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Performance of Dye-Sensitized Solar Cell using *Hamelia Patens* leaves as natural dye

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Abstract

Dye-Sensitized Solar Cells (DSSC), a 3rd generation solar cell has gained huge attention in the field of solar photovoltaics as a substitute for the silicon solar cell. The performance of the DSSC mainly depends on all the important components such as transparent conductive oxide substrate, cathode, photo-anode, dye, and electrolyte. Additionally, sensitizing dyes also perform a vital role in the absorption of light and the conversion of solar energy into electrical energy in DSSC. However, its efficiency is low and it consumes good amount of energy in manufacturing. In this respect scientists and researcher are more focus on how to improve its efficacy and production cost to make it economically viable. For this purpose, in this present work we have the natural dyes from *Hamelia patens* plant's leaf which is available throughout the year for the fabrication of DSSC at low temperature. Semiconductor film electrode, ZnO has been synthesized via. chemical bath deposition process, which is anchored on the FTO glass substrate. Various characterizations techniques such as UV-vis absorption, FTIR were done for the extracted natural dye. XRD and FE-SEM were also performed for crystallinity and morphological analysis of ZnO material. XRD data reveals the formation of hexagonal ZnO (JCPDS card no. 01-082-9744 where $2\theta^\circ$ at 31.799, 34.454, 36.289, 47.586 corresponds to (100), (002), (011), (012) respectively). Using the ZnO and natural dyes, a sandwiched type DSSC has been fabricated and various parameter such as power conversion efficiency, V_{oc} (open circuit voltage), I_{sc} (short circuit current) has also been measured for continuous 3 days. DSSCs which is fabricated by using natural dye extracted from *Hamelia patens* leaves (sample 1) shows $V_{oc} = 132.2$ and $I_{sc} = .065$ mA.

Keywords - Chemical bath deposition, Natural dye, DSSC, *Hamelia patens*

1. Introduction

As we know energy is everything and everything is energy, every minute of our time and every square inch of space around us has touch of energy. Energy affects each social and economic indicator of our life. The total primary energy consumption of the world is 161,250 billion kWh [1]. Sun can provide this much amount of energy within an hour, but still renewable energy contributes to only 5% in the total consumption because we cannot tap that much amount of energy completely, so DSSC can play an important role in effectively tapping the energy from sun by emitting very less amount of carbon emissions in manufacturing in comparison with silicon solar cell. DSSC concept was presented in 1991



by Regan and Gratzel [2]. DSSC has been discovered as a 3rd generation solar cell, because of its structure and manufacturing cost which is low as compare to silicon solar cell [3]. One of the most challenging aspects of DSSC is its long-term stability, which is impacted by electrolyte leakage, dye desorption and dye degradation [4,5]. The operation of DSSC is similar to that of a photo synthesis process, the dye which are extracted from natural sources like leaves of a plant, flower etc., are non-toxic whereas ruthenium dye which was used earlier in DSSC are not easily available [6]. Fluorine doped tin-oxide (FTO) is one of the conducting glasses, which we have used in the work, its specification as follows: -

- Dimensions: 50mm × 25mm x 1.1mm
- Specified FTO Sheet resistivity ≤ 10 ohms/sq.
- Typical FTO Sheet resistivity 9-11 ohms/sq.
- Transmittance: $> 79\%$
- FTO film Thickness 1800-2000 Å

The conducting side of the FTO provide a medium for electrons to travel. And Semi-conductor material absorbs the dye molecule and whatever the electron has been injected to ZnO molecule, electron should pass under the percolating network of the zinc oxide [7]. Role of dye is to absorb the light, so that electron can go from ground state to excited state. Since the artificial dyes are toxic in nature that's why in our experiment, we have used natural dye [8]. Anthocyanin, Beta-carotene [9], Chlorophyll [10] are the three different pigments found in different parts of a plant and are used as a dye extracted from leaf, flowers, fruits and roots etc. Once the electron is in conduction band, depending upon the energy level this electron will try to come to next favourable energy level and zinc oxide provides that matrix. So, whatever the electrons that are injected to the ZnO, percolates through and finally comes to the photoanode whereas whatever holes left behind that comes back to the ground state. But this process needs to be done again and again, so that the cycle will continue [11,12]. For electrolyte we have used iodine and tri-iodide. Iodine tri-iodide electrolyte participate in oxidation reduction reaction and it regenerate whatever the oxidized dyes in the ground state, so that this process can repeat and we can regenerate electron flow inside the circuit. In this work, the natural dyes used are from the leaves of *Hamelia patens plant*. ZnO has deposited on FTO by the process of Chemical bath deposition technique. Interaction between the ZnO and the dye will excite the electron and transfer it from the dye molecule to the conduction band of the ZnO [13,14]

A dye sensitized solar cell absorbs light, generates carrier, transport carriers to the external load at higher voltage and brings back the carrier in the cell at lower voltage. The operation of DSSC can be explained in the figure-1.

