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Properties and Performance of Dye Sensitized Solar Cell Using Beta Vulgaris

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ABSTRACT

Dye sensitized solar cells were fabricated using natural dyes extracted from beetroot. The ZnO nanorod working electrode has been prepared by simple hydrothermal method. The crystallinity and morphology of the prepared electrode has been studied using X-ray diffraction and scanning electron microscopy (SEM) techniques. The effect of natural dye extract temperature, pH of the dye and the solvent used for dye preparation on the solar cell characteristics have been studied. The efficiency of beetroot extract sensitized ZnO nanorod solar cells are found to be value of 0.69% at 50^0 C in ethanol better than the other solvents using methanol.

Keywords: Beta vulgaris, X-ray diffraction, ZnO Nanorods, Natural DSSC, ITO.

1. INTRODUCTION

The vast uses of organic solar cells, causing carbon emission and human cell disorders, have led us to focus on the sustainable energy sources for the future[1,2]. Among the photovoltaic energy sources, *Beta vulgaris* dye based solar cells have attracted a great interest as a solution to this situation[3-5]. To date, the organic photovoltaic devices have power-conversion efficiencies over 20%[6]. However, the issues of high cost and environmentally-harmful waste in the processing technologies of organic materials based solar cells should be resolved[7]. In fact, in semiconductor p-n junction solar cell charge separation is taken care by the junction built in electric field, while in dye sensitizes solar cell charge separation is by kinetic competition as in photosynthesis *(Späth et al., 2003*). The organic dye monolayer in the photo electrochemical or dye sensitized solar cell replaces light absorbing pigments (chlorophylls), the wide bandgap nanostructured semiconductor layer replaces oxidized dihydro-nicotinamide-adenine-dinucleotide phosphate (NADPH), and carbon dioxide acts as the electron acceptor. Moreover, the electrolyte replaces the water while oxygen as the electron donor and oxidation product, respectively *(Lagref. et al., 2008; Smestad & Gratzel, 1998).*

Researchers are seeking to use of a flowering plants in the family *Amaranthaceae* such as *Beta vulgaris* for converting high-energy light into multiple electrons, using solid-state electrolytes for superior temperature response and modify the doping of TiO_2 or ZnO to match it with the electrolyte that is being used[8]. TiO_2 nanoparticle-based dye-sensitized solar cells are a highly promising approach, giving efficiencies over 10%[9]. The dye molecules are adsorbed onto the surface of sintered nanoparticles. Lot of the present research on DSSCs is focused on improving spectral absorbance by making modifications in the dye, enhancing hole transport, replacement of the liquid electrolyte with conducting polymers or ionic solids and improving electron transport using alternative core-shell structures or wide band gap semiconductor materials[10].

The overall cell efficiency of dye sensitized solar cell is found to be proportional to the electron injection efficiency in the wide bandgap nanostructured semiconductors. This finding has encouraged researchers over the past decade. ZnO_2 nanowires, for example, finding have been developed to replace both porous and TiO_2 nanoparticle based solar cells *(Law et al., 2005)*[11]. Also, metal complex and novel man made sensitizers have been proposed *(Hasselmann & Meyer, 1999; Isalm et al., 2000; Yang et al., 2000)*[12-14]. However, processing and synthesization of these sensitizers are complicated and costly processes *(Amao & Komori 2004; Garcia et al., 2003; Hao et al., 2006; Kumara et al., 2006; Polo & Iha, 2006; Smestad, 1998; Yanagida et al., 2004)*. Development or extraction of photosensitizers with absorption range extended to the near IR is greatly desired. In our approach, the use of natural dye extracts, we found that our environment provides natural, non toxic and low cost dye sources with high absorbance level of UV, visible and near IR[15].

In this our work dye-sensitized solar cells (DSSC) were constructed by using the Beet root (Beta vulgaris), as natural sensitizers of anatase-phase nanostructured ZnO nano rod deposited on ITO coated SLG. Beet root (Beta vulgaris), extract is in the main components in the natural dyes obtained from these natural products. The polymer blend was complexed with potassium iodide (KI_2) and some iodine crystals were added to the polymer-KI_2 solution to provide I^-/I^{3-} redox couple. The photovoltaic properties of the cell have been studied and the best overall solar energy conversion efficiency was obtained, under A.M 1.5 irradiation.

2. EXPERIMENTAL PART

2.1 Deposition of Indium Doped Tin Oxide Thin Films (ITO)

The Indium doped Tin Oxide (ITO) thin films were deposited on soda lime glass by thermal evaporation technique using the system under vacuum conditions. In_2O_3 - SnO_2 powders of 1:1 were used as the evaporation source materials. Glass was precleaned with ethanol and acetone, respectively. The chamber was evacuated to a background pressure of 10^{-2} mbar initially, and the working pressure during the film deposition was fixed to 10^{-6} mbar by utilizing liquid nitrogen (99.999%). The deposition process is carried out at room temperature, that is, the substrate is not heated during the film deposition.

