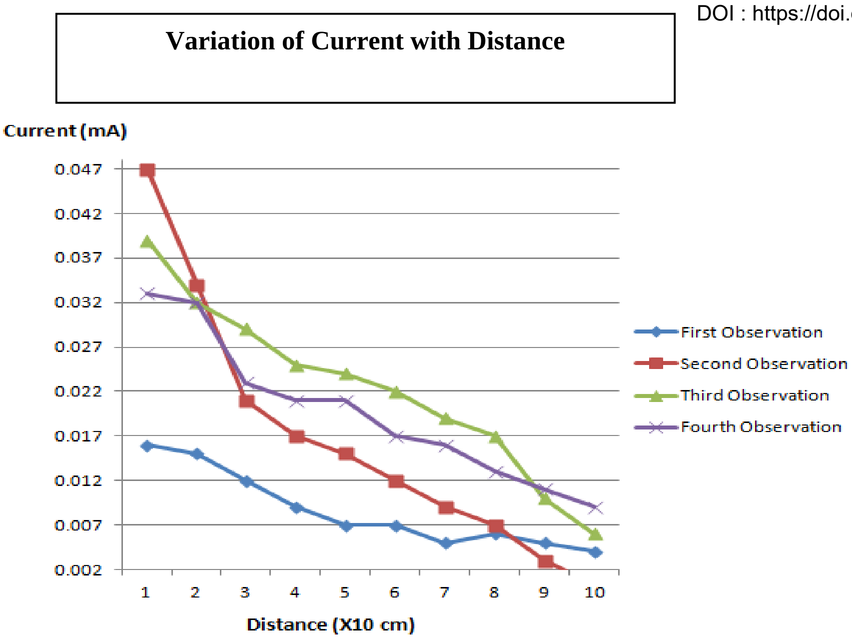

A. Variation of Voltage with Distance from the light source

The variation of voltage is observed with distance from the light source for the consecutive four days. It can be clearly seen that when distance between light source and the solar cell is minimum, the values of voltage obtained is maximum and as the distance between the cell and light source increases the value of voltage starts to decrease. It is also displayed through the plots. Thus, cell is more efficient when light source lie near to the cell.

Distance from Light Source (cm)	Potential Difference (V)			
	First Observation	**Second Observation**	**Third Observation**	**Fourth Observation**
100	0.052	0.064	0.109	0.064
90	0.049	0.070	0.108	0.070
80	0.053	0.079	0.112	0.076
70	0.053	0.080	0.117	0.083
60	0.050	0.090	0.125	0.092
50	0.050	0.104	0.135	0.100
40	0.064	0.111	0.146	0.120
30	0.070	0.135	0.162	0.139
20	0.068	0.161	0.174	0.166
10	0.080	0.187	0.207	0.206

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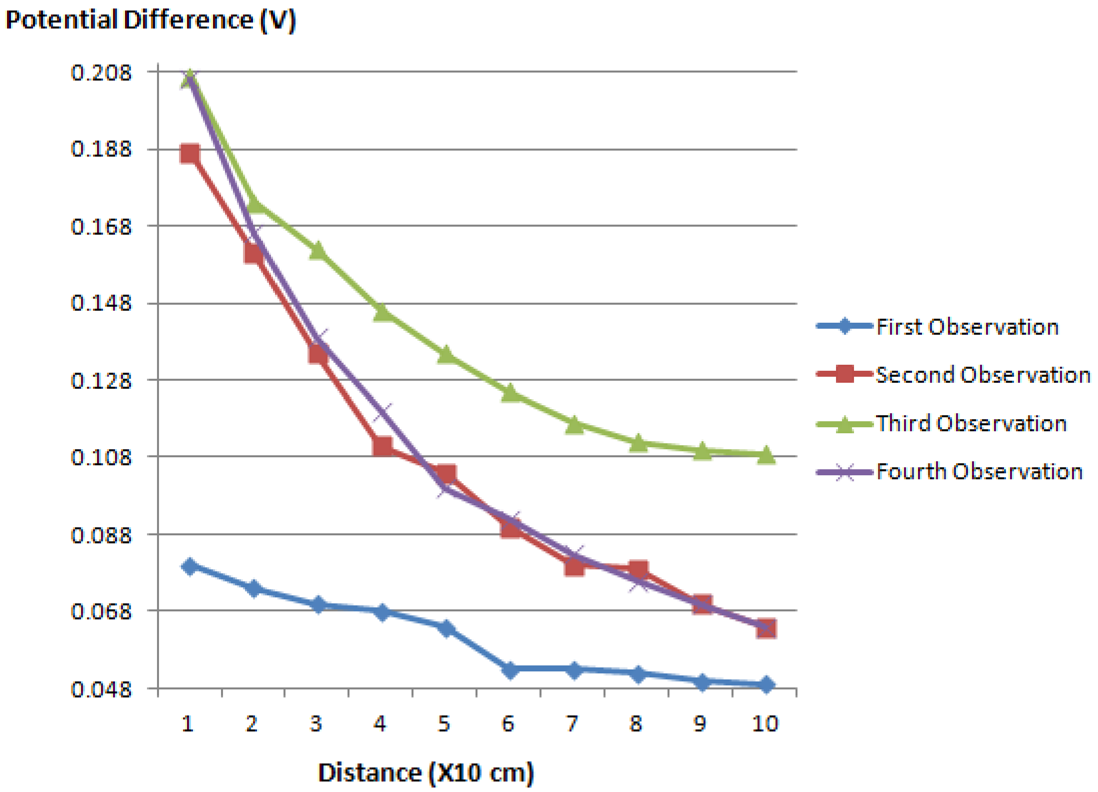
Variation of Potential Difference with Distance



CONCLUSION

The X-Ray Diffraction (XRD) of the coated TiO_2 glass plate is obtained. The obtained XRD is in accordance with the XRD of pure sample. The other peaks obtained in the graph are the peaks of XRD of the ITO substrate. The variation of value of current and potential with number of days shows a peak like behavior while the variation with distanced from the light source shows decreasing trend with increasing distance. Maximum value of voltage and current are observed when the light source is nearest to the cell. However, the variation with number of days does not follow the same trend. The voltages and currents increase with increase in the number of days and then decrease. Thus it can be concluded that the efficiency of the solar cell is better when light source is incident on it. More research is needed to be done in the field of effect of number of days, increasing the stability and efficiency of the solar cell.

The experiment was carried out with a very basic set up with nominal apparatus and materials. The main aim of this research was to work on different alternatives of developing a solar cell using environment friendly, natural and economical materials.

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