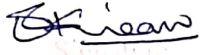


KAKATIYA GOVERNMENT COLLEGE
HANUMAKONDA

Name : D.S.Kiran
Designation : Asst. prof. of physics
Year of Award of Ph.D. : 2022
Name of the University : Osmania University
Year of entering into Govt. Service : 30.08.2020

S. No.	Details of copies of Certificates	Remarks
1	Copy of Ph.D Certificate	Enclosed
2	Press note	Enclosed
3	Research work dates of seminars and Pre-Ph.D Date of joining in this college 30.08.2020	Enclosed
4	Details of Ph.D Admission-part time or full time Part time - 21.10.2010	Enclosed
5	Copies of RDC Approval letters of Ph.D	Enclosed
6	Name of guide/supervisors with mobile number, email id : Dr.G.Vendar, 9010726691, upendarg@osmania-ac.in	Enclosed
7	Copies of guide allotment letter	Enclosed
8	No. of increments sanctioned for Ph.D.	03
9	Published Research article-copies.	Enclosed
10	Original Ph.D Thesis.- Book.	Available at office


PRINCIPAL
KAKATIYA GOVT.COLLEGE
Hanamkonda.


Dr. S. Kiran
Asst. prof of physics
KGC, Hanamkonda.

Osmania University

OU 969117



Faculty of *Science*



This is to certify that Hiran Purasi
son / daughter of Saraiiah
having pursued a course of study prescribed by this University
and having passed the requirements by Examination and by
thesis has been admitted to the Degree of

Doctor Of Philosophy

in the Subject of Physics

The title of the Thesis is :

Development of Nanocomposites for Dye Sensitized Solar Cells (DSSCs)
Applications

The candidate has been declared qualified for the award of the
Degree of Ph.D. on 08 Sep 2022

Given under the seal of the University



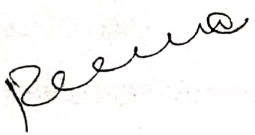


CN102380601



Hyderabad, T.S.
Dated Kartika 9, 1945
October 31, 2023


Vice-Chancellor

Degree Prepared, Verified & Compared by

Prepared by	Section Incharge	Controller of Examinations
		



CONFIDENTIAL SECTION
EXAMINATION BRANCH
NO. 631/Ph.D/Exams/2022

OSMANIA UNIVERSITY
HYDERABAD-500 007,T.S.
Dated: 08 Sep, 2022

PRESS NOTE

The following candidates who had presented the Thesis on the subject mentioned against each for the degree of Ph.D are declared qualified for the award of Degree of Doctor of Philosophy (Ph.D.) of Osmania University, Hyderabad.

Ph.D.

S.N	Reference No.	Name of the Candidate/ Father Name	Subject	Thesis Title	Supervisor/ Regn. Date
1	PHD43280	Mr. Rekha Venkateswarlu S/o. Rekha Kotaiah	Physics	Studies of Enhanced Ionic Transport in Nano Dispersed Sodium, Potassium and Barium Nitrate Composite Solid Electrolyte Systems	Prof. A Sadananda Chary Dept. of Physics, O.U., Hyd. (08/06/1999)
2	PHD43281	Mr. Varukolu Mahipal S/o. Narsaiah	Chemistry	Synthesis, Spectrophotometric, Spectroscopic Characterization and DFT/TD-DFT/PCM Computations of New Organic Donor- π - Acceptor Charge Transfer Complexes and their Applications	Prof. V Manaiah (Retd.) Dept. of Chemistry, O.U., Hyd. (25/01/2017)
3	PHD43282	Mr. D Arjun S/o. D Saraiah	Textile Technology	Studies on the Properties of Active Cool Sportswear	Prof. J Hayavadana Dept. of Textile Technology, O.U., Hyd. (27/03/2017)
4	PHD43283	Ms. Tulja Bhavani D/o. Jaswanth Lal	Commerce	Human Resource Accounting and Reporting-A Study of Select Companies	Prof. V Usha Kiran Dept. of Commerce, O.U., Hyd. (02/01/2012)
5	PHD43284	Mr. Kiran Surasi S/o. Saraiah	Physics	Development of Nanocomposites for Dye Sensitized Solar Cells (DSSCs) Applications	Dr. G Upender Asst. Professor, Dept. of Physics, Nizam College, Hyd. (21/10/2010)
6	PHD43285	Mr. M V Patwardhan S/o. M V Ramkishan Rao	Telugu(Oriental)	Sri Madipally Bhadrachari Gari Rachanalu-Samagra Parishilana	Dr. T Sreenivasulu Faculty of Ori. Languages, O.U., Hyd. (20/03/2017)

Copy forwarded to:

