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Performance Analysis of Mixed Natural Dye and Nanostructured Tio$_2$ based DSSC

A. Ayaz, D. Sinha, D. De

Abstract*: The performance of the mixed natural dye based DSSC has been evaluated in this paper. The mixture of beet root, spinach and turmeric are used with nanostructured TiO_2 are used for the fabrication of DSSC. TiO_2 is synthesized by sol-gel technique and considered as semiconductor metal oxide (SMO) to act as photo anode here. Nano wire type of morphology of TiO_2 is found from the FESEM image which exhibits unidirectional and uniform electron flow. The XRD study reveals anatase and rutile phases of TiO_2 that ensure the stability of synthesized TiO_2. The mixed dye made of beet root, spinach and turmeric shows their congruent characteristics with the broad light absorption spectra, lower diffused reflectance spectra after anchoring with SMO and better I-V characteristics in comparison with the individual one. The mixed dye-based DSSC provides the open-circuit voltage of 0.755V, short circuit current of 2.05mA, voltage and current at maximum power equal to 0.51V and 1.7mA, respectively with the efficiency of 0.867 %, in comparison to the efficiency of the individual dyes 0.305%, 0.266% and 0.473% with beet root, spinach and turmeric, respectively.

Keywords*: DSSC, Sol gel method; Tauc's plot; Photo sensitizing properties; Diffused reflectance spectra (DRS)

I. INTRODUCTION

The dye sensitized solar cell (DSSC) known as Gratzel's cell, is operating according to the process of photosynthesis. As a renewable energy source DSSC has a remarkable impact in recent time due to its low cost and simple fabrication process. Its structure comprises 4 vital parts. The semiconductor metal oxide (SMO), which is coated on a transparent conductive glass (TCO) substrate and formed the photo anode. It acquires and conveys the excited photo electrons from dye to TCO. In this paper nano-structured TiO_2 is used as a SMO, which is well known and more efficient photo anode for photon to electron conversion [1-5] although its morphology and phase composition have great impact on the performance of DSSC.

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* Correspondence Author

Abdul Ayaz, Department of Electrical Engineering, Rampurhat Govt. Polytechnique College, Rampurhat, India. Email: aayaz1962@gmail.com

Dola Sinha*, Department of Electrical Engineering, Dr B. C. Roy Engineering College, Durgapur-713206 India. Email: dola.sinha@bcrec.ac.in, dola.sinha@gmail.com

Debasis De, Applied Electronics and Instrumentation Engineering Department, Dr. B. C. Roy Engineering College, Durgapur-713206, India. Energy Institute Bangalore, VTU PG Campus, Chikkabalapura, Karnataka Email:debases.ju@gmail.com

TiO_2 is considered as ideal semiconductor for photo-catalysis still it has certain limitations, such as poor absorption of visible radiation and rapid recombination of photo generated electron/hole pairs. These limitations can be improved by using efficient dye, another vital part of DSSC. At sunlight, the electrons of the dye molecules are energized, and these electrons are transferred to the conduction band of SMO. Here a mixed natural dye is used as a photo-sensitizer. The natural dyes are abundant in nature, economic, biodegradable, non-toxic materials and they can extract easily in compare with other synthetic dye [6]. A mixed of beet root, (contains betalain pigment), spinach (contains chlorophyll pigment) and turmeric (contains betaxanthin pigment) is used here. These dyes are compatible to each other and their mixed one has the advantages of these dyes. Electrolyte is another essential part of DSSC. Regeneration of dye takes places through the electrolyte reduction process, where electrolyte supplies the electrons from the conduction band of SMO in a closed circuit among the FTOs [7]. The performance of the mixed dye based DSSC is analyzed over the individual dye. Not all the dyes available in nature are compatible. Some dyes are compatible and didn't exhibit better performance. Some are not compatible with each other. We have tested lots of combinations of dyes and found these dyes are consistent and provide better performance than their individual performance. The dyes are chosen, such as their UV-Vis light absorption ranges are different. Turmeric has an absorption in lower wavelength, beet root has lower to middle range and spinach has absorption at lower, middle as well as higher wavelength. For the mixed one, it has the absorbance in all the region of all these three and has lower diffused reflectance spectra (DRS). The paper is structured as: in section 2, the methodology is discussed. In section 3 results and performance of the mixed dye is analyzed and at last, some conclusion has been made.