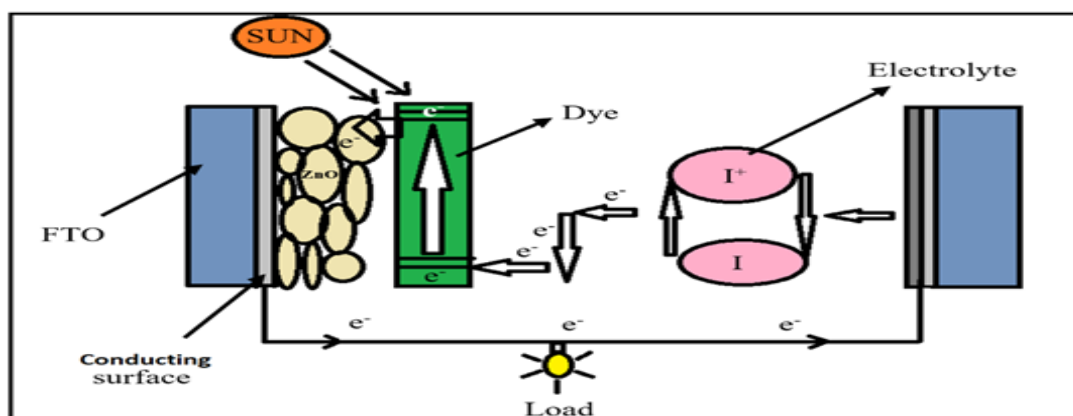


Figure 1- Photo-physics of DSSC

2. Materials and Method

2.1. Material

Leaves of *Hamelia patens* plant used in this study were collected from Kapurthala city, Punjab. FTO (Fluorine doped tin oxide) glass whose dimension are 50mm, 25mm, 1.1mm length, width and thickness respectively, its transmittance is greater than 79 percent and FTO film thickness 1800-2000Å. Zinc Nitrate hexahydrate $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ chemical was used for the preparation of the layer of ZnO over FTO, ammonium hydroxide, potassium iodide chemical were used. The chemicals were used as it is, no further purification was done.

2.2. Process of Dye Extraction

We have made the dye from the leaves of *Hamelia patens* plant, 23 gm of fresh leaves of *Hamelia patens* were taken, washed the leaves properly with double distilled water to remove the dust particle over it, followed by drying the leaves with wind blower for 1 hour. Then crushed the leaves in a properly cleaned mortar and made fine paste of the leaves. 38ml of acetone as a solvent was used to extract the dye of 20ml from the paste and discarded the remaining residue paste of 10gm. The dye was filtered with the wattman-42 filter paper of .7µm particle retention size to remove unwanted particles. Then centrifuged the dye solution at 10,000 rpm for 10 minutes at 4°C (Eppendorf centrifuge-5430 R) and took the supernatant in the different vials and discard the pellets formed at the bottom, this supernatant was used as natural sensitizer.

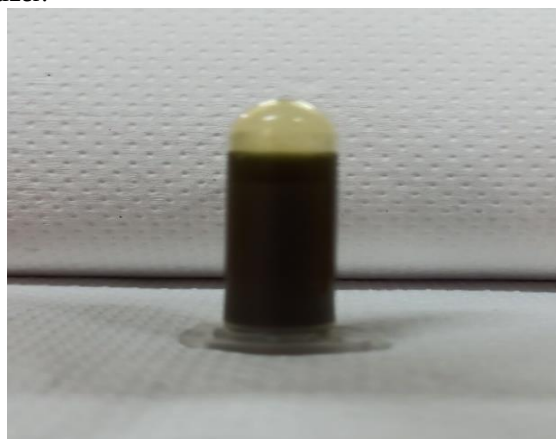


Figure 2- *Hamelia patens* leaf's dye.