1. The Candidate _____
2. P.A. to Controller of Examination, O.U.
3. The Dean, Faculty of Commerce / Oriental languages / Science / Technology , O.U.
4. The Chairperson, BOS in Biotechnology/ Chemistry/ Commerce/ Physics/ Telugu(Oriental)/ Textile Technology, O.U.
5. The Head Dept of Biotechnology/ Chemistry/ Commerce/ Physics/ Telugu(Oriental)/ Textile Technology/Journalism, O.U.
6. The Secretary to the Vice-Chancellor/P.A. to Registrar, O.U.
7. The Deputy Registrar/ Accounts/ Admin/ Academic/ UGC Cell, O.U.
8. The Librarian, General Library, O.U.
9. The Public Relations Officer, O.U.
10. The Cheif Warden, Hostel and Messes, O.U.
11. The ACOE(EDP), Examination Branch, O.U.
12. The Director, Infrastructure, Admin. Buildings, O.U.
13. The Secretary, Assoc. of Indian Universities, 16, Kotla Road, New Delhi-110002
14. The Director, Research Division, Assoc. of Indian Universities, 16, Kotla Road, New Delhi-110002
15. The Secretary, UGC, 35, Feroz Shah Road, New Delhi-110002
16. The Editor, University News, AIU Campus, Kotla Road, New Delhi-110002
17. The Senior Statistical Officer, U G C, (Info & Stats Bureau), 35, Feroze Shah Road, New Delhi - 110 221.
18. The Local Press (through DIPR), Govt. of T.S., Hyderabad.
19. The Examiner _____

With a request to send the remuneration bill dully filled in immediately and also to return the copy of the Thesis/Dissertation if it is not done so far.



Department of Physics
University College of Science
Osmania University, Hyderabad – 7

Mr. S. Kiran, Research scholar, working under the supervision of Dr. G. Upender has presented the Pre-submission Seminar on 05-01-2022 in the Department of Physics, University College of Science, Osmania University as a part of pre-condition before submitting the thesis. The topic of his research work is “Development of Nanocomposites for Dye Sensitized Solar Cells (DSSCs) Applications” He has explained the details of the research work carried out and the organization of the thesis. He has answered the questions raised by the faculty and research scholars.

The quantum of work carried out and the explanation offered to interpret the results obtained are quite satisfactory and therefore, the committee recommends the submission of the thesis to the Osmania University for necessary further action.

(Prof. D. Karuna Sagar)

HEAD

DEPARTMENT OF PHYSICS
OSMANIA UNIVERSITY

(Prof. M. Srinivas)

CHAIRMAN

BOARD OF STUDIES IN PHYSICS
DEPARTMENT OF PHYSICS
OSMANIA UNIVERSITY

(Dr. G. Upender)

SUPERVISOR

DEPARTMENT OF PHYSICS
OSMANIA UNIVERSITY



**OFFICE OF THE DEAN
FACULTY OF SCIENCE
UNIV. COLLEGE OF SCIENCE
OSMANIA UNIVERSITY
HYDERABAD - 500 007**

6437

No. /DFSc/2008

Date: 12 MAY 2008

ORDERS

Sub: Faculty of Science – Admission to Ph.D. Course for the year 2006-2007–
Orders - Issued

Ref: O.U. Notification No. 230/Ph.D./2007/Acad, dated 21.8.2007

...

The candidates in the enclosed list are provisionally admitted to the Ph.D. course of Osmania University for the academic year 2006-2007 on the recommendation of the Admission Committee in the Faculty of Science in the subject mentioned against his/her name.

The selected candidates are required to fulfill the conditions, if mentioned against their names, and to submit their Joining Reports (Proforma provided), by **2.6.2008** failing which their admission orders would be deemed to have been withdrawn. No further notice will be given. The Joining Reports along with the original D.D. and all necessary documents duly forwarded by the Supervisor(s) and the concerned Head of the Department of Osmania University should be submitted by the prescribed date to the Dean, Faculty of Science, Osmania University. **No joining report will be accepted without the T.C. (Transfer Certificate) in original or a letter from the respective University where from the Post Graduate Degree has been obtained to the effect that no separate Transfer Certificate will be issued by that University.** The Dean's office shall then issue a list of names of the admitted candidates to the Heads of the Departments concerned, which shall be final.

The registration is valid for a period of four years for Full Time Research Scholars and five years for Part Time Research Scholars from the date of joining after which period it will be cancelled unless otherwise extended. The candidates should submit half yearly progress reports on their work through the Supervisor and concerned Head of the Department regularly. Irregularity in submission of progress reports will make the candidates liable for cancellation of registration as per rules.