II. METHODOLOGY

A. Fabrication of Photo anode

In this present work, we have used nanostructured Titanium di oxide (TiO2) as a photo anode. TiO2 is synthesized from Titanium isopropoxide. In a cleaned beaker 60ml of Ethanol (99.9%) is mixed with 9ml of Titanium isopropoxide and 18ml of acetic acid. After 20days the mixture formed in white gel and then the gel is heated in 70ºC in air for drying. It then becomes white power form of mesoporus TiO2. Again it is heated in a furnace at 650ºC for 2 h. Now, the synthesized TiO2 is mixed properly with acetone and using spin coating method at 3000 rpm it is coated over FTO at room temperature.

Again the TiO2 coated FTO is heated in a furnace at 450ºC to make firm anchor between FTO and TiO2. A flow chart in this process is shown in Fig.1.

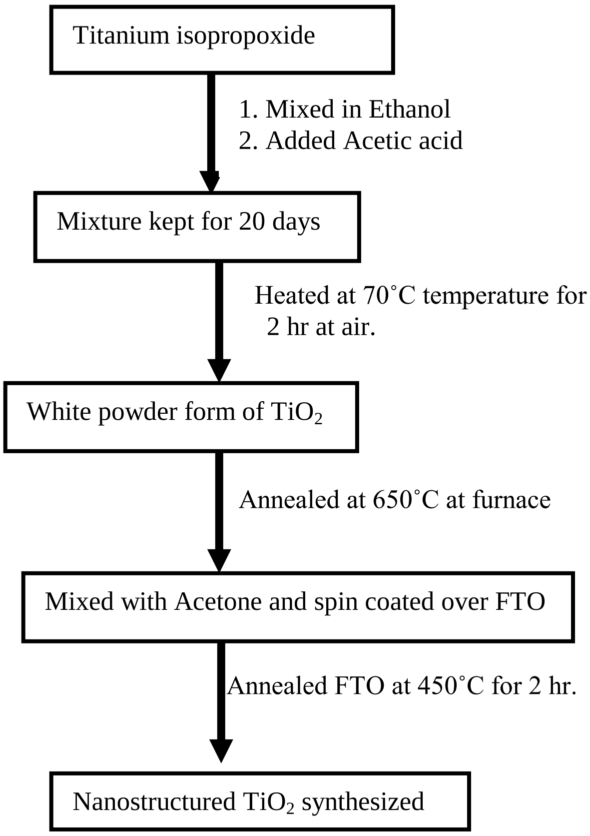

Fig. 1.Synthesis of nanostructured TiO_2

B. Synthesis of dyes

Chlorophyll is extracted from fresh spinach leaves. Betaxanthin is extracted from fresh turmaric and betalain is extracted from fresh beet root. Individually the dyes are extracted as reported in the papers [8-10]. Then the extracted juice of the mentioned dyes are mixed in 1:1:1 ratio and the total mixed dye is mixed with ethanol at a ratio of 1:1.

C. Fabrication of DSSC

The synthesized TiO_2 coated FTOs are dipped with prepared dyes individually for 24 hrs and DSSCs are fabricated with different dyes following the process as illustrated in [9]. The performances of the fabricated DSSCs are analyzed by a solar simulator with a constant light source of 100 mW/cm^2.

III. RESULTS AND DISCUSSIONS

A. Morphology of photo anode

The FESEM image of surface layer of synthesized TiO2 on FTO glass reveals the nano wire of circular shaped morphology as shown in Fig. 2. The nano wires are oriented in different direction but the thicker sides are connected in one point with each other. It depicts the unidirectional and uniform electron flow through the photo anode. The average length of the nano wire is 2 µm and diameter is 300 nm. Diameter of the nano wire reduces while approaching from bottom to top. Fig. 3 shows the X ray defraction pattern. The XRD shows the most stable phases of TiO2 i.e., anatase and rutile both phases are present. The diffraction peaks at 25.95º, 36.81º, 38.27º, 48.48º and 55.41º show the anatase phase and 28.11º, 41.61º, 44.45º, 54.63º and 57.13º show the rutile phase of TiO2. Rutile has high absorbance property than anatase, and it is more stable. Anatase is metastable but more active than rutile. Both the phases are tetragonal. With the heat treatment anatase phase can be converted to rutile phase.

