Terminalia Catappa Fruit Pigments for Dye Sensitized Solar Cell Applications

P. Naresh Kumar[1*], K. Sakthivel [2], M. Saravanakumar[3], Akila Yuvapragasam[2], B. Vijayakumar[1]

[1] Department of Physics, SNS College of Technology, Coimbatore, Tamilnadu, India.

[2]Department of Physics, Coimbatore Institute of Technology, Coimbatore, Tamilnadu, India.

[3]Department of Physics, SVS College of Engineering, Coimbatore, Tamilnadu, India.

naresh_pnk@yahoo.co.in

ABSTRACT

The dye sensitized solar cells have been assembled by using natural dye extracted from *Terminalia catappa* fruits. The photoelectrode for dye sensitized solar cell were prepared using green synthesized ZnO nanoparticles using doctor blade technique. The photoelectrode were sensitized using the extracted dyes. The fabricated solar cell exhibited short circuit current density of 4.9 mA and open circuit voltage of 0.472 V. The efficiency of the cell was found to be 1.58%. The photovoltaic performance of the constructed solar cell shows good conversion efficiency. This indicates that *Terminalia catappa* fruit extracts can be used as an effective sensitizer.

Indexing terms/Keywords: Dye Sensitized Solar Cells, Natural Dyes, Zno Nanoparticles.

Academic Discipline and Sub-Disciplines: Physics and Solar cells

1. Introduction

ZnO nanoparticles have attracted technological interest due to their variety of applications in the fields of optoelectronic devices, piezo electric devices, sensors, UV-LED, etc. [1-4]. ZnO is one of the best photo catalysts with good transparency and electron mobility property. ZnO nanoparticles also possess the potential to be used as a photoelectrode in dye sensitized solar cells. The dye sensitized solar cells are devices used to convert sunlight into electric current. The dye sensitized solar cell is considered as the third-generation solar cell. These cells have many advantages like low cost, easy to fabricate and eco-friendly when natural dyes are used. The DSSC cell consists of a nanocrystalline wide band gap semiconductor oxide layer on low resistance FTO substrate, counter electrode coated with platinum or carbon, redox electrolyte and dye for sensitizing the semiconductor layer. The photo anode was prepared by ZnO nanoparticles synthesized through green synthesis process. Various methods are involved in synthesizing ZnO nanoparticles like sol-gel method, precipitation method, laser ablation method etc. These methods involve hazardous chemicals and time-consuming methods. The green synthesis method is a best alternative to the above methods with eco-friendly approach and simple process. The ZnO nanoparticles are synthesized using *Amorphophallus paeoniifolius* tuber extracts. The phytochemicals present in the tuber extract acts as a reducing agent in the synthesizing process. The synthesized nanoparticles are used as a photo anode in the dye sensitized solar cell. The performance of the dye sensitized solar cell highly depends on the dye sensitizer and the acceptor material. Recently highest efficiency of 13% was achieved through molecular engineering of porphyrin sensitizers [5]. Ruthenium based dyes showed an efficiency of 12%. In order to achieve good efficiencies, the dye should have absorption spectrum in the visible or near infrared regions of solar spectrum [6]. The cost of these solar cells can be highly reduced if the ruthenium dyes are replaced by natural dyes. Cost effective eco-friendly dyes and electrolyte have been utilized in these solar cells and were successful with better conversion efficiencies [7-12]. Several natural pigments such as chlorophyll, anthocyanins, tannin and carotene are successfully used as sensitizers in DSSC [13]. The natural dye offers various advantages such as non-toxic environmental friendly.

In this paper we report fabrication of dye sensitized solar cell using natural dye extracted from *Terminalia catappa* fruit to sensitize green synthesized ZnO nanoparticles. The performance of the fabricated solar cell is analyzed by open circuit voltage (V_{oc}), short circuit current density (J_{sc}) through I-V characteristics curve.