All the selected candidates both Full-Time and Part-Time have to pay the fee as under:

1. Both Full Time and Part Time Scholars .. Rs.2000 per year
working in the Osmania University
2. Scholars working in recognised Research
Centres outside the University .. Rs.5000 per year

through a demand draft in favour of "Dean, Faculty of Science, Osmania University." They should submit their Joining Reports to their Supervisor in the prescribed proforma in triplicate along with the Original DD., and M.Sc., Certificate (Xerox Copy) in proof of satisfaction of the conditions stipulated.

If the candidate fails to pay the fees mentioned above within the specified time his/her admission will be cancelled without further notice to the candidate.

The selected candidates are required to submit an undertaking to the effect that they do not ask for hostel facilities (Annexure II) along with their joining reports, failing which they will not be granted admission.

Candidates selected under the category "Part Time" are required to submit an undertaking in triplicate on the proforma provided (Annexure-III) that they would be taking necessary leave as per rules of the University and would be submitting the leave sanction letter from their office within three months from the date of joining as research scholars.

Their admission is conditional upon realization of dues to the University if any from the candidates.

All provisionally admitted candidates are permitted to attend Pre-PhD., classes to be held in the concerned Department. They have to appear for the Pre-Ph.D., examination on the dates to be announced in due course by the Controller of Examinations, O.U. In case the candidate does not appear or fails to pass the Pre-Ph.D. examination within the two consecutive chances, his/her admission would be cancelled without further reference to the candidate.

S.N	Name of the Candidate	Department	Name of the Supervisor	Status	Place of Work
1	Kiran Surasi	Physics	Dr.S.Ramana Murthy	Part Time	Osmania

U. V. Surasi
DEAN
Faculty of Science
 Osmania University
 HYDRABAD-500'007..

: 3 :

The admissions are made on the basis of the present occupation of the candidates. In case there is a change in occupation or place of work during the period of their candidature in the Ph.D., course, their admission is liable to be cancelled. Any change in their occupation should be brought to the notice of the Dean, through the Supervisor and the Head of the Department, and the Dean may permit the candidate to continue his/her Ph.D. course as per the rules.

The candidates who are admitted to the Ph.D. course shall not pursue any other course or appear for any other examination leading to any other Degree (both Full-Time and Part-Time) of this University or any other University. Any violation of this regulation will lead to the cancellation of admission.

U.V. Suresh
DEAN 12/05

Faculty of Science, O.U.

To

The Research Scholar concerned.

Copy forwarded for information and necessary action to:-

1. Principal, University College of Science, O.U.
2. The Vice Principal, Hostels, Univ.College of Science, O.U.
3. The Head, Department of.....,O.U.
4. The Controller of Examinations, O.U.
5. The Addl. Controller of Examinations (Confidential), O.U.
6. The Dean, Development and UGC Affairs, O.U.
7. The Joint Registrar (Academic),O.U.
8. The Librarian, University Library, O.U.
9. The Secretary to Vice-Chancellor, O.U.
10. The Officer on Special Duty to Vice-Chancellor, O.U.
11. The P.A. to Registrar, O.U.
12. The Chief Warden, Hostels & Messes, O.U.
13. All Constituent Colleges / Research Centres concerned.





OSMANIA UNIVERSITY PA214946

MEMORANDUM OF MARKS

Examination PRE Ph.D NOVEMBER 2010
FACULTY OF SCIENCE

REF NO.: 5661

DATE: 03/02/2011

NAME: KIRAN SURASI

ROLL NO.: 100709558001

FATHER'S NAME: SARAI AH

SL. NO.	SUBJECT NAME	UNIVERSITY EXAMINATION		RESULT
		MAXIMUM MARKS	MARKS SECURED	
1	RESEARCH METHODOLOGY	100	70	PASS
2	SPECIALISATION (BROAD FIELD)	100	56	PASS
TOTAL		200	126	
GRAND TOTAL		===	===	

TOTAL IN WORDS: ONE TWO SIX

GRAND TOTAL AT THE END OF THE COURSE : ===

RESULT: PASS

CLERK-IN-CHARGE

SUPERINTENDENT

CONTROLLER OF EXAMINATIONS



**JOINING REPORT OF Ph.D./M.Phil. COURSE,
FACULTY OF SCIENCE, OSMANIA UNIVERSITY**

1. Name :: S. KIRAN

2. Father's Name :: S. SARAIAH

3. Details of Scholarship if any :: _____

4. College/Institute at which the Candidate proposes to work :: Department of PHYSICS, O.U

5. Full-Time / Part-Time :: Part-time

6. Name of the Supervisor :: Prof. S. Ramana Murthy

7. Date of joining :: 21-01-2010 21-10-2010 S.N

8. Department :: Physics DEAN
Faculty of Science
OSMANIA UNIVERSITY

9. Topic of Research :: Preparation & Characterization of NanoComposites for sensor Applications

To
The Dean,
Faculty of Science

// Through Proper Channel //

Ref:

Sir,

I am herewith submitting my joining report today i.e. on 21-01-2010 21-10-2010 S.N

I have read the rules and regulations of the Ph. D. Course / M.Phil Course and I undertake to abide by them.