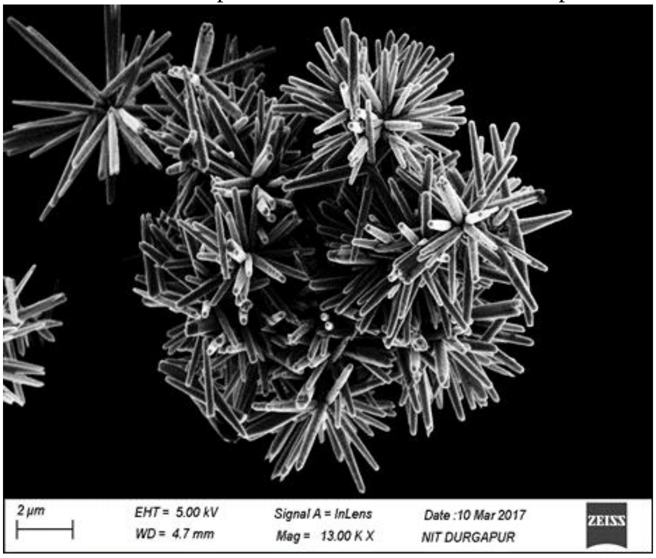

Fig. 2. FESEM image of synthesized TiO_2

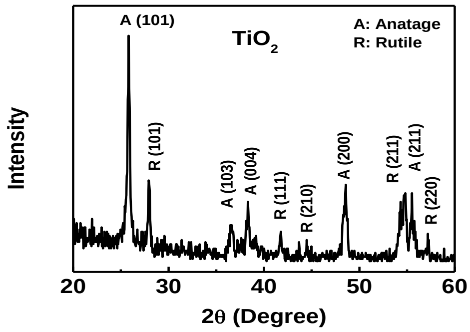

Fig. 3. XRD pattern of synthesized TiO_2

B. Photo-sensitizing properties of extracted and prepared dyes

The UV and visible light absorption characteristics of the extracted dyes are shown in Fig.4. The spinach consisting chlorophyll dye has peaks at 412nm, 666nm and 735nm with a broad spectrum of light absorption at 516nm to 600nm. The turmeric consisting betaxantin pigment has light absorbption at 397nm to 424 nm with a peak of 415nm and 509nm to 568nm with a peak of 528nm. The beet root consisting betalain pigment has light absorption at 438nm to 461nm with a peak of 452nm and other peaks are at 474nm and 490nm. The mixed dye is compatible with all these dyes and shows a broad spectrum of light absorption characteristics with a combination of all these dyes. At lower wavelength, it has absorption at 410nm to 431nm with a peak of 418nm, at the middle wavelength of 506nm to 600nm with a peak at 515nm and at higher wavelength, it has same absorption that of spinach, i.e., at 666nm and 735nm. Fig.5 shows the diffused reflectance spectra (DRS) of dye and TiO_2 before and after dye loading. It shows that after 370nm TiO_2 has reflectance and gradually it increases upto 80% at a higher wavelength.

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After mixed dye loaded with TiO_2, its DRS reduced. At 700 nm it has full reflectance of 43% only. Lower DRS proves light-harvesting ability of the dye and the mixed dye shows better light-harvesting ability in comparison with the individual dyes as reported in [11, 12].

Fig. 6 shows the bandgap energy of the synthesized TiO_2 and the extracted and prepared mixed dye through Tauc's plot. In the Tauc's plot photon energy is plotted in absentia and the quantity $(\alpha hU)^{1/n}$ is plotted in ordinate. By extrapolation of the linear region to zero absorbance, the bandgap energies are calculated. For direct bandgap "n" is considered as 2 [9]. For TiO_2 as two types of phases are present, anatase has a little higher bandgap energy approx 3.2 eV and rutile has 3.0 eV. Here the Tauc's plot provided average bandgap energy of 3.18 eV, which ensures the stable form of TiO_2.

