

ENHANCING THE PERFORMANCE OF TiO₂ BASED N-DSSC USING DYE EXTRACTED FROM COMBRETUM INDICUM AND MIXED SENSITIZER

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Abstract- Natural dye sensitized solar cell were fabricated using the dye extract from combretum indicum flower(F), leaves(L) and Mixed (M). Sensitizer was extracted using ethanol as a solvent. TiO₂ nanoparticle were coated on FTO substrate using doctor blade method as a photo-anode. Optical and electrical properties were carried out for comparative study of fabricated photo-anode. The individual dye sensitized photo-anode has made more significant absorption in the visible region compared with the mixed photo-anode using UV-Vis spectrophotometer. FT-IR studies were performed for the extracted dye for the chemical elucidation of presence of favourable functional groups that ensures the anchoring capability of dye molecule towards the TiO₂ particle. The recombination mechanism of fabricated photo-anode were analysed using photoluminescence spectra. Photovoltaic parameters of assembled N-DSSCs sensitized with sensitizer F, L and M were calculated from the J-V graph.

INTRODUCTION:

A non-disappearing, noiseless, renewable energy source, sunlight comes from the Sun and is unaffected by pollution or other external noise sources. It may be used to offset the energy used to produce fossil fuels and other non-renewable energy sources like the earth's oil reserves. From one generation to the next, the technique for producing solar cells has undergone several stages of refinement [1]. Since they directly convert sunlight into electrical current, solar cells are also known as photovoltaic cells. Solar cells, which are durable, compact, and low-maintenance, produce renewable energy. Solar cells are frequently utilized to generate electricity to power equipment for industrial purposes and are employed in remote locations.

The most effective material for turning sunlight into energy is solar cells, which are constructed from a particularly pure kind of silicon. Due to their high conversion efficiency, silicon-based solar cells are typically employed in solar energy systems. Yet, it is commercially expensive to employ very pure silicon as a coating. Due to this, the Dye Sensitized Solar Cell (DSSC) became an additional efficient way. O'Regen and Gratzel were the first created the DSSC in 1991[2]. A photochemical device called a DSSC uses electrolyte as a medium to transform light energy into electrical energy. The possibility exists that it will eventually dominate other solar cells.

A low-cost solar cell that is a member of the class of thin film solar cells is a dye-sensitized solar cell. It is based on a photoelectrochemical system's semiconductor, which is created when a photo-sensitized material and an electrolyte come together [3]. The energy is then transmitted to metal oxides, such as titanium dioxide, through dye-sensitized solar cells (DSSCs), which employ a dye to absorb incoming sunlight and create excited electrons. The DSSC is made up of four parts: metal oxides, dye, electrolyte, and counter electrode [4]. The doctor blade method is used to create a thin coating of TiO₂ designated a photo-anode, which serves as a transparent substrate for absorbing synthetic or natural colour. This serves as the device's photo-anode. In order to capture the circuit's external electrons, the counter electrode is made of a transparent conductive sheet coated with graphite or platinum.

The dye employed as the sensitizer heavily influences DSSC performance. In order to determine efficiency, measurements on the dye's conductivity and absorbance on semiconductor material are necessary. As a sensitizer for DSSC, several synthetic dyes are used. N719 and black dye, which are ruthenium-based metal complexes, were the most widely used synthetic dyes [5]. They have a high conversion efficiency and are prone to absorbing a wide range of light. Around 11–12% conversion efficiency was recorded. Nevertheless, the drawbacks of synthetic dyes are their toxicity, expensive price, and limited colour range.

As a result, ecologically acceptable natural dyes are employed as an alternative photosensitizer for fabricating Natural-DSSCs (N-DSSCs). Natural dyes have the advantages of being inexpensive, readily accessible from the environment, having a wide range of colour variations, and being environmentally friendly. Plant parts like leaves, flowers, fruits, the trunk, the roots, the seeds, and the rind may all be used to make natural dyes [6]. Chlorophyll, anthocyanin, carotene, tannin, and flavonoids are pigment molecules found

in plants that are utilised as natural colours [6, 7]. Due to the differences in the orbitals that make up their conduction band and valence band, TiO₂, ZnO and Nb₂O₅ are the best options for photoanodes. This dissimilarity increases the carrier lifespan and minimizes the chance of charge recombination in these materials. Rutile, anatase, and brookite are three states of TiO₂. The 3 most thermodynamically stable of the three states is the rutile structure, whereas the other two are metastable. TiO₂ of the anatase phase has a greater energy band gap of 3.2 eV compared to the rutile phase, which has 3.0 eV, and it is employed for DSSC applications because it improves photo-activity performance [8]. In this work, ethanol is used as a solvent to extract a natural dye from the flowers[F] and leaves[L] of *Combretum indicum*. Mixture of dye extracts are used to form mixed dye[M] in a 1:1 ratio. TiO₂ is deposited to a bare photo-anode using the doctor blade technique. The counter electrode has a carbon coating. Using KI, iodine, and acetonitrile, liquid electrolyte is prepared. Liquid electrolyte was used to build the photo-anode and counter electrode using binding clips. The light-absorbing capacity of extracted dye and constructed photo-anodes is evaluated using UV-Vis spectra. The extracted dye's functional groups are quantitatively analysed using FT-IR, and the dye's recombination process is studied using PL. J-V was used to measure N-DSSC efficiency, and photoelectric parameters are addressed in depth.