I understand that my admission may be cancelled, if the statements I made in my application are found to be false.

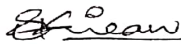
I have satisfied all conditions stipulated in my admission order and I am enclosing herewith the necessary certificates (if applicable).

LIST OF ENCLOSURES

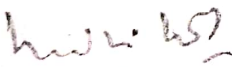
1. D.D.No: 014673 Date 04-10-2010 Amount 2000/-
- 2.
- 3.



SIGNATURE OF SUPERVISOR



SIGNATURE OF CANDIDATE



**SIGNATURE OF THE HEAD OF
INSTITUTION IN WHICH CANDIDATE
PROPOSES TO WORK**

Head of the Dept of Physics
Osmania University

**SIGNATURE OF THE HEAD
OF THE UNIV. DEPARTMENT**



SIGNATURE OF THE DEAN
DEAN

Faculty of Science
OSMANIA UNIVERSITY,
HYDERABAD-500007.



OSMANIA UNIVERSITY
HYDERABAD - 500 007

No. 1485 /F/982/2010/Acad.III

Dated: 27-9-2010

To

The Dean,
Faculty of Science, OU,
Hyderabad.

Sub:- Admission to Ph.D. programme – Admission of Mr. S. Kiran in the Department of Physics under the supervision of Prof. S. Ramana Murthy – Reg.

Ref:- Your Letter dated:9-8-2010.

Sir,

With reference to your letter on the subject cited, I am desired to communicate the approval of the University for admission of Mr. S. Kiran into Ph.D. programme in the Department of Physics under the supervision of Prof. S. Ramana Murthy as the order were already issued by the Dean, Faculty of Science during May, 2008.

Yours faithfully,

D. K. C. S. Kulkarni

ASSISTANT REGISTRAR
(Academic)

Dvd

File

SA



PHD 6568

Osmania University

Ref. No. PHD43284

Receipt no.:CN092200068

Provisional Certificate

This is to certify that KIRAN SURASI
SARAI AH
son/daughter of _____

having pursued a course of study prescribed by this University and
having passed the requisite examinations in _____
SEPTEMBER 2022

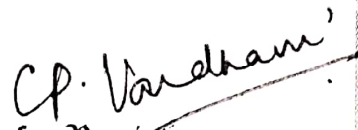
by dissertation/thesis, has been admitted to the Degree of
Ph.D. in Physics _____ in the Faculty of _____
SCIENCE

Hyderabad

Dated 24/09/2022




Section - incharge


for Registrar

PROCEEDINGS OF THE REGIONAL JOINT DIRECTOR OF INTERMEDIATE
EDUCATION: WARANGAL.

RC.NO.1230/C1-A/2011.

Date. 02-05-2011.

Sub:- APIES- Permission to the Junior Lecturers working
in the Govt. Junior Colleges to do Ph.D. on part- time
basis- Orders-Issued.

Ref:-1. Proposals from the concerned principals of Zone -V.

@@@@

In the circumstances reported by the Principals, Govt. Junior
Colleges Concerned the undersigned is pleased to accord permission to
the following **Junior Lecturers to do Ph.D. on Part - Time basis** as
detailed here under.

Sl.No.	Name of the J.L. & Place of working.	Name of the Course.	Name of the University.
1.	S.Kiran, J.L. in Physics, G.J.C. Gudur, Warangal	Ph.D.	Osmania University, Hyderabad.
2.	Mohd Abdur Rakeeb, J.L. In Economics, U/M. C. (A&C) Karimnagar.	Ph.D.	Dravidan University, Kuppam.
3.	V. Srinivas, J.L. in Commerce, G.J.C. Vemulawada, KNR. Dist.	Ph.D.	Rayalaseema University, Kurnool.
4.	D. Parvathi, J.L. in Botany, G.J.C. (Co-Edn) Manankonda, Wgl. Dist.	Ph.D.	Kakathiya University, Warangal.

The permission is hereby accorded to the above said Junior
Lecturers subject to the following conditions.

- 1). That there should not be any financial commitment to the
Government.
- 2). That his research work should be in any way detrimental
to his normal duties.
- 3). That he should not accept any financial Assistance from
any source.
- 4). That he should under take the research work at his own
Cost.
- 5). That he should under take the research work only after he is
Selected for the course.
- 6). That this permission shall not be made a ground for either
transfer or retention in further.