Vials of this dye's solution was covered by a foil paper and stored in the dark place to protect it from exposure to direct light (figure-2), this dye were further characterized and analysed.

2.3. ZnO Deposition

Before the deposition of ZnO, FTO substrate was properly cleaned with acetone. ZnO deposition as a photo anode on FTO was done by Chemical bath deposition technique (CBD). Similar process of ZnO deposition has already been discussed in earlier research [15]. Prepared 40 ml solution of $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ of 0.1 M concentration using double distilled water, stir it using magnetic stirrer at 100 rpm. Then add ammonium hydroxide drop by drop till the solution gets transparent & while doing so, kept on stir the solution at 200 rpm.

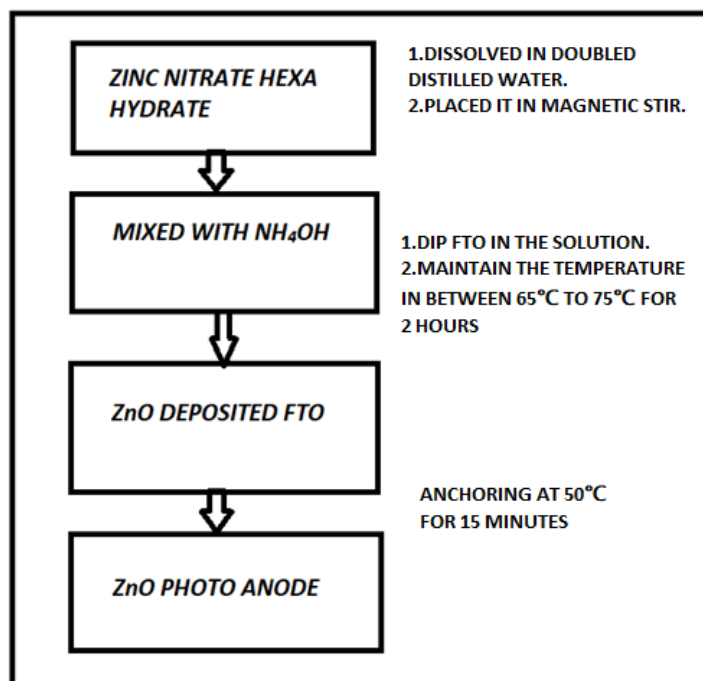


Figure 3- Flow-chart of ZnO deposition on FTO glass substrate

Some portion of FTO was covered with double sided paper tape (10mm x 25mm). Immersed the FTO in the solution and maintain the temperature of the solution in between 65° C to 70° C for 2 hours. The nano particles of ZnO deposited over the conducting layer of FTO glass substrate during these 2 hours (Figure 3). After that FTO was taken out and for better anchoring of ZnO on FTO, we heated it at only 50°C for 15 minutes, then send the precipitated whitish powder for its XRD and FE-SEM characterizations.

2.4. Electrolyte preparation

Electrolyte helps to keep the continuity of the charges [16], so in this work we have used iodide/tri-iodide as an electrolyte, 5M of potassium iodide solution was made by using 20ml of acetonitrile and 5ml of ethylene glycol. After that add .05M of iodine in that solution, stirred the solution for 30 minutes. Kept it for settling for 24 hours and stored it in the dark place.

2.5. DSSC Fabrication

In this work we have prepared one sample of dye sensitized solar cell from the natural dye of *Hamelia patens* leaves its respective solar cell is named as sample 1. The effective cell area of 1000mm² and the complete area of the cell is of 1250 mm². So, the effective cell area was of 80% of total area of the substrate. The ZnO coated FTO glass substrate was immersed in the dye for 12 hours, so that dye would get effectively absorbed on the ZnO coated FTO substrate. Then sample was sent for UV characterization to test absorbance as shown in figure 4 & 5 for sample 1. The Counter electrode was prepared by coating the layer of graphite on the conducting side of another FTO glass substrate. Then after that, sandwiched both the electrodes on one another, kept a layer of electrolyte in between them and tightly packed them with clips. The performance of this sample of DSSC was determined by measuring their Voc, Isc, Vmp, Imp & efficiency.