2. EXPERIMENTAL PROCEDURE:

2.1 PREPARATION OF NATURAL DYE:

For making photo-anodes, dyes derived from *Combretum indicum* leaves, flowers and mixed sensitizer were used. To begin with, the *Combretum indicum*'s leaves and flowers are separated and thoroughly cleaned with distilled water. Precisely 15g of each are crushed using a crusher and pestle and steeped in 50ml of ethanol for three days at room temperature in the dark. Ethanol-based natural dye extraction demonstrated better efficiency as compared to other solvents [9]. After that, filter paper is used to filter the solution. The dyes collected from flowers and leaves are combined in a 1:1 ratio to create mixed dye.

2.2 PREPARATION OF PHOTO-ANODE:

To fabricate the photo-anode, ALDRICH furnished titanium (IV) oxide powder with primary particle sizes of 20 nm was used. Fluorine doped tin oxide (FTO) is employed as the transparent substrate because of its excellent chemical durability and thermal stability [10].

The working electrode serves as the foundation for the construction of the photoanode and counter electrode because it's crucial to the transfer of electrons. For the purpose of fabricating bare photo-anodes, titanium (IV) oxide is deposited on the FTO's conducting surface.

The FTO substrate is first washed with acetone and ethanol in an ultrasonic bath for 15 minutes. By exposing the active layer of 1cm² that has to be coated, the FTO substrate is then covered with scotch tape on the remaining portion of the film. TiO₂ sol-gel paste was prepared by mixing 0.1g of TiO₂ while adding 20 ml of nitric acid and 10 ml of acetic acid drop by drop in a 3:1 ratio. The mixture is subsequently placed in a magnetic stirrer for around two hours, resulting in a fine paste. The masked FTO substrate was coated with prepared paste using the doctor blade procedure. By positioning a sharp blade at a certain distance from the surface to be coated, a process known as "doctor blade coating" is employed to create films [11].

To prevent cracking or causing the fracture of the film, the coated plate is held in a furnace at 450° C for 30 minutes until being allowed to cool naturally and slowly to room temperature. This procedure, known as the annealing process, results in a rise in the size of the crystals, the elimination of organic compounds from the precursor paste, and the formation of an electron transport network in sintered granular structures that have good contact with FTO substrate [12]. For efficient dye anchoring on the film, the manufactured bare photo-anode was submerged in a filtrated dye solution for 24 hours in a dark room at room temperature, without interruption [13].

2.3 PREPARATION OF COUNTER ELECTRODE:

A sensitised TiO₂ based photo-anode cast with liquid electrolyte and a counter electrode are fixed to construct the dye-sensitized solar cell (DSSC). Using 6HB pencils, the carbon is applied to the conducting surface of an FTO plate to prepare the counter electrode. This carbon-coated film was annealed at 450°C for 30 minutes and allowed to cool naturally. After that, it is washed with ethanol to get rid of any unreacted carbon on the film's surface. As a result, the counter electrode with a carbon coating is utilised as a catalyst to increase cell efficiency [14].

2.4 PREPARATION OF ELECTROLYTE:

Solvent, ionic conductor, and additives are the three main elements that make up liquid electrolytes. Using a rice pellet and acetonitrile, 0.83 g (0.5 M) potassium iodide (KI) and 0.127 g (0.05) iodine were mixed to produce an iodide electrolyte solution in this experiment. The mixture was stirred for 30 minutes without the use of any other additives [15], because it is the case that a more prominent influence of additives on the photo-anode reduces DSSC efficiency [16]. Transport of internal charges between the photo-anode and counter electrodes as well as dye regeneration are carried out by the electrolyte. It is important in estimating photocurrent density (J_{sc}) since it may be influenced by the redox couple's charge transport, photovoltage (V_{oc}), which is caused by the electrolyte's redox potential, and fill factor (FF), which is caused by the diffusion of charge carriers in electrolytes.

2.5 FABRICATION OF DSSC:

The dye-sensitized solar cell (DSSC) is assembled by fixing a TiO₂ based photo-anode cast with liquid electrolyte and Counter electrode. On the Counter electrode, the dye-sensitized photo-anode will be placed with its

downward face. To connect with the crocodile clips as an output terminal, it should be slightly offset. Also, by positioning two electrodes at the film's borders, the electrolyte was squeezed against them. By means of capillary action, the electrolyte was pulled in between the electrodes.