2.2. Preparation of Working Electrode

In our experiment, Zinc Oxide photo anode was deposited on Indium doped tin oxide (ITO) coated glass substrate. Initially, the FTO glass substrates were ultrasonically soaked in acetone and ethanol, and then dried at 100 °C in an oven. To synthesize ZnO nanorods, two step chemical methods have been used. In the first step, ZnO seed layer has been prepared by simple sol-gel method[16].

To prepare ZnO seed layer, 0.3 M of zinc acetate dehydrate ($Zn(CH_3COO)_2 \cdot 2H_2O$) was dissolved in a mixture of 10 ml ethanol and 0.25 ml water. ITO coated glass substrates were dipped in the prepared solution and this resulted in the formation of seed layer, these seed layer films are annealed at 300 °C for 30 minutes[17]. In the second step, ZnO nanorods have been prepared by microwave irradiation method. To prepare ZnO nanorods, an aqueous precursor solution was prepared by NaOH (0.4M), and zinc chloride ($ZnCl_2$) (0.2M), solutions were mixed slowly with molar ratio of 2: 1, respectively. The above solution was stirred for 10min. After that, a small quantity of TEA was added, and stirring continued for another 10min. This solution was put for microwave irradiation at 700W in two steps, that is, 40°C for 20 min and 60°C for 30min.The solution was transformed into teflon stainless steel autoclave and the seed layer coated substrate was vertically dipped in the aqueous solution and it was maintained at a bath temperature of 85 °C for 4 hrs.After the growth period, the substrates were removed from the solution and were thoroughly washed with deionized water to remove the residual salt from the surface of the film. Now the prepared film was annealed at 300°C for 1hr and this resulted in the formation of ZnO nanorods[18].

2.3. Preparation of Natural Dye Sensitizer

For beetroot extract preparation, the cleaned vegetables were cut into small pieces and put into two different beakers. Chopped vegetables were soaked in 200 ml of ethanol at different temperatures. Then the residual parts were removed by filtration and the filtrate was washed with hexane several times to remove any oil or chlorophyll present in the extract. This was directly used as dye solution for sensitizing ZnO nanorod electrodes. The beetroot was extracted from the ethanol solvent at different temperatures such as room temperature, 50 °C, 75 °C and 100 °C. To study the effect of pH on the performance of solar cell, the pH of the solution was changed by adding dilute HCl and dye solution with three different pH values 1.0, 2.0 and 3.0 have been used as sensitizer. To study the effect of extracting solvent on the performance of solar cell, the beetroot was also extracted by using methanol.

2.4. Assembling the Solar Cell

To assemble the natural dye sensitized ZnO nanorod based solar cell, the prepared ZnO nanorod electrode were immersed in the synthesized dye solution at room temperature for 24 h, after that period the film was rinsed in anhydrous ethanol and then dried (Fig.2(b)). A carbon-coated ITO electrode was then placed over the dye-adsorbed ZnO nanorod electrode. A redox electrolyte was prepared using 0.5M KI, 0.05M I_2, and 0.5M 4-tert-butylpyridine and a drop of electrolyte solution was injected into the cell.

2.4. Characterization

The structure of the prepared films has been studied by X-ray diffraction studies using a Rigaku X-ray diffractometer (XRD) using Cu Kα irradiation. The surface morphology of the films were studied using scanning electron microscopy (SEM;VEGA 3 TE SCAN),The photocurrent-voltage (J-V) characteristics of the devices were measured using white light from a xenon lamp (max.150 W) using a sun 2000 solar simulator (Sponsor: MHRD &IIT-BOMBAY). Light intensity was adjusted using a Si solar cell to ~AM-1.5. Incident light intensity and active cell area were 100 $mWcm^{-2}$ (one sun illumination) and 0.4 cm^2 (0.5 × 0.8cm), respectively.