2. EXPERIMENTAL DETAILS

Precursor Zinc acetate dihydrate Zn $(CH_3COO)_2{\cdot}2H_2O$ (99%), is purchased from Sigma-Aldrich. Fresh *Amorphophallus paeoniifolius* tubers and *Terminalia catappa* fruit were purchased from local market in Coimbatore, Tamilnadu, India.

2.2 Preparation of tuber extract

Fresh *Amorphophallus paeoniifolius* tubers were washed thoroughly with double distilled water. The outer skin of the tubers was peeled out and the corm alone was chopped into tiny pieces. 10 gm of chopped tubers were taken in a glass beaker with 200 ml of double distilled water and heated at 70℃ for 30 min. Then the content was allowed to cool at room temperature, filtered and stored in a glass beaker.

2.3 Preparation of ZnO nanoparticles

The preparation of ZnO nanoparticles involves 0.2M of Zinc acetate dihydrate which was dissolved in 100 ml of de-ionized water using magnetic stirrer at 70℃ for 30 min. Then 20 ml of prepared *Amorphophallus paeoniifolius* tuber extract was added to the zinc acetate dihydrate solution and was stirred at 80°C for 1hour resulting in the formation of pale yellowish precipitate. The solution was decanted and the precipitate and was dried in microwave oven for 5 minutes. Finally a white powder was obtained and was annealed at 400°C for 1 hour.

2.3 Preparation of ZnO photoelectrode

The prepared ZnO nanoparticles are coated onto conducting side of FTO substrate by doctor blade method. Few drops of very dilute acetic acid were added to 1 g of prepared ZnO nanoparticle and grinded in a mortar and pestle until a colloidal suspension with a smooth consistency was observed. Then 2-3 drops of the ZnO suspension was dropped on the conductive side of FTO substrate and spread out evenly on the surface of the FTO with glass rod. Then the substrate was dried at 200 °C for 30 min and naturally cooled down to room temperature.

2.4 Extraction of natural dye sensitizers

The dyes used to sensitize the ZnO photoelectrode have been extracted from fruits of *Terminalia catappa*. The flesh from the fruits of Terminalia catappa along with the skin was allowed to dry in shade. After drying it completely, the dried skins of the fruits were powdered in a blender. The powder was soaked in 100 ml of ethanol at room temperature for 24 h and then the solid residues were filtered out. The filtrate was washed with hexane several times to remove any oil presence. This was directly used as dye solution for sensitizing the prepared ZnO photoelectrode.

2.5 Sensitization of ZnO photoelectrode

The prepared photoelectrode has to be sensitized by a light absorbing dye in order to inject electrons to the electrode by photo excitation process. Each ZnO photoelectrode was immersed into the separate beakers containing the dye extracted from the fruits of *Terminalia catappa*. The sensitization was carried in a dark environment at room temperature for about 10 h. After sensitization the electrodes were rinsed with ethanol to remove the excess of dye present in the electrode and then the electrode was dried. Thus, the prepared ZnO photoelectrode was sensitized with natural dyes.

2.6 Dye sensitized solar cell assembly

The fabrication of dye sensitized solar cell involves basic components like dye sensitized photoelectrode (working electrode), electrolyte and a counter electrode. In the present work the dye sensitized ZnO photoelectrode acts as the working electrode. The platinized FTO glass is used as counter electrode and it was placed on the top of the dye sensitized ZnO photoelectrode and sealed with 30 µm thick thermal adhesive film. The iodide/Triiodide redox electrolyte solution was filled into the space between the photoelectrode and the counter electrode through a hole made on the counter electrode due to capillary action. After filling the electrolyte, the hole was sealed using the adhesive film. With the same procedure five solar cells were constructed with each dye and their J-V characteristics were analyzed.