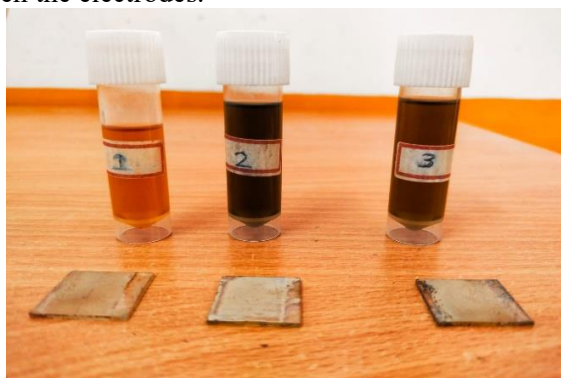


Fig 1: Extracted dyes and coated photoanode with dyes.

3. CHARACTERISATION AND MEASUREMENTS:

Using V-770 JASCO UV-VIS-NIR spectrophotometer, the extracted dye's UV and visible area absorption spectra are investigated. FP8300 JASCO FTIR spectrometer is used for quantitative assessment of the presence of different functional groups in the dye extract. FP8300 spectrofluorometer analysis was done on the electronic photo-anode structure that was fabricated. Using a KEITHLY 6517B electrometer and the Peccell solar simulator as an input power source, the total efficiency of the built cell was assessed.

3.1 UV-Vis SPECTROSCOPY:

UV-Vis spectroscopy is an analytical technique that measures the amount of discrete wavelengths of UV or visible light that are absorbed by or transmitted through a sample in comparison to a reference or blank sample. The light absorbance capability of the extracted dye and TiO₂ dye-anchored photo-anode is measured using UV measurement instrument Jasco UV-V770. The light absorption capability of extracted dyes from combretum indicum flower (F), combretum indicum leaves (L) and Mixed (M) as sensitizer, dye sensitized photoanode combretum indicum flower (FA), combretum indicum leaves (LA), Mixed (MA) and bare TiO₂ photoanode (BA) are studied using UV-V is spectroscopy. In figure 2(a), the absorption spectra of the extracted dye is compared. It is evident that the absorption of the dyes from the graph indicates that the wavelength takes near ultra violet region and passes on to the visible region of the spectrum for all the extracted dyes. In general leaves consist of chlorophyll which is essential for preparation of food in plants. chlorophyll absorption ranges from 600 to 700nm in electromagnetic spectrum (17). It is clear evident from the graph (2) that chlorophyll is present in the extracted dye at the visible region. The sensitizer (L) makes the highest peak at 666nm and sensitizer (M) making the highest peaks at 405, 418 and 670nm represents the presence of chlorophyll. The sensitizer (L) had made a wider and broader absorption levels in both UV and visible region of spectrum, this confirms that it has both active ingredients present in the individual dye and making it more efficient in light harvesting. The works of Giuseppe Calogero for *Undaria pinnatifida* and Andery Lim et al. (17) for *Cladophora* obtained a similar kind of absorption spectra when comparing with M sensitizer and exhibited a good photoconversion efficiency.

In the figure 2 (b-d) compares the absorption spectra after sensitizing the dye on the photoanode and bare anode. In figure 2b and 2c, the absorbance rate of individual photoanode (FA, LA) in visible region of the spectrum is increased more broadly and smoothly when comparing with the BA. This increase in absorption in visible region is mainly due to the anchorage of dye molecule which makes dense coverage of the dye on the TiO₂ film [18]. Whereas in figure 2d, the absorbance rate for Mixed anode is almost equal when compared with the Bare Anode. This is due to the dye molecule that binds on top of another dye molecule instead of TiO₂ surface, this may contribute to the lower photovoltaic function as it could not effectively interact with TiO₂ surface for proper electron injection [19] and due to poor interactions between the dye molecules and TiO₂ molecule [20]. The absorption of dye molecule determines the efficiency of a device, if dye molecules are not covered properly on the TiO₂ surface then the reaction between electron injection and tri-iodide ion takes place in back electron transfer. In the case of highly loaded films with dye also results in lowering the efficiency this is because the injection of electron decreases due to multilayer adsorption [21]. Therefore, this suggest that the individual sensitized photoanode (FA, LA) perfectly suitable for harvesting of the light in DSSC mechanism.