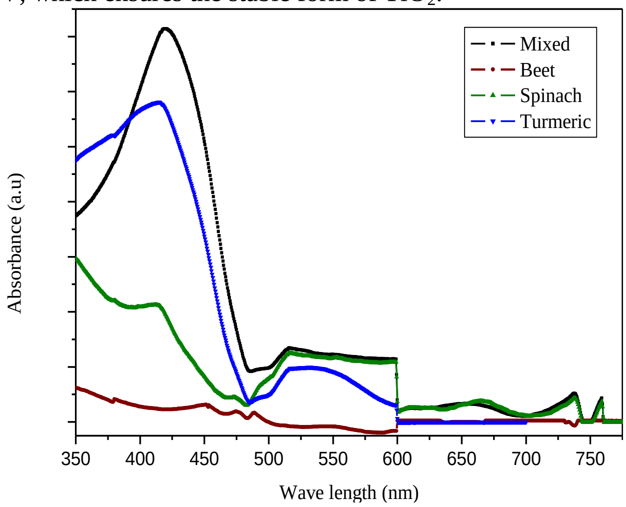

Fig. 4: UV-visible light absorption characteristics of extracted and mixed dyes

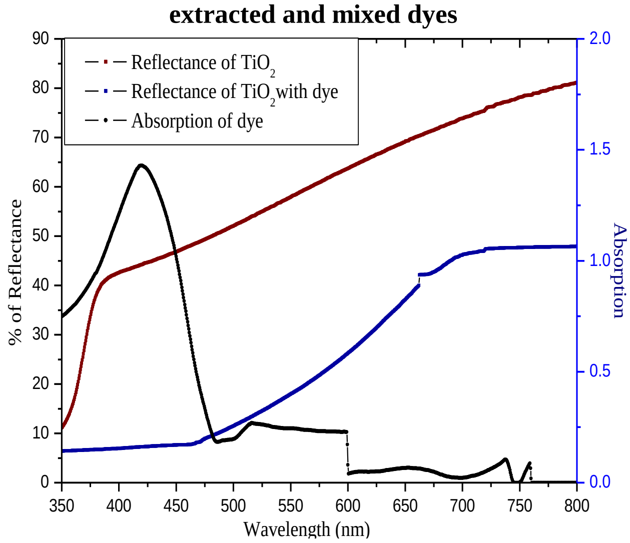

Fig. 5: Diffused reflectance spectra of dye and TiO_2 before and after dye loading

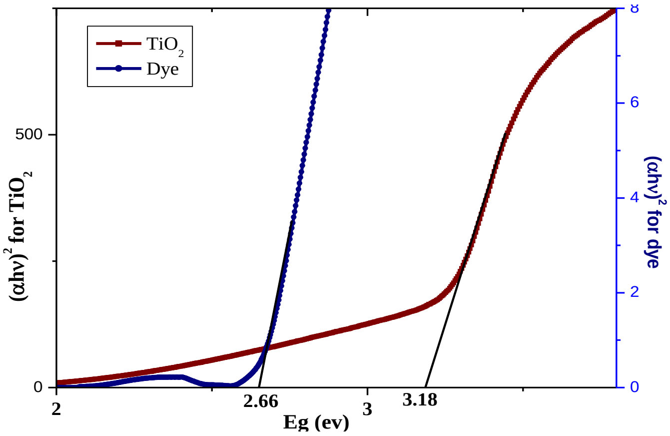

Fig. 6 Tauc's plot of Mixed dye and TiO2

C. Performance analysis of fabricated DSSCs

The performances of the DSSCs are evaluated through I-V and P-V characteristics of individual and the mixed dyes, as shown in Fig. 7 and Fig. 8, respectively and are summarized in Table.1.

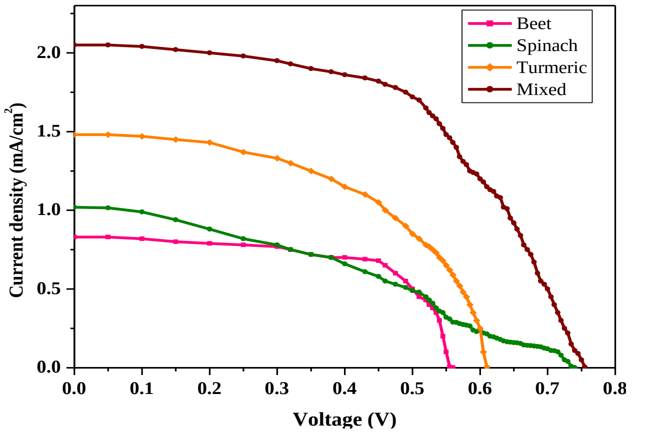

Fig. 7. I-V characteristics of DSSCs fabricated by individual dyes and their mixture

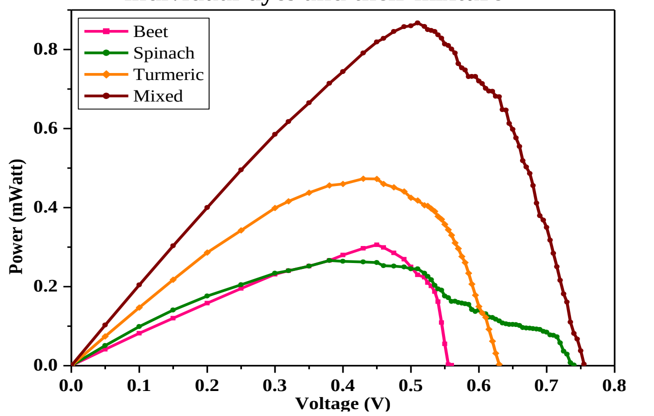

Fig. 8. P-V characteristics of DSSCs fabricated by individual dyes and their mixture