3. RESULTS AND DISCUSSION

3.1. Structural and Morphological Analysis

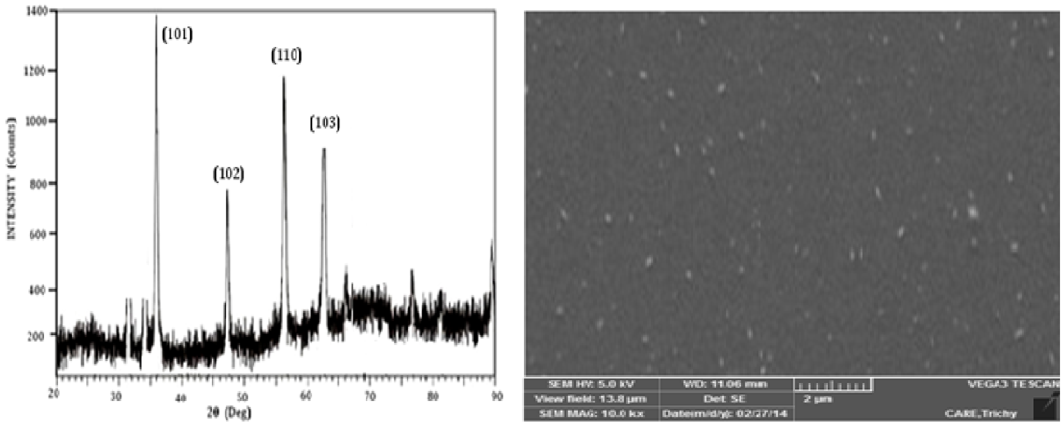

Fig.1. (a) X-ray diffraction pattern of the ZnO nanorods. (b) SEM image of ZnO nanorods

Figures (a) shows the X-ray diffraction patterns for the film. The diffraction peaks observed at 36.4°, 47.9°, 56.0°, and 62.5° are attributed to the (101), (102), (110), and (103) planes, respectively, of hexagonal wurtzite structure, as can be seen in comparison with the JCPDS card nos. 00-003-0752 and 01-075-1526. The films are polycrystalline in nature and highly oriented along (101) plane. The crystallite sizes were calculated using Scherrer's formula using information on broadening of diffraction peak (β), X-ray wavelength (λ), and incident X ray angle with crystal plane (θ_B).The average crystallite size for the (100), (002), and (101) XRD peaks was found to be between 14–17 nm. The calculated lattice parameter *c* was 0.5224 nm, higher by 0.0018 nm than that of standard ZnO crystals. The average grain size was 15 nm, calculated from the broadening of the (101) line by Scherrer's formula,

$$D = \frac{k\lambda}{\beta \cos\theta} \tag{1}$$

Where, k is the constant 0.94, λ is the wavelength of the X-ray used, β is the FWHM in radian and 'θ'is the diffraction angle obtained from 2θ of the XRD pattern.

Figure 1(b) is the scanning electron microscope image of ZnO nanorods. The SEM image shows that the prepared films have rod like structure. The ZnO nanorods are spherical in shape and the distribution is closely packed giving rise to little porosity and voids. Figure shows a nanoscale system with a uniform morphology with bright flower-shaped agglomerates of grains. When the metal precursors Zn/O combination is increased the film exhibited dense layers with fine grains. The grain size revealed from SEM pictures was found to increase with the increase in the deposition parameters, which is also confirmed by the increase in the crystallite size revealed from x-ray diffraction data.

3.2. J-V characterization of the Solar Cell

Figure.2 shows the photocurrent density-voltage (J-V) characteristics of beetroot natural dye (prepared at room temperature) sensitized ZnO nanorod based solar cell. The conversion efficiency (η) of the beetroot extract sensitized ZnO nanorod based solar cell is 0.19 % with short circuit current density 0.86 mA/cm^2, open circuit voltage 0.43V and fill factor of 0.53.

Table 1: Solar cell parameters of the ZnO nanorod based solar cells sensitized with beetroot dye.

Natural Dye	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Cell Efficiency η %
Beetroot	0.43	0.86	53	0.19

Table 2: Solar cell parameters of the cells sensitized with Beetroot dye extracted with different pH Values

pH	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Cell Efficiency η %
1	0.45	0.81	69	0.25
2	0.43	0.58	59	0.14
3	0.39	0.80	61	0.19

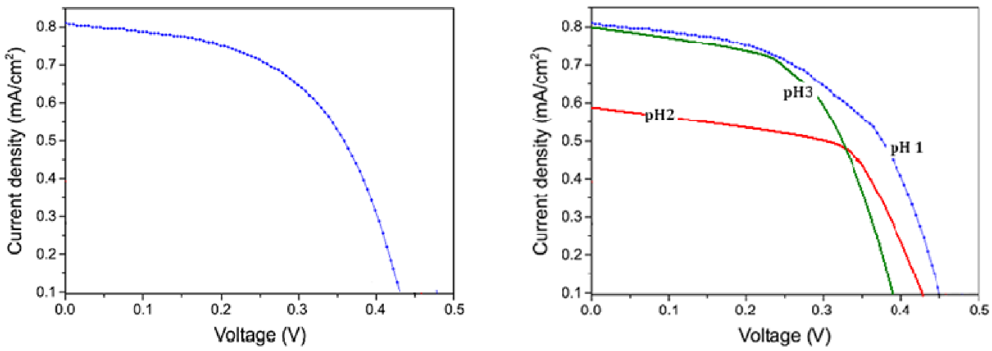

Figure (2, 3): J-V characteristics of Beetroot dye & extracted at different pH values

The pH of the dye extract has an important effect on the performance of Beetroot natural dye sensitized solar cells and it is shown in Table 2. The solar cells fabricated using ZnO nanorod sensitized using dye extract with pH values 1, 2 and 3 show efficiency values of 0.25%, 0.14%, 0.19 % respectively(Fig.3).The dyes synthesized at pH = 1 shows good interaction with the working electrode, the reason is at pH = 1, the betanin and vulgaxantin acids existed as Betanin ion, which is stable form of Beetroot; an increasing pH hydrated this ion to quinonoidal bases. However, the cell deterioration by acid leaching is expected as the pH goes higher (pH = 2, 3…), which results in a lower efficiency.