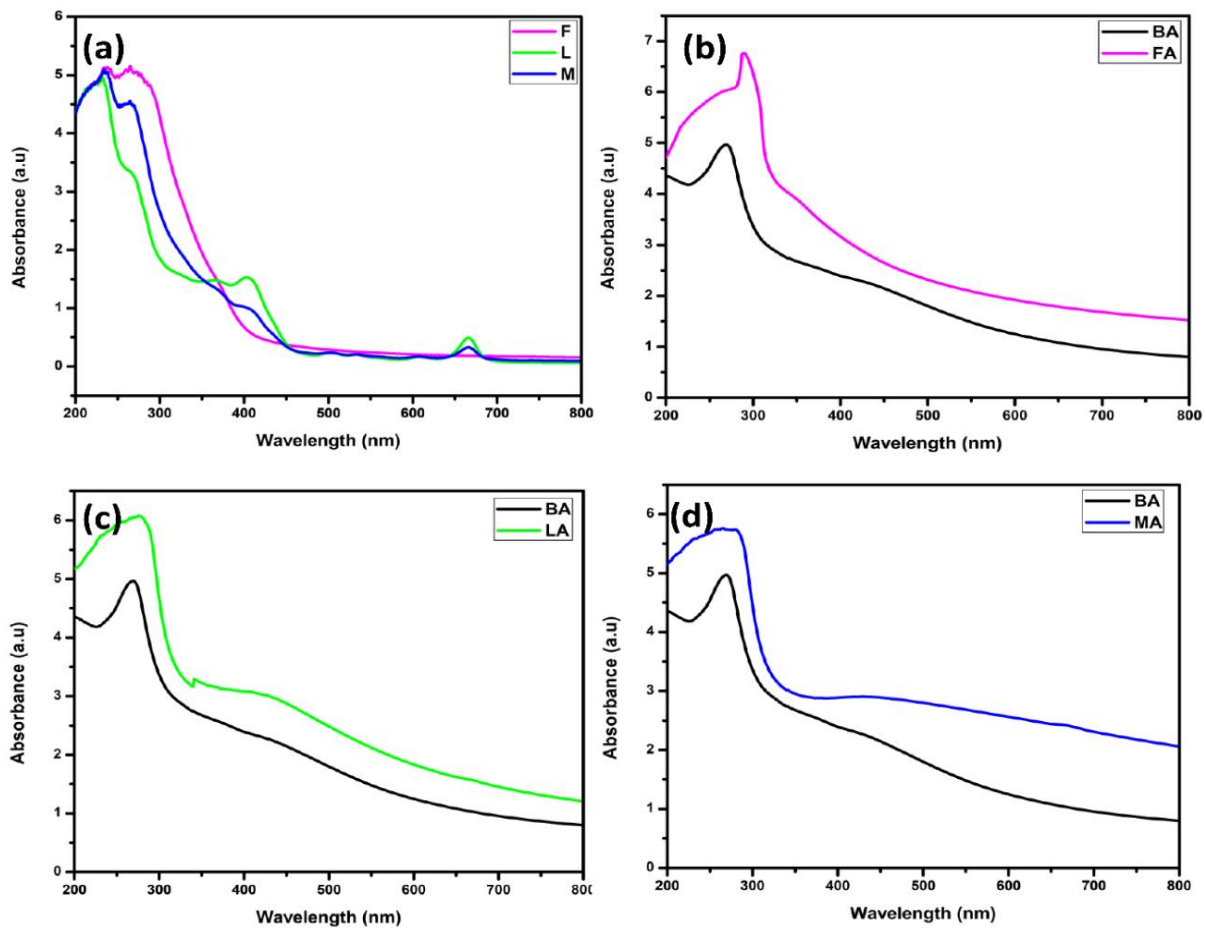


Figure 2: a) Absorption spectra for extracted dyes b) comparison of absorption spectra for bare photoanode(BA)and leaf (FA) c) leaf anode(LA) and d) mixed anode (MA).

3.2 PHOTOLUMINESCENCE SPECTROSCOPY(PL):

Photoluminescence emission spectra is widely used to investigate photo carrier generation, such as immigration, transfer and recombination. In this study it compares the separation efficiency of photogenerated electron and holes for the fabricated photoanode (FA, LA, MA). Fluorescence emission spectra was studied using 250nm at room temperature as an excitation source. Photoluminescence emission spectroscopy showed same kind of emission pattern for all the dye sensitized photoanode with varying in their intensities. The peak at 380nm shows that it is attributed to the band-edge emission of the spectra. Smaller peaks present in all the three films are observed due to the transition involved in the recombination of electrons because of intrinsic oxygen vacancies and surface defects present in the dye coated photoanode. In the same way the highest peak is at 280nm and second highest peak at 470nm this is due to back electron transport resulting in dark current and it is known that efficiency of electron transfer is determined from the degree of recombination rates (22). From this analyse it is clear that intensity of emission spectra for FA has relatively lower intensity, when compared with the other anodes MA, GA and says that electrons and holes are very hard to recombine in this state. In general, the lower intensity values in PL refers to the less charge carrier recombination rate whereas higher PL intensity indicates a higher charge carrier recombination rate, which could be unfavourable for exhibiting higher photocatalytic properties in photo-anode. In higher intensity there are more number of free electrons are available so that effective light harvesting is established by inhibiting recombination. Hence all the films, exhibit lower PL intensity value in the visible region of the spectrum and showed good photocatalytic properties. In addition, higher PL intensity indicates the longer lifetime of carrier thereby enhancing the Voltage of the device. Therefore, all the fabricated dye sensitized photoanode can assist the free electron in effective light harvesting.