2. Results and discussion

The X-ray diffraction patterns of the synthesized ZnO nanoparticles are shown in the Fig. 1 The peaks at 32.58°, 35.14°, 37.01°, 47.90°, 57.03°, 63.35°, 68.29°, 69.54°, 77.44° corresponding to (100), (002), (101), (102), (110), (103), (201), (112), (202) positions clearly indicate the prepared ZnO nanoparticles are in wurtzite phase. The particle size of is calculated using Debye scherrer's equation

$$D = 0.89\lambda / (\beta \cos\theta)$$

Where D is the crystallite size, λ is the wavelength of X-ray used, θ is Bragg's angle and β is the full width half maximum. The average crystallite size was determined to be 14 nm. Fig. 2 shows the FESEM image of granular shaped ZnO nanoparticles.

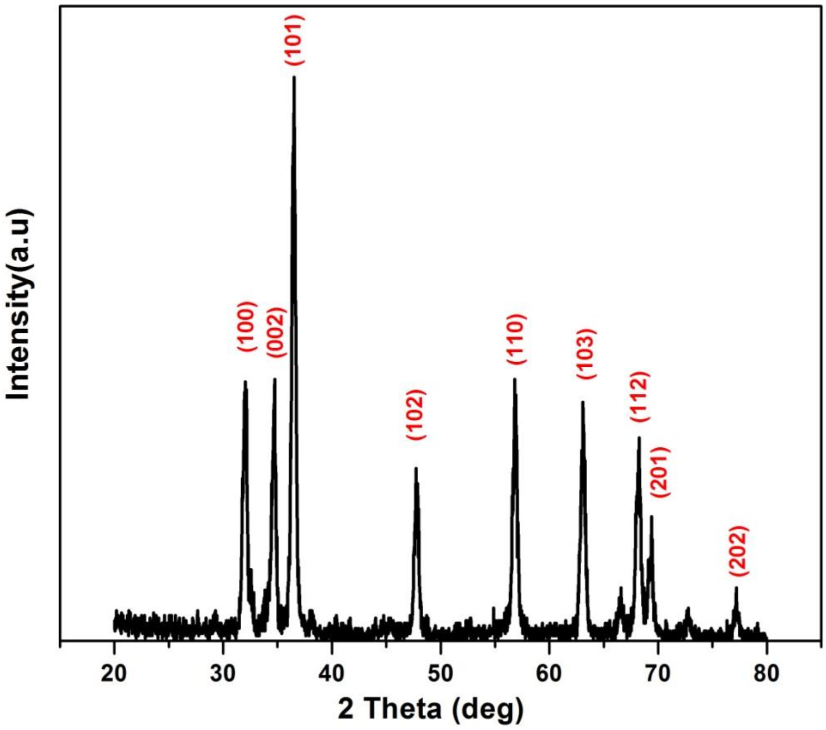

Fig. 1. XRD pattern of green synthesized ZnO nanoparticles.

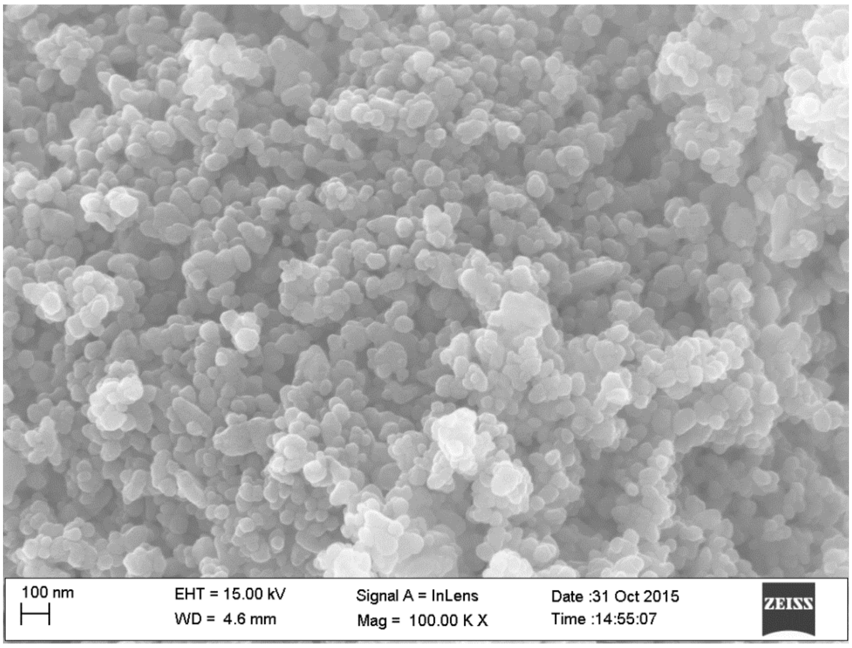

Fig. 2. FESEM image of green synthesized ZnO nanoparticles.