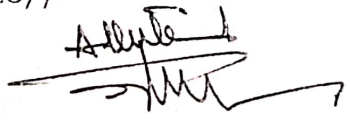
Sd/-N. JANGAMAIAH
REGIONAL JOINT DIRECTOR(FAC)

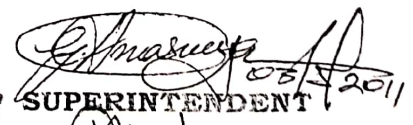
To

The individual concerned through the Principal.

Copy to the Principal's of the Govt. Jr. Colleges concerned.

// t.c.f.b.o//


Principal
GOVT. JUNIOR COLLEGE
GUDUR, Dist. Warangal.


SUPERINTENDENT
02/05/2011



OFFICE OF THE DEAN FACULTY OF SCIENCE
OSMANIA UNIVERSITY, HYDERABAD-500 007

No: 444 /DFSc/OU/2015.

Date: 17.04.2015

ORDERS

Sub: Faculty of Science – Extension to Ph.D., Course – Orders – Issued.

At the request of the following candidate and on the recommendations of the Head of Department, the period of registration for Ph.D in the Faculty of Science has been extended as detailed below. The last date for submission of his thesis is mentioned against his name:

S. No	Name of the candidate	Supervisor's name	Department	Date of joining	Reg. Extended till
✓ 1	S.Kiran (P.T.)	Dr.S.Ramanamurthy	Physics	21.01.2010	20.01.2016 *
2	P.Nagaraju (P.T)	Dr.M.V.Ramana Reddy	Physics	04.04.2008	03.04.2016 ***
3	Sair.Md.Taqiullah (P.T.)	Dr.Syed.Rahman	Physics	12.02.2009	11.02.2016 **
4	E.Shravya Puri (F.T.)	Dr.A.Sabitha Rani	Botany	07.03.2011	06.03.2016 *
5	Kiran Kumar.Thota (F.T.)	Dr.D.Karuna sagar	Physics	09.04.2008	08.04.2015 ***
6	A.Narsaiah (P.T.)	Dr.D. Karuna sagar	Physics	08.04.2008	07.04.2016 ***

First extension, 2nd ** extension 3rd *** extension

DEAN

Faculty of Science, O.U.

Faculty of Science
OSMANIA UNIVERSITY,
HYDERABAD-500 007

To

The Research Scholar concerned.

COPY to:

1. The Head, Department of Physics/Botany , UCS.O.U.
2. The Addl. Controller of Examinations (Confidential,O.U.



Preparation and characterization of $(100 - x) \text{TiO}_2 + (x) \text{ZnO}$ nanocomposites for dye-sensitized solar cells using *Beta vulgaris* and *Syzygium cumini* natural dye extract

S. Kiran¹ · T. Ramesh² · S. R. Murthy¹

Received: 28 December 2017 / Accepted: 10 May 2018
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Abstract

The present paper attempts to report the preparation of $\text{TiO}_2\text{-ZnO}$ nanocomposite photoanode materials for dye-sensitized solar cells (DSSC) and analyse the efficiency of DSSC with natural dyes. The structural and optical characteristics of the composites were studied by transmission electron microscopy, X-ray diffraction, field effective scanning electron microscopy, energy dispersive spectrometry, photoluminescence and absorption spectroscopy. The synthesized nanocomposites formed on FTO substrates are applied as photoanode in a dye-sensitized solar cell (DSC). The natural dyes extracted from *Beta vulgaris* (Beetroot) and *Syzygium cumini* (black plum) were used in the fabrication of DSSC. The solar cells' photovoltaic performance in terms of short-circuit current, open circuit voltage, fill factor and energy conversion efficiency was tested with photocurrent density–voltage measurements. The evolution of the solar cells parameters is explored as a function of the photoanode and type of dye used in DSSC fabrication. The obtained results show that the efficiency of DSSC significantly changes with the addition of ZnO to TiO_2 , while the *Beta vulgaris* dye has evidently shown higher photo sensitized performance compared to *Syzygium cumini* in the preparation of DSSC.

1 Introduction

In recent years, the development of dye-sensitized solar cells (DSSCs) has attracted much attention of researchers due to their environmental friendliness, ease of fabrication and cost-effectiveness [1–5]. A DSSC consists of a photoanode (semiconductor electrode), absorbed dye, a counter electrode and an electrolyte containing iodide and triiodide ions [6, 7]. In DSSCs, the photo-anode plays a crucial role in absorbing sunlight and converting solar energy into electric energy. An ideal photo-anode for DSSCs should have features of high specific surface area, high loading of dye molecules, fast electron transport and less interfacial electron recombination [7]. Intensive work has been devoted to the development of TiO_2 based photo-anodes due to its unique properties like, high bandgap (3.2 eV for anatase),