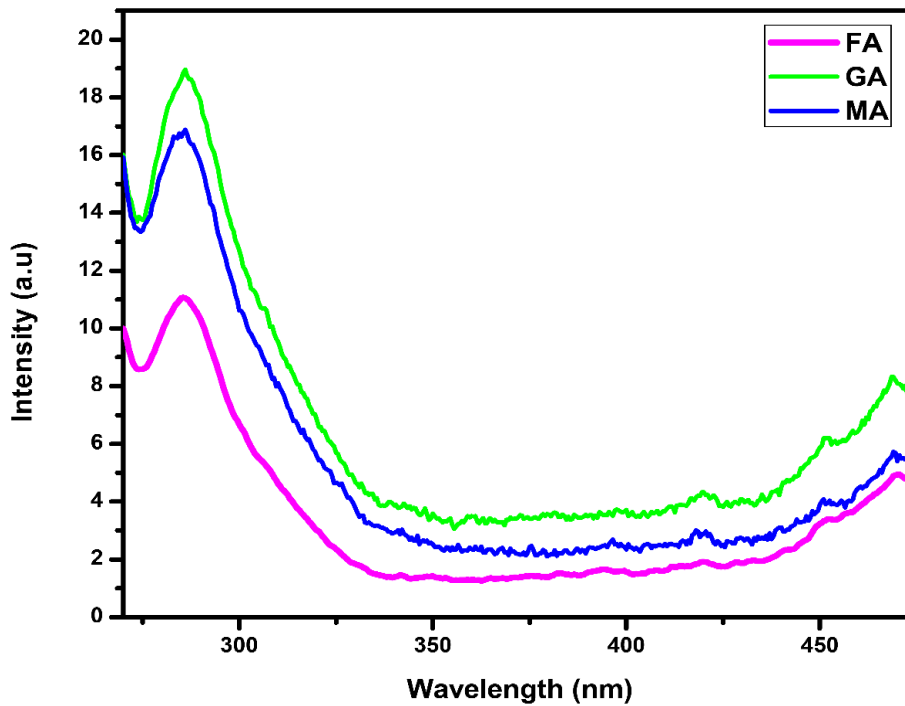


Figure 3: PL spectra for photoanodes (FA, GA, MA).

3.3 FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR):

FT-IR spectroscopy were studied for the identification of functional group of extracted dye and to analyses the electron transport rate. To enhance the electron transportation rate the adsorption of the coated TiO_2 should be higher. For the effective adsorption, the dye molecule should possess some functional group, which leads to the photon to electron conversion rate (23). It was mentioned in the previous report, presence of functional group such as hydroxyl (-OH), esters and carbonyl (C=O) in the dyes are responsible for chemical adsorption of dyes on the surface of nanostructured TiO_2 film (24,25,26). The figure(4) represents the FTIR transmission spectra for the extracted dyes. FTIR spectra obtained are almost similar for all three sensitizers ranging from 4000 cm^{-1} to 400 cm^{-1} . These shows the presence of functional group. The four major peaks observed at **F** is at 3354.08 cm^{-1} , 2974.66 cm^{-1} , 1083.0 cm^{-1} , 876.88 cm^{-1} . The similar peaks are absorbed for **L** at 3340.1 cm^{-1} , 2973.7 cm^{-1} , 1083.3 cm^{-1} , 878.417 cm^{-1} and absorption for **M** at 3351.68 cm^{-1} , 2974.66 cm^{-1} , 1083.8 cm^{-1} , 878.26 cm^{-1} .

The appearance of the peaks at 3350 cm^{-1} to 3200 cm^{-1} contributes to the strong bond appearance in the region. This peaks corresponds to the presence of intermolecular hydrogen bond O-H stretching vibration and the dye belongs to the phenol group.

The appearance of the peaks at 3000 cm^{-1} to 2840 cm^{-1} contributes to the medium bond appearance in the region. The peaks observed at 2973.7 cm^{-1} , 2974.66 cm^{-1} corresponds to the presence of C-H stretching vibration and the dye belongs to the alkane group.

The appearance of the peaks at 1085 cm^{-1} to 1050 cm^{-1} contributes to the strong bond appearance in the region. The peaks observed at 1083.3 cm^{-1} , 1083.8 cm^{-1} corresponds to the presence of C-O stretching vibration and the dye belongs to the primary alcohol group.

The appearance of the peaks at 890 cm^{-1} to 870 cm^{-1} contributes to the strong bond appearance in the region. The peaks observed at 1083.3 cm^{-1} , 1083.8 cm^{-1} corresponds to the presence of C=C bending vibration and the dye belongs to the alkene group. The extracted dyes F, L, M, confirms the presence of functional groups like O-H, C-H, C-O and C=C group. The presence of O-H group plays a major role in adsorption of dye onto the TiO_2 surface.