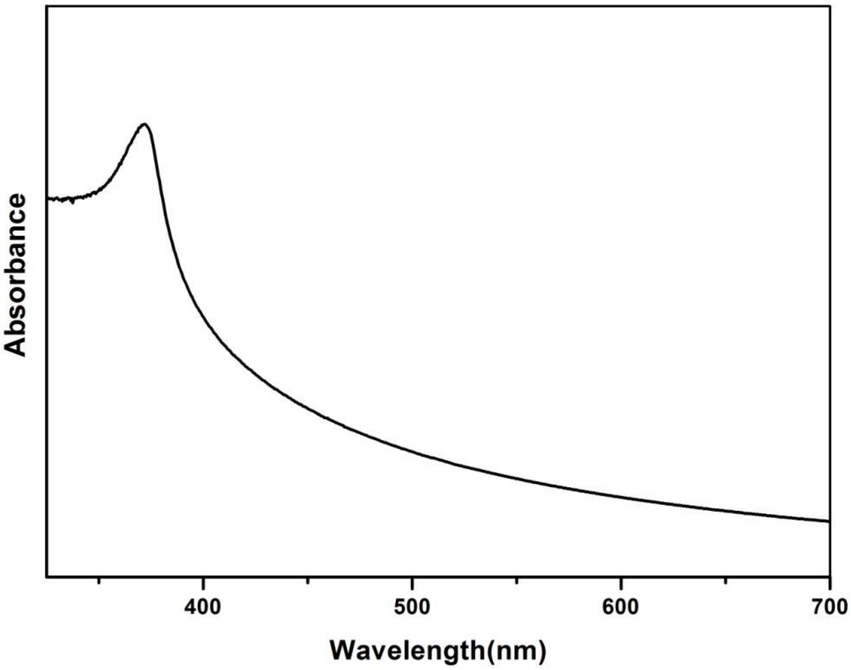

Fig. 3. UV-Vis spectroscopy of green synthesized ZnO nanoparticles.