Table 3. Solar cell parameters of the cells sensitized with Beetroot dye extracted with different temperatures.

Temperature °C	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Cell Efficiency η %
Room temp	0.43	0.86	53	0.19
50 °C	0.45	1.86	83	0.69
75 °C	0.42	1.70	79	0.56
100 °C	0.38	1.64	78	0.48

Table 4. Solar cell parameters of the cells sensitized with Beetroot dye extracted with different solvents

Solvent	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Cell Efficiency η %
Ethanol	0.45	1.86	83	0.69
Methanol	0.44	1.81	80	0.63

The effect of dye ex-tracting temperature on the performance of dye sensitized solar cells is shown in Table 3. Solar cell sensitized using dye extracted at 50 °C shows a power conversion efficiency of 0.69%, with Voc of 0.45 V, Jsc of 1.86 mA/cm^2 and FF of 0.83.

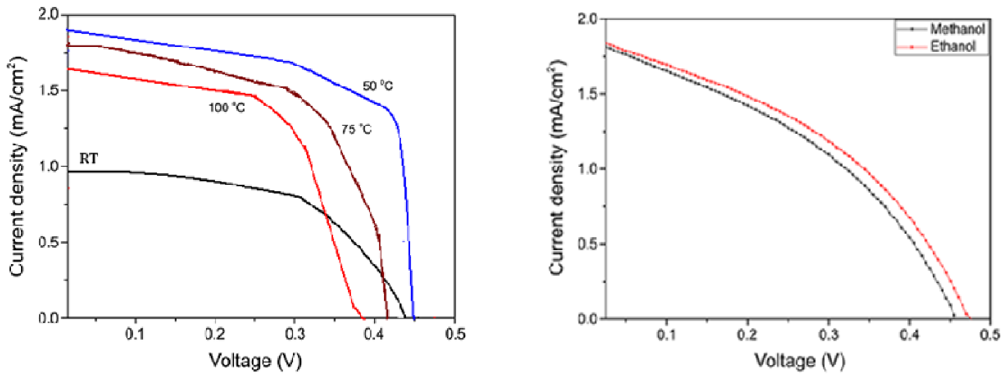

Figure (4, 5): J-V characteristics of natural dye extracted at different temperatures & solvents

Solar cell Sensitized using the dye extracted at 75 °C shows power conversion efficiency of 0.56%, with Voc of 0.42V, Jsc 1.70 mA/cm^2 and FF of 0.79. Solar cell sensitized using dye extracted at 100 °C shows a conversion efficiency of 0.48% with Voc of 0.38V, Jsc of 1.64 mA/cm^2 and FF of 0.78(Fig.4).

Figure 5.shows the photocurrent density-voltage (J-V) characteristics of natural dye (extracted using different solvent) Sensitized ZnO nanorod based solar cells. As shown in Table 4, the solar cells prepared using natural dye extracted in ethanol shows a higher efficiency than that of Solar cells prepared using natural dye extracted in methanol. The Figure (5) clearly shows that the dye extracted using methanol absorbs less light compared to that of the dye extracted using ethanol.

4. CONCLUSION

DSSCs as promising alternatives to the conventional silicon based solar cells require specific modifications and inspired connections before they can be applied to a production line. The electrolyte thickness, the efficient current collection, and effective isolation of the cells to the module are of the main issues to be solved before. X-ray diffraction patterns for ZnO nanorods shows hexagonal wurtzite structure, as can be seen in comparison with the JCPDS card nos. 00-003-0752 and 01-075-1526. The films are polycrystalline in nature and highly oriented along (101) plane. The average crystallite size for the XRD peaks was found to be between 14–17 nm. The SEM image shows that the prepared films have rod like structure. The ZnO nanorods are spherical in shape and the distribution is closely packed giving rise to little porosity and voids. The efficiency of Beetroot extract sensitized solar cell shows better performance than the some natural dye sensitized solar cells. It was also found that the efficiency of the dye sensitized solar cells can be enhanced by changing the solvent used in the preparation of the dye, changing the dye extracting temperature and pH of the extract. Ethanol is found to be the suitable solvent for natural dye, the optimum dye extracting temperature is found to be 50 °C and the suitable value of pH is found to be 1.

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