2.6. Characterizations

UV-Visible light absorption characterization was done by the UV-vis spectrophotometer SHIMADZU 2550. Powder X-Ray diffraction (PXRD) studies were performed by Bruker D8Advance X-ray

diffractometer of wave length $1.54\text{\AA}$, using Ni-filtered Cu-K α radiation with a step size of 0.001° and a step time of 1 sec. Fourier transform infrared spectroscopy (FTIR) was performed using Perkin Elmer instrument in the wavenumber between 500 cm^{-1} and 4000 cm^{-1} . DSSC performance was tested continuously for 3 days by using DMM multi-meter with the light source (make of Eco-sense) whose illumination was equivalent to the sunlight irradiance of 1000w/m^2 .

3. Results and discussions

3.1. UV-vis absorption analysis of Dyes

The absorption band of Dye extracted from the leaves of *Hamelia patens* is in higher wavelength region (500nm to 700nm) as well as in the lower wavelength region (323nm to 500nm) having 5 different peaks at 327nm, 411nm, 429nm, 533nm, 610nm and 665nm as shown in Figure 4.

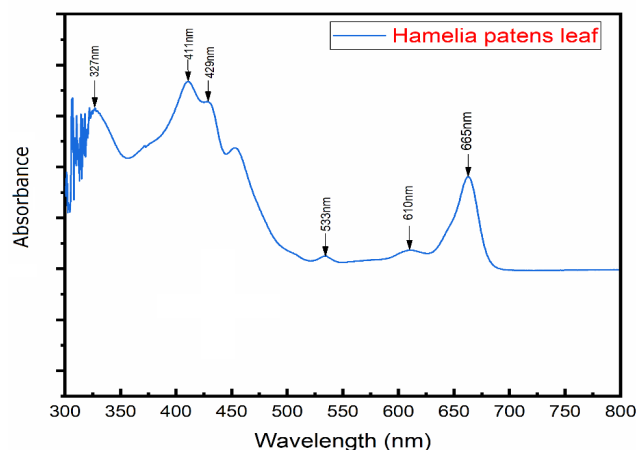


Figure 4- UV-vis absorption spectra of the dye.

The UV-vis light absorption when dye is loaded on ZnO coated FTO glass substrate is shown in Figure 5. Now if we observe the absorption of the dyes, we can find the shift in the peaks for sample 1 (ZnO & *Hamelia patens* leaves' dye) we can observe the shifting of the peaks, but one peak was at same wave length at 665nm.

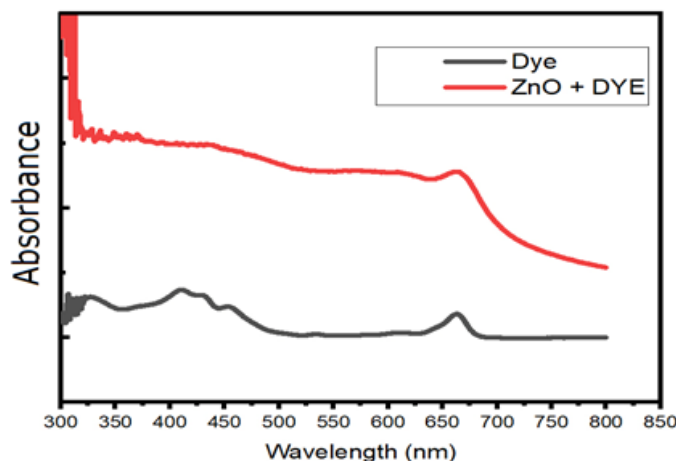


Figure 5- UV-vis absorption spectra of dye extracted from *Hamelia patens*' flower loaded on ZnO

3.2. Microstructural analysis

The micrographs of ZnO deposited on FTO of samples 1 is shown in figure 6. FE-SEM image for sample 1, show that bunch of nano-size rods together form a complete flower kind of structure whose 5 petals are in a plane and flower disc is out of plane.