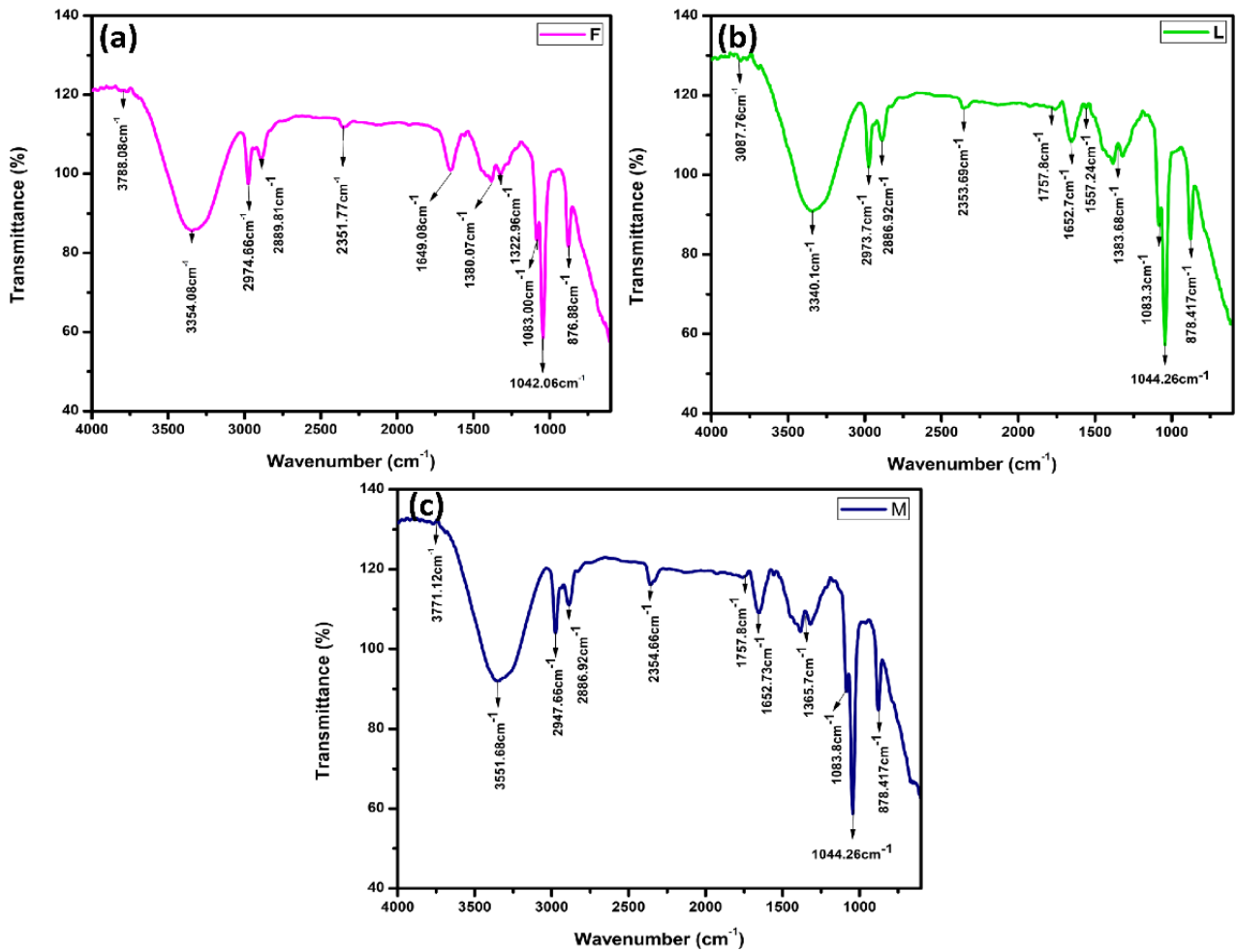


Fig4: FTIR Adsorption spectra for sensitizers (F, L, M)

3.4 J-V CHARACTERISTICS:

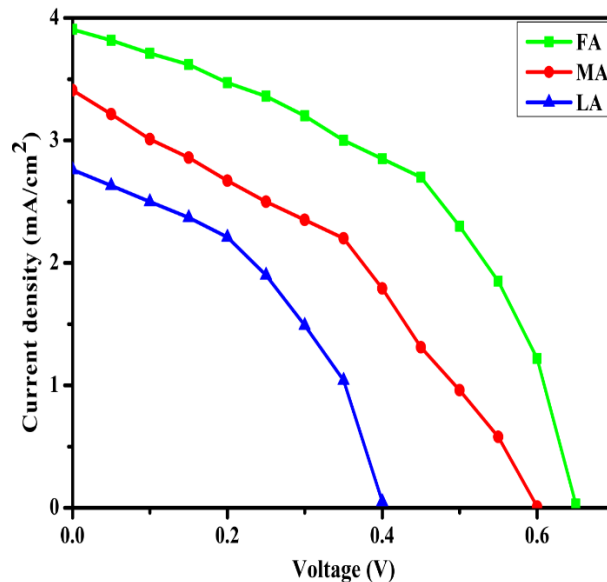


Fig5: J-V Characteristics curve for the photoanodes(FA, MA, LA).

Electrical parameters of assembled cells such as fill factor (FF) and overall efficiency (η) were obtained by substituting the values derived from the J-V graph. Short circuit current (J_{sc}), open-circuit current (V_{oc}), maximum current density (J_{max}), max voltage (V_{max}), and intensity of input power (P_{in}) were substituted in the following equations.

$$FF = \frac{J_{max} \times V_{max}}{J_{sc} \times V_{oc}}$$

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{P_{in}}$$

J-V characteristics of the three different DSSCs using FA, LA, and MA were obtained via front illumination, as shown in Figure 5. The electrical parameter for all three cells have been calculated and listed in Table 1.