chemically inert, photocorrosion stability, as well as inexpensive. However, the sluggish electron mobility and high electron–hole recombination process limit the efficiency of TiO_2 during photo degradation [8]. Many attempts were made to overcome the limitation in the efficiency of the TiO_2 based DSSC such as the fabrication of bi-layer electrode [9, 10], preparation of composite semiconductor photoanode, use of different dyes etc. [11–14]. In this process, the coupling of various semiconductors has been proposed for the design of composite photoanode to decrease the rate of recombination regarding individual semiconductors. Therefore, to explore efficient photo-anode materials, efforts have been made to utilize bi-functional materials including ZnO/TiO_2 [15], $\text{SnO}_2/\text{TiO}_2$ [16], ZnO/SnO_2 [17], $\text{SrTiO}_3/\text{TiO}_2$ [18]. Particularly, ZnO based composites has attracted great attention due to its high electron mobility ($\sim 100 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$), thermal conductivity and bandgap (3.3 eV) [19].

Herein, we report the microwave hydrothermal preparation of $\text{TiO}_2\text{-ZnO}$ composite as the photoanode in DSSC for the enhancement of the energy-conversion efficiency. After the structural, morphological and optical characterization, DSSCs have been fabricated using $\text{TiO}_2\text{-ZnO}$ composite semiconductor electrode and sensitized using the extracts of

T. Ramesh
ramanasarabu@gmail.com; rameshouphysics@gmail.com

¹ Department of Physics, Osmania University, Hyderabad, India

² Department of Physics, BVRIT Hyderabad College of Engineering for Women, Hyderabad, India

Beta vulgaris (beetroot) and *Syzygium cumini* (black plum). *Syzygium cumini* dye extract has been shown to contain anthocyanin while beetroot contains betalains that are excellent light-harvesting pigments for the generation of charge carriers in the production of electricity.

2 Experimental procedure

2.1 Synthesis of ZnO and TiO₂ powders

The ZnO and TiO₂ nano crystallites were prepared by a microwave hydrothermal approach. For ZnO synthesis, firstly, 30 mL NaOH (3.2 mol/L) solution was slowly added to 30 mL Zn(CH₃COO)₂·2H₂O (1.6 mol/L) solution. For TiO₂ synthesis, 30 mL NaOH (3.2 mol/L) solution was slowly added into 30 mL TiCl₄ (1.6 mol/L) solution. These mixed solutions were transferred individually to a Teflon-lined autoclave of 50 mL capacity and then irradiated using a temperature controlled microwave synthesis system (MARS-5, CEM Corp., Mathews, NC, frequency 2.45 GHz, maximum power 1200 ± 50 W) at 180 °C for 45 min. After microwave reaction, the solution of the mixtures was cooled to room temperature. The resulting white precipitates were collected by filtration and washed with deionized water multiple times and then dried at 80 °C for 12 h in air.

2.2 Preparation of ZnO–TiO₂ composites

TiO₂–ZnO composites were prepared by mechanical mixing of synthesized ZnO and TiO₂ powders in the weight percentages defined as (100–*x*) TiO₂ + *x*(ZnO), where the weight percentages are *x* = 0, 10, 30, 50, 70, 90 and 100%. In general, TiO₂ exists in three phases: anatase, rutile and brookite. Pure brookite phase is unstable and difficult to synthesize. Pure rutile phase has limited photoactivity, and, therefore, is less photo efficient than anatase phase. For the application of TiO₂ in photocatalysis and DSSC, anatase phase of TiO₂ is considered to be more active. To attain the anatase phase of TiO₂ in composite samples, mixed powders were microwave heated at 550 °C for 90 min in the air atmosphere using a multimode cavity of 2.45 GHz microwave oven.

2.3 Natural dye extraction

A fresh *Syzygium cumini*/*Beta vulgaris* were cut into small pieces and soaked in 150 mL acetone (1:15 ratio) with stirring for 12 h at room temperature. The crude solution was filtered using filter paper to remove solid residue. Finally, the filtrate was washed multiple times with hexane to remove any oil or chlorophyll present in the extract and shielded from exposure to direct light and stored in a refrigerator at 5 °C.