The efficiencies of DSSC fabricated by beet root, spinach and turmeric are 0.306%, 0.266% and 0.473% respectively, whereas the mixed dye shows

Table I: Performance parameters of fabricated DSSCs

Dyes	V_{mp} (V)	I_{mp} (mA/cm^2)	V_{oc} (V)	I_{sc} (mA/cm^2)	FF	% η
Beet	0.45	0.69	0.56	0.83	66%	0.306
Spinach	0.38vi	0.7	0.74	1.02	35%	0.266
Turmeric	0.43	1.1	0.63	1.48	50.7%	0.473
Mixed	0.51	1.7	0.755	2.05	56%	0.867

better performance of 0.867%. The mixed dye-based DSSC shows the maximum current density of 2.05mA/cm2 and an open-circuit voltage of 0.755 V whereas voltage and current density at maximum power is 0.51V and 1.7 mA/cm2 and a fill factor of 56%.

IV. CONCLUSION

In this paper the performance of DSSC fabricated by mixed natural dye and nanostructured TiO_2 has been explored. The natural dyes of beet root, spinach and turmeric are compatible to each other and absorbs light in three different regions of wavelength. Hence the mixed one provides a broad range of light absorption, and comparatively
low diffused reflectance spectra when anchored with TiO_2. TiO_2 is synthesized by the sol-gel method, which exhibits the presence of both anatase and rutile phase of TiO_2. FESEM shows nano wire structure which provides unidirectional electron flow. The Tauc's plot provides the approx bandgap energies of 2.66 eV and 3.18 eV for mixed dye and TiO_2 respectively. The efficiency of the individual dyes are 0.305%, 0.266% and 0.473% for beet root, spinach and turmeric respectively, and the mixed dye-based DSSC provides 0.867% efficiency. In this paper, no efficiency enhancement technology is used, but the effectiveness of the mixed dye is established. Using other composite materials as SMO with this mixed dye, the efficiency of the fabricated DSSC will be higher.

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AUTHORS PROFILE

Mr. Abdul Ayaz, Completed his BE in Electrical Engineering from Burwan University on 2004, and M.Tech in Power System Engineering on 2016 from MAKAUT University. He has made his post graduate dissertation on Design of dye sensitized solar cell. Now pursuing PhD on the same field from MAKAUT University. He has several publications in the international journals on the same field. Also his research work includes electrical machines and power system. He has membership of professional body like Institute of Engineers. Presently he is working as a principal of Rampurhat Govt. Polytechnique College, Rampurhat, Birbhum, India.

Dr Dola Sinha, Completed her BE in Electrical Engineering from Burwan University on 2004, and M.Tech in Industrial Electrical System (Department of Electrical Engineering) in 2006 from NIT Durgapur. Her post graduate dissertation was on Power System Engineering. She has completed PhD on 2013 from ISM Dhanbad from Department of Electrical Engineering. The PhD dissertation was on Energy efficient high frequency induction heating and specialization on Power Electronics. Her research interest includes Inverters, High frequency heating, nanomaterials, DSSC, Fuzzy logic controller etc. She has several publications on the said fields in national and international levels. She has got several best paper awards in IEEE conferences. Mentor the students for model competitions and achieved position in national and state levels. She has membership of professional body like Institute of Engineers. Presently she is working as an assistant professor of Dr. B. C. Roy Engineering College, Durgapur.

Dr. Debasis De completed his BE in Electronics and Telecommunication engineering from Nagpur University in 2004 and M.tech in Nanoscience and Technology in 2006 from Jadavpur University Kolkata. His post graduate dissertation was on magnetic storage system. He has completed PhD in 2012 from IIT Kharagpur. The PhD dissertation was on colossal magnetoresistance system. His research interests includes solar cells, hydrogen/oxygen evolution, nanotechnology, electronics, etc. He has several publications on the said fields in national and international levels. He had presented his research work in several international conferences. He had also delivered many invited lectures in the said field. He has several membership of professional bodies like international solar energy society, Indian magnetic society, the institute of engineers (India). Presently he is working as a faculty of energy institute Bangalore (a centre of RGIPT, an Institute of National importance, Government of India) Bangalore.