From Table 1, it has been clear that the J_{sc} value of all three cells is in the order of UV absorption spectra. Because there would be a more significant number of dye molecules anchored on the active surface of photo-anode, which in turn, enhance the transport of electron injection; resulting in an increase in J_{sc} , i.e, in the order of FA (3.9 mA cm^{-2}) > MA (3.4 mA cm^{-2}) > LA (2.7 mA cm^{-2}). V_{oc} reflects the difference in potential between TiO_2 (fermi-level) and electrolyte (redox potential). Thereby dye coverage over photo-anode is indirectly proportional to the recombination rate. The recombination rate decreases when dye coverage increases by blocking the reduction site and stoppage of the back electron transfer, leading to higher V_{oc} [24]. Thereby both J_{sc} and V_{oc} are significant factors in determining the efficiency of the fabricated cell.

It is observed that short circuit current density (J_{sc}) has increased as absorption increases. The reduction of energy band gap occurs with an increase in absorption [25,26]. Hence, higher efficiency in DSSC is established by effective electron transfer and enhanced absorption in the device along with higher V_{oc} . Table1 compare the conversion efficiencies and photovoltaic performance of N-DSSCs.

Table 1: Electrical parameter of fabricated N-DSSC

Dye	Sample Name	Solvent used for dye extract	Metal oxide	JSC (mA/cm^2)	VOC (V)	FF	η (%)
combretum indicum(flower+leaf)	MA-DSSC	Ethanol	TiO_2	3.4	0.60	0.377	0.51
combretum indicum(flower)	FA-DSSC	Ethanol	TiO_2	3.9	0.65	0.470	0.79
combretum indicum(leaf)	LA-DSSC	Ethanol	TiO_2	2.7	0.40	0.398	0.29

4.CONCLUSION:

N-DSSCs were successfully fabricated using extracted dyes from combretum indicum flower (F), combretum indicum leaf (L) and mixed sensitizer (M). UV-Vis spectras revealed that, the absorption rate of individual photoanode have a great significant in harvesting the photons. FT-IR confirmed the presence of O-H group in the extracted dyes, so that the dye molecules can bond with TiO_2 and transfer excited electron from sensitizer from the valence band to the conduction band of metal oxide. Good photocatalytic properties have been exhibited by all three photoanode (such as MA, FA and LA) because of higher PL intensity.

J-V Characteristics for FA incorporated with N-DSSC shows higher efficiency (0.79%) than other photoanode (MA, LA) incorporated with N-DSSC.

REFERENCES:

- 1) Sharma, Shruti Jain, Kamlesh Sharma, Ashutosh Preface: Solar Cells: In Research and Applications—A Review (2015) doi: [10.4236/msa.2015.612113](https://doi.org/10.4236/msa.2015.612113).
- 2) B. O'Regan, M. Gratzel. A low-cost, high-efficiency solar cell based on dyesensitized colloidal TiO_2 films. Nature, 353, 737– 740 (1991) doi:[10.1038/353737a0](https://doi.org/10.1038/353737a0)
- 3) Sharma, K., Sharma, V., & Sharma, S. S. Dye-sensitized solar cells: fundamentals and current status. *Nanoscale research letters*, 13, 1-46.(2018). <https://rdcu.be/dnMRu>
- 4) H. Iftikhar, G.G. Sonai, S.G. Hashmi. S.G, A. F. Nogueira and P.D. Lund. Progress on Electrolytes Development in Dye-Sensitized Solar Cells. *Materials* 12 1-68 (2019). <https://doi.org/10.3390/ma12121998>
- 5) Hanna Ellis, Susanna K. Eriksson, Sandra M. Feldt, Erik Gabrielsson, Peter W. Lohse, Rebecka Lindblad, Licheng Sun, Håkan Rensmo, Gerrit Boschloo, and Anders Hagfeldt. *The Journal of Physical Chemistry C* **2013** 117 (41), 21029-21036DOI: [10.1021/jp403619c](https://doi.org/10.1021/jp403619c)