2.4 Preparation of dye-sensitized solar cells

Fluorine doped tin oxide (FTO; Techinstro) conductive glass sheets were first cleaned by dipping it in detergent solution for 10 min, then sonicated using an ultrasonic bath for 5 min, rinsed with deionized water and then dried. Photoelectrodes were prepared on FTO glass slide via doctor blade technique with a glass slide and scotch tape as a spacer. To make a homogeneous slurry, prepared nano-composite powders were mixed with water, acetylacetone and Triton-X 100 in pestle and mortar. Using this slurry, thin films of area 1.0 cm × 1.0 cm were prepared, dried at room temperature, followed by annealing at 450 °C for 30 min. For sensitization, the fabricated electrodes were dipped in natural dye (*Syzygium cumini*/*Beta vulgaris*) solution for 24 h. The counter electrode was made by spin coating 5 mmol/L H₂PtCl₆·6H₂O (Chloroplatinic acid hexahydrate) in isopropyl alcohol on FTO glass and sintering it at 385 °C for 15 min. For the complete fabrication of DSSC, the sensitized electrode and the counter electrode was assembled and a few drops of electrolyte, comprising of Li, I₂, TBP and TBAI in acetonitrile, were injected in between the electrodes.

2.5 Characterization

The phase identification of as-synthesized (TiO₂, ZnO) and composite (ZnO–TiO₂) powders was carried out using X-ray diffractometer [(XRD), Philips PW 1830] using CuKα radiation with λ = 0.15418 nm. The morphological characterization of synthesized and composite samples was determined using TEM (Jeol, JEM 2100) and FESEM [(FESEM), Carl Zeiss EVO 18] respectively. The quantitative elemental composition analysis has been carried out using energy dispersive X-ray spectroscopy (EDAX; OXFORD analytical). The optical properties of composite powders were examined via UV–Visible spectrophotometer (Shimadzu Uv 1800) and photoluminescence spectra (Fluorolog 3, Horiba Jobin-Yvon). Photoluminescence (PL) spectra of the TiO₂–ZnO composites have been recorded using a 450 W xenon lamp equipped with a Fluorolog 3, Horiba Jobin-Yvon fluorescence spectrometer at an excitation wavelength of 325 nm. Photocurrent density–voltage (J–V) characteristics of the developed DSSC have been measured under simulated solar light (AM 1.5 solar simulator, Newport, Model 96000) with Xe lamp and source meter (Keithley, Model 2400).