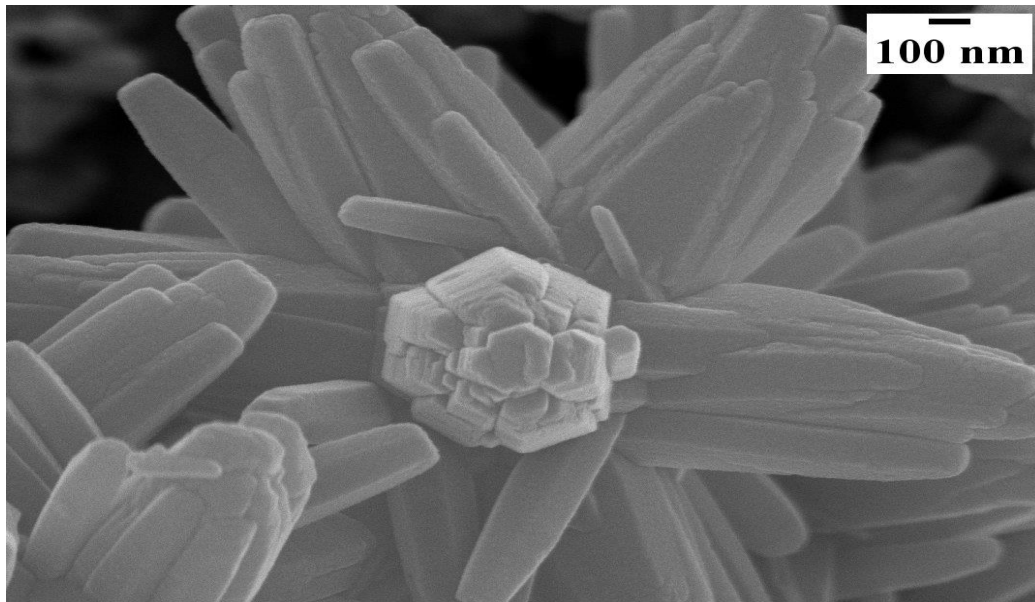


Figure 6- FE-SEM image of ZnO deposited on FTO-sample 1.

3.3. X-Ray Diffraction Analysis

The crystal structure of ZnO for the sample 1 was evaluated by XRD characterization done by X-Ray diffractometer (make of BRUKER) as shown in the figure 7. In Figure 7 sample 1 represents the XRD of synthesized material where 2θ at 31.799, 34.454, 36.289, 47.586, 56.653, 62.922, & 68.020 correspond to (100), (002), (011), (012), (110), (013), & (11-2) planes respectively. This powdered XRD for sample 1 is well matched with JCPDS card no. 01-082-9744 which is hexagonal phase of ZnO.

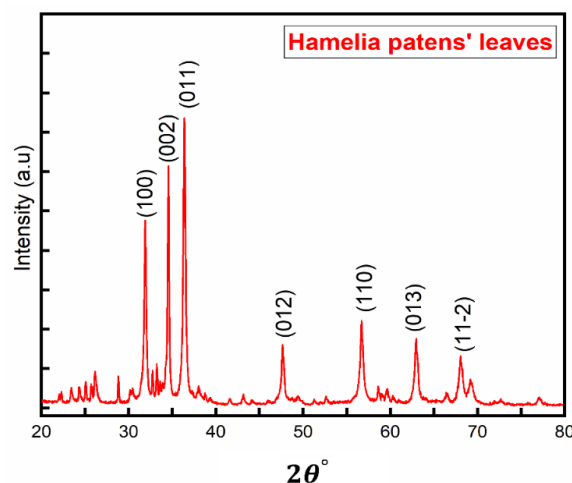


Figure 7- XRD pattern of synthesized ZnO

3.4. FTIR Analysis

The FTIR (make of Perkin Elmer) characterisation of the dyes is shown in Figure 8 and table 1, this study was done to know the chemical compounds present in the dyes [17].