- 6) S. Shalini, R.B. Prabhu, S. Prasanna, T.K. Mallick, S. Senthilarasu. Review on natural dye sensitized solar cells: Operation, materials and methods. *Renewable and Sustainable Energy Reviews*. 51 1306-1325 (2015). <https://doi.org/10.1016/j.rser.2015.07.052>
- 7) H. Chang, M. Kao, T. Chen, C. Chen, K. Cho. Characterization of natural dye extracted from wormwood and purple cabbage for dye-sensitized solar cells. *J. Photoenergy*. 159502 1-8 (2013). <https://doi.org/10.1155/2013/159502>
- 8) S. Na-Phattalung, M.F. Smith, K. Kim, M.H. Du, S.H. Wei, S.B. Zhang, S. Limpijumnon. First-principles study of native defects in anatase TiO₂ *Phys. Rev. B*; 73(12), 125205: 1- 6 (2006). DOI: <https://doi.org/10.1103/PhysRevB.73.125205>
- 9) K. Wongcharee, V. Meeyoo, S. Chavadej, *Sol. Energy Mater. Sol. Cells*. 91, 566 (2007). <https://doi.org/10.1016/j.solmat.2006.11.005>
- 10) . R. G. Gordon. *MRS Bull*, Criteria for Choosing Transparent Conductors, 25, 52– 57, (2000). DOI: <https://doi.org/10.1557/mrs2000.151>
- 11) Cherrington, R., & Liang, J. Materials and deposition processes for multifunctionality. *Design and Manufacture of Plastic Components for Multifunctionality: Structural Composites, Injection Molding, and 3D Printing*, 19-21.(2016)
- 12) Y. Chen, E. Stathatos, D.D. Dionysiou. sol-gel modified TiO₂ powder films for higher performance dye- sensitized solar cells. *A.*, 203 (2-3), 192-19 (2009). <https://doi.org/10.1016/j.jphotochem.2009.01.019>
- 13) A. Kumar, S. Mukherjee, S. Sahare, R.K. Choubey. Influence of deposition time on the properties of ZnS/p-Si heterostructures. *Materials Science in Semiconductor Processing*, 122, 105471 (2021).
- 14) V.K. Magotra, T.W. Kang, A.T.A. Ahmed, A.I. Inamdar, H. Im, G. Ghodake, R.K. Choubey, V. Kumar, S. Kumar. Effect of gold nanoparticles laced anode on the bioelectro-catalytic activity and power generation ability of compost based microbial fuel cell as a coin cell sized device. *Biomass and Bioenergy*, 152, 106200 (2021). <https://doi.org/10.1016/j.biombioe.2021.106200>
- 15) B. O'regan, M. Gra'tzel, *Nature* 353, 737 (1991)
- 16) M.C. Mathpal, P. Kumar, A.K. Tripathi, R. Balasubramaniyan, M.K. Singh, J.S. Chung, A. Agarwal, *New. J. Chem.* 39, 6522 (2015)
- 17) R. Syafinar, N. Gomesh, M. Irwanto, M. Fareqa, Y.M. Irwana. Chlorophyll Pigments as Nature Based Dye for Dye-Sensitized Solar Cell (DSSC), *Energy Procedia* 79, pp. 896902 (2015). <https://doi.org/10.1016/j.egypro.2015.11.584>
- 18). B.Q. Liu, X.-P. Zhao, W. Luo. The synergistic effect of two photosynthetic pigments in dye-sensitized mesoporous TiO₂ solar cells, *Dyes and Pigments*, vol. 76, no. 2, pp. 327–331, (2008). <https://doi.org/10.1016/j.dyepig.2006.09.004>
- 19). R. Kato, N. Fuke, A. Furube, N. Koide. Effect of dye coverage on photo-induced electron injection efficiency in N719-sensitized nanocrystalline TiO₂ films, *Chem. Phys. Lett.* 489(4-6), 202-206 (2010). <https://doi.org/10.1016/j.cplett.2010.02.076>
- 20) S. Ito, H. Miura, S. Uchida, M. Takata, K. Sumioka, P. Liska, P. Comte, P. Pechy, M. Gra'tzel. High-conversion-efficiency organic dye-sensitized solar cells with a novel indoline dye. *Chemical Communications*, (41), 5194. doi:10.1039/b809093a *Chem. Commun*, 5194–5196, (2008).
- 21). A.C. Khazraji, S. Hotchandani, S. Das, P.V. Kamat. Controlling Dye (Merocyanine- 540) Aggregation on Nanostructured TiO₂ Films. An Organized Assembly Approach for Enhancing the Efficiency of Photosensitization. *The Journal of Physical Chemistry B* .103, 4693 (1999). <https://doi.org/10.1021/jp9903110>
- 22) Yi-Hua Fan, Ching-Yuan Ho and Yaw-Jen Chang Department of Mechanical Engineering, Chung Yuan Christian University, Chung-Li, Taiwan(2017).
- 23) N.A. Ludin, A.A.A. Mahmoud, A.B. Mohamad, A.A.H. Kadhum, K. Sopian, N.S.A. Karim, Review on the development of natural dye photosensitizer for dyesensitized solar cells. *Renewable and Sustainable Energy Reviews*, 31, 386–396 (2014).
- 24) W. Maiaugree, S. Lowpa, M. Towannang, P. Rutphonsan, A. Tangtrakarn, S. Pimanpang, P. Maiaugree, N. Ratchapolthavisin, W. Sang-Aroon, W. Jarernboon. A dye sensitized solar cell using natural counter electrode and natural dye derived from mangosteen peel waste. *Sci. Rep.-Uk* 5,15230, (2015). <https://doi.org/10.1038/srep15230>
- 25). I.C. Maurya, A.K. Neetu, P. Gupta, L. Bahadur, Srivastava. Callindra haematocephata and Peltophorum pterocarpum flowers as natural sensitizers for TiO₂ thin film-based dye-sensitized solar cells. *Opt. Mater.* 60 ,270, (2016).
- 26) T.G. Vignesh Prabhu, J. Chandrasekaran, D. Thangaraju, et al. Fabrication and performance analysis of set standard natural dye-sensitized solar cell (n-dssc). *J mater sci: mater electron* 33, 17331–17342 (2022). DOI:10.1007/s10854-022-08611-0.