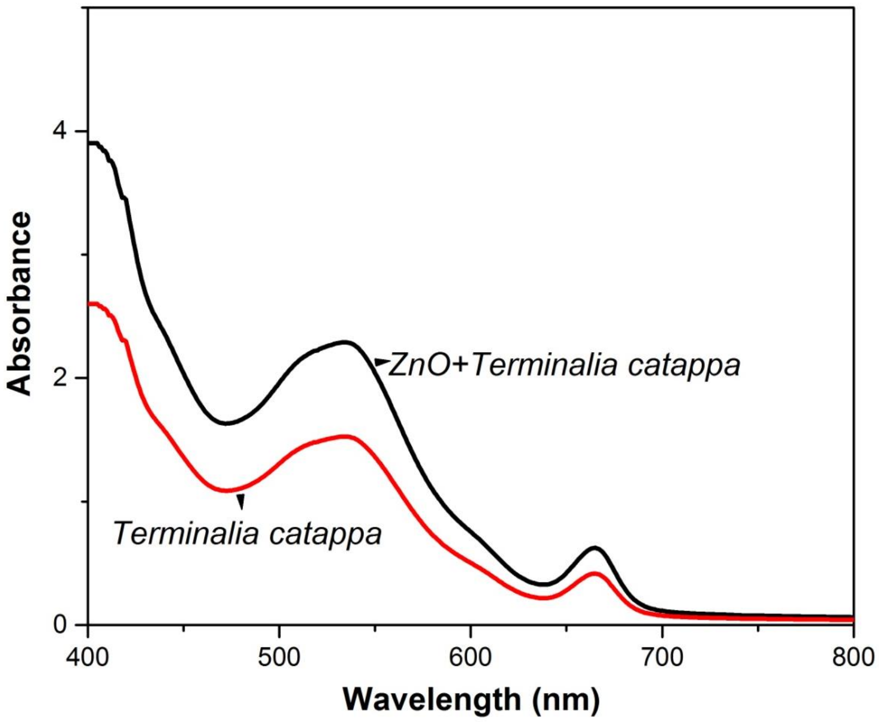

Fig. 4. Absorbance spectra of fruit extracts of *Terminalia catappa* and *Terminalia catappa* sensitized ZnO photo anode.

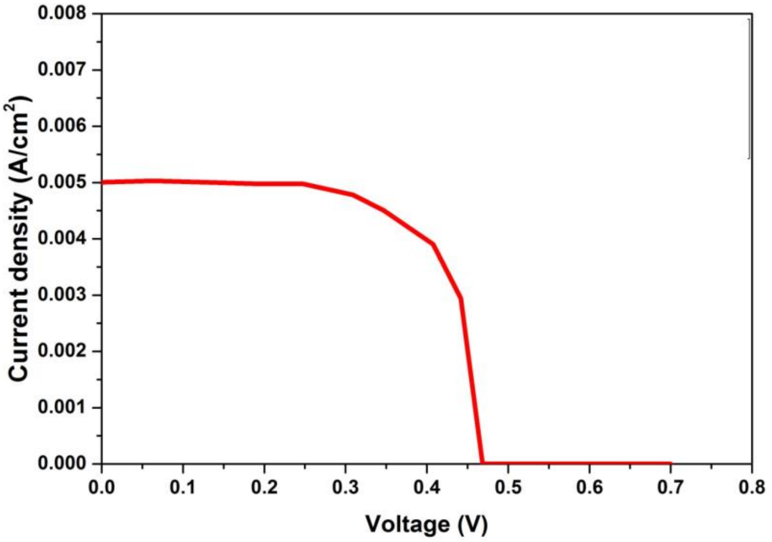

Fig 5 J-V characteristics of *Terminalia catappa* fruit extract sensitized solar cell.

Figure. 3 shows the UV-Vis absorption spectra of as synthesized ZnO nanoparticles. A sharp absorption was observed in the wavelength of 373 nm which can be assigned to the intrinsic energy band gap of ZnO nanoparticle. The energy band gap is calculated by the formula

$$E_g = \frac{1240}{\lambda}\ \text{eV}$$

Where h is plancks constant, c is the velocity of light and λ is the wavelength. The band gap energy of zinc oxide was found to be 3.32 eV. This in agreement with the previous studies [14].

Figure 4 shows the absorption spectra ZnO photoelectrode sensitized by fruit extracts of *Terminalia catappa* in ethanolic solution. The light absorbance of ZnO photoelectrode has been improved by the sensitization of fruit extracts of *Terminalia catappa*. 100 g of the fruits of *Terminalia catappa* contains β-carotene (2.1 mg), ascorbic acid (138.6 mg) and vitamin E (7.25 mg) as the major constituents [15]. The improvement in light absorption of the sensitized photoelectrode is mainly due to the presence of ascorbic acid in the dye.

Figure 5 shows the J-V characteristics of prepared solar cells. The open circuit voltage, short circuit current density, fill factor was found to be 0.47 V, 0.0049 A/cm^2 and 0.683 respectively. The efficiency of the prepared ZnO photoelectrode sensitized by *Terminalia catappa* fruit extracts showed an efficiency of 1.58%. The devices remained stable for 14 days after which there was a decrease in J_{sc} values.