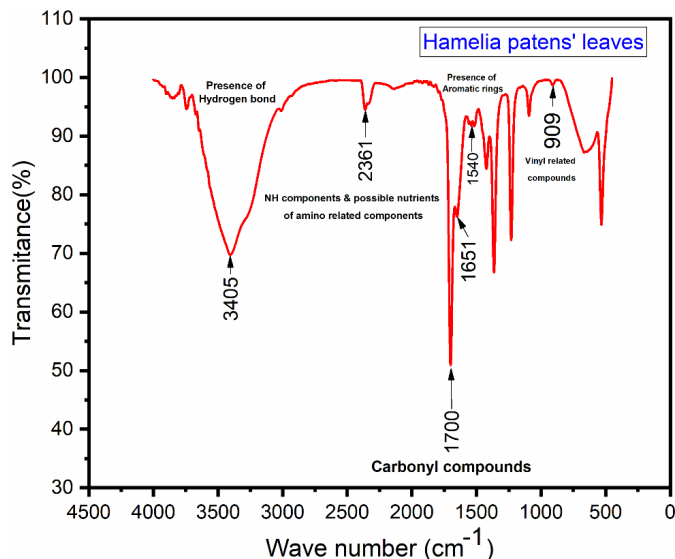


Figure 8- FTIR spectra of dyes

The compound tested would be simple organic compounds with low molecular weight since the number of absorption bands in the region of the complete spectra is less than five. The existence of a large absorption band in the region of 3650 cm^{-1} and 3250 cm^{-1} indicates the presence of a hydrogen bond, which is followed by presence of spectra in the range of $1600\text{--}1300\text{ cm}^{-1}$ indicates the presence of a hydroxyl group in the dye. The peak at 2361 cm^{-1} indicates the presence of NH components as well as probable nutrition of amino related components. Because of the peaks at 1540 cm^{-1} and 1516 cm^{-1} are visible, aromatic rings are also present. Low-intensity peaks between 2000 and 1700 cm^{-1} indicate the presence of simple aromatic chemicals (see Table 1).

Table 1. FTIR peaks and respective Functional groups

Hamelia patens leaf's dye	Wave number(cm^{-1})	Functional group
	3405	Hydroxyl group
	2361	NH components and possible nutrient is of amino related components
	1651 & 1700	Carbonyl compound
	1540 & 1516	Aromatic rings
	Low intensity peaks in between 2000-1700	Simple aromatic compounds
	909	Vinyl related compounds

3.5. DSSC performance

DSSC performance was tested continuously for 3 days by using DMM multi-meter with the light source (make of Eco-sense) whose illumination was equivalent to the sunlight irradiance of 1000 W/m^2 as shown in figure 9 and Table 2.

Table 2. Different measured parameters of DSSC (V_{oc} , I_{sc} , V_{mp} , I_{mp})

Sample 1 (DSSC from <i>Hamelia patens</i> ' leaves)			
Parameters	Day 1	Day 2	Day 3
$V_{oc}(\text{mV})$	132.2	114.2	106.9
$I_{sc}(\text{mA})$	.065	.026	.027
$V_{mp}(\text{mV})$	112.37	97.07	90.865
$I_{mp}(\text{mA})$	.0617	.0247	.0256
Efficiency $\times 10^{-4}(\%)$	6.9	2.39	2.33

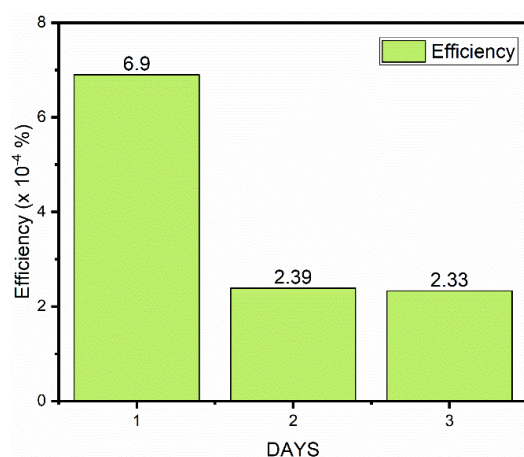


Figure 9: Efficiency vs Days for DSSC

4. Conclusions

- Natural dye from the leaves of *Hamelia patens* has been extracted for DSSCs fabricated.
- Various characterizations techniques such as UV-vis absorption was done for the dye and peaks were found $\lambda_{Hamelia patens leaf's dye} = 411 \text{ nm}$.
- FTIR was done for the extracted natural dye which shows that Hydroxyl group and aromatic compounds are present in the dye.
- XRD and FE-SEM were also performed for crystallinity and morphological analysis of ZnO material, XRD data reveals the formation of hexagonal ZnO.
- DSSCs which is fabricated by using natural dye extracted from the leaves of *Hamelia patens* (sample 1) showing $V_{oc} = 132.2$ $I_{sc} = .065 \text{ mA}$ on day1. However gradual decrement in efficiency can be seen in the DSSC with increment of time.

Since climate change is now really a serious topic of our concern, we should start call it as climate crisis instead of climate change, we have a very short window to help our nature to recover itself, although solar cell can play very vital role in that but in long run the silicon solar cell would become a scrap too for us. To solve our present problem slowly we are giving birth to a problem which may occur after 100 years. So, we should go for 3rd generation solar cell that is dye sensitized solar cell (DSSC), by putting some effort we can achieve its efficiency greater than a silicon solar cell.

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