3. Conclusion

ZnO nanoparticles have been synthesized by green synthesis method using *Amorphophallus paeoniifolius* tuber extracts. The X-ray diffraction studies confirm that the prepared sample is ZnO nanoparticles. The band gap energy determined from UV-Vis spectroscopy studies is 3.32 eV. The photoelectrode for dye sensitized solar cell application is prepared using the synthesized ZnO nanoparticles. ZnO photoelectrode were sensitized using natural dyes extracted from fruits of *Terminalia catappa*. The J-V characteristic of the constructed solar cell shows an efficiency of 1.58%. The results confirm that the dye extracted from fruits of *Terminalia catappa* is an effective sensitizer for dye sensitized solar cell.

4. Reference

1. Belhaj, Marwa, et al. "Study of ZnO nanoparticles-based hybrid nanocomposites for optoelectronic applications." *Journal of Applied Physics*119.9 (2016): 095501.

2. Vidor, Fábio F., et al. "ZnO nanoparticle thin-film transistors on flexible substrate using spray-coating technique." *Microelectronic Engineering* 159 (2016): 155-158.

3. Wahab, Rizwan, et al. "Utilization of photocatalytic ZnO nanoparticles for deactivation of safranine dye and their applications for statistical analysis."*Physica E: Low-dimensional Systems and Nanostructures* 69 (2015): 101-108.

4. Lima, F. Anderson S., Igor F. Vasconcelos, and Monica Lira-Cantú. "Electrochemically synthesized mesoporous thin films of ZnO for highly efficient dye sensitized solar cells." *Ceramics International* 41.8 (2015): 9314-9320.

5. Mathew, Simon, et al. "Dye-sensitized solar cells with 13% efficiency achieved through the molecular engineering of porphyrin sensitizers." *Nature chemistry* 6.3 (2014): 242-247.

6. Giribabu, Lingamallu, and Ravi Kumar Kanaparthi. "Are porphyrins an alternative to ruthenium (II) sensitizers for dye-sensitized solar cells?."*Current Science(Bangalore)* 104.7 (2013): 847-855.

7. Yuan, Liu, et al. "Acceptor End-Capped Oligomeric Conjugated Molecules with Broadened Absorption and Enhanced Extinction Coefficients for High-Efficiency Organic Solar Cells." *Advanced Materials* (2016).

8. Liu, Shenghua, et al. "Au/Ag core–shell nanocuboids for high-efficiency organic solar cells with broadband plasmonic enhancement." *Energy & Environmental Science* 9.3 (2016): 898-905.

9. Bella, Federico, Jijeesh R. Nair, and Claudio Gerbaldi. "Towards green, efficient and durable quasi-solid dye-sensitized solar cells integrated with a cellulose-based gel-polymer electrolyte optimized by a chemometric DoE approach." *RSC Advances* 3.36 (2013): 15993-16001.

10. Chiappone, Annalisa, et al. "Structure–Performance Correlation of Nanocellulose-Based Polymer Electrolytes for Efficient Quasi-solid DSSCs."*ChemElectroChem* 1.8 (2014): 1350-1358.

11. El-Ghamri, Hatem S., et al. "Dye-sensitized solar cells with natural dyes extracted from plant seeds." *Materials Science-Poland* 32.4 (2014): 547-554.

12. Kumar, P. Naresh, and K. Sakthivel. "PREPARATION AND CHARACTERIZATION OF LOW COST PRUSSIAN BLUE SENSITIZED SOLAR CELL." *Journal of Ovonic Research Vol* 11.4 (2015): 169-173.

13. Shanmugam, Vinoth, et al. "Performance of dye-sensitized solar cells fabricated with extracts from fruits of ivy gourd and flowers of red frangipani as sensitizers." *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 104 (2013): 35-40.

14. Hammad, Talaat M., Jamil K. Salem, and R. G. Harrison. "Structure, optical properties and synthesis of Co-doped ZnO superstructures." *Applied Nanoscience* 3.2 (2013): 133-139.

15. Dikshit, Madhurima, and Rupali Krishna Samudrasok. "Nutritional evaluation of outer fleshy coat of Terminalia catappa fruit in two varieties." *International journal of food sciences and nutrition* 62.1 (2011): 47-51.