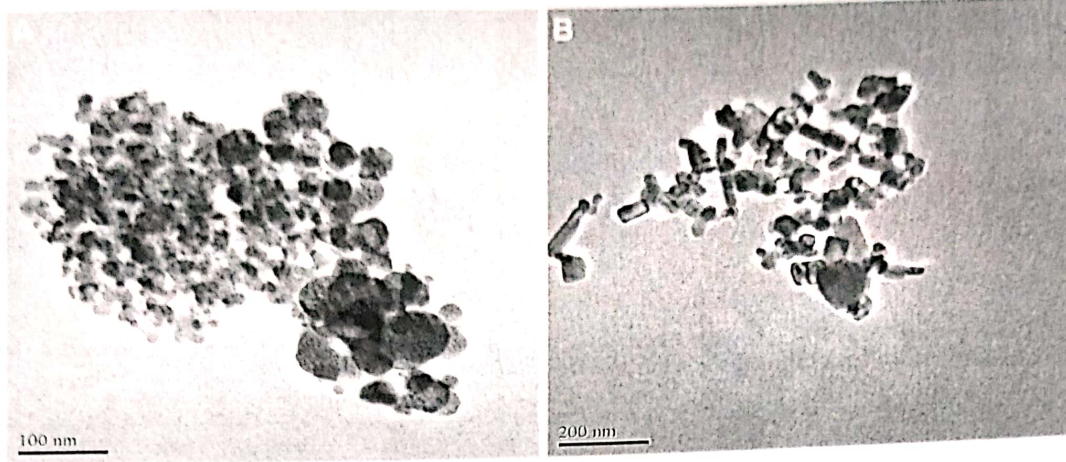


Fig. 1 TEM images of synthesized a) TiO_2 , b) ZnO powders

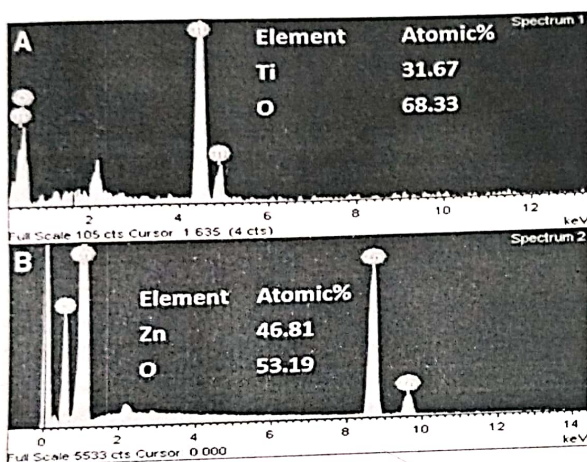


Fig. 2 Energy dispersive analysis (EDAX) of a) TiO_2 , b) ZnO powders

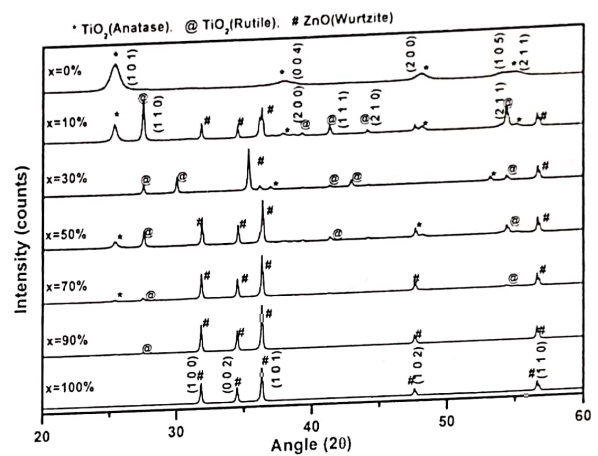


Fig. 3 Powder X-ray (Cu $K\alpha$ radiation) diffraction patterns of $(100-x)\text{TiO}_2 + x(\text{ZnO})$ composite samples

3 Results and discussions

Figure 1a, b show the TEM images of microwave hydrothermal synthesized TiO_2 and ZnO nanoparticles. It can be seen from the figure that the powder particles are uniform and of nearly spherical in shape in TiO_2 whereas ZnO nanoparticles have mixed morphology of spherical and elongated rod shape. It was revealed that the particle sizes of the TiO_2 and ZnO were 12 and 19 nm respectively. The elemental compositions of the synthesized powders were investigated via FESEM-EDX. The results of EDX analysis are shown in Fig. 2 and confirmed the presence of titanium and zinc, corresponding to the primary elements present in TiO_2 and ZnO powders, respectively.

Figure 3 shows the X-ray diffraction patterns of $(100-x)\text{TiO}_2 + x(\text{ZnO})$ composite samples. From the

Figure, it can be observed that the prepared TiO_2 and ZnO powders shown pure anatase phase (JCPDS No.: 84-1286) and the wurtzite phase (JCPDS No. 36-1451) respectively. Compared to the monocomponent nanomaterials (TiO_2 or ZnO), the nanocomposites indeed consist of wurtzite ZnO along with both anatase TiO_2 and rutile TiO_2 which is clearly shown in the XRD pattern. The sharp peaks observed from XRD patterns confirm the formation of highly crystalline phases. Furthermore, with the increase of the ZnO concentration, the characteristic peaks of anatase TiO_2 gradually decreased, and the characteristic peaks of wurtzite ZnO gradually increased in contrast. These XRD results further confirmed the successful preparation of the nanocomposites consisting of both TiO_2 and ZnO phases.

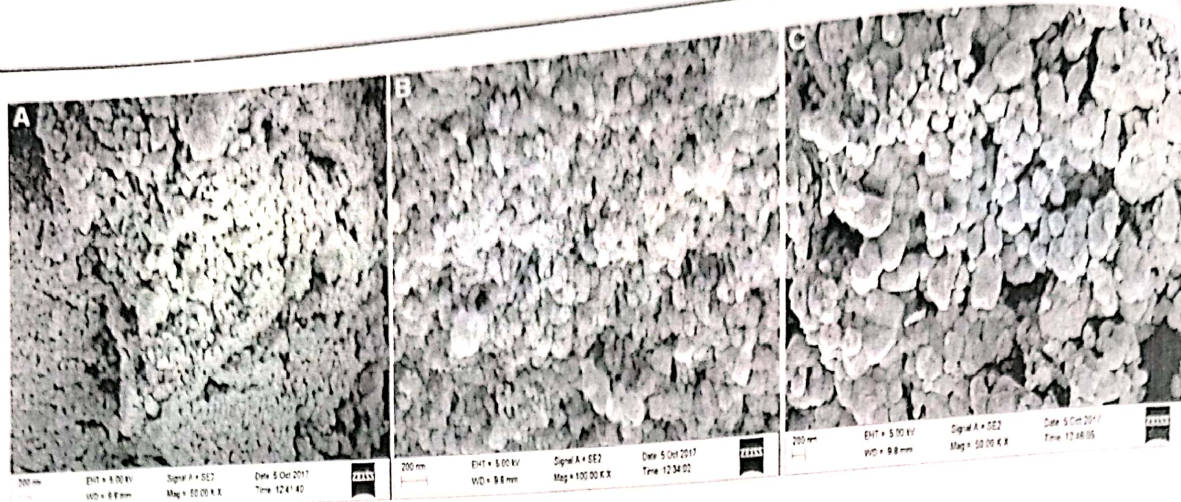


Fig. 4 FE-SEM images of $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composite electrodes a $x=0\%$, b $x=50\%$ and c $x=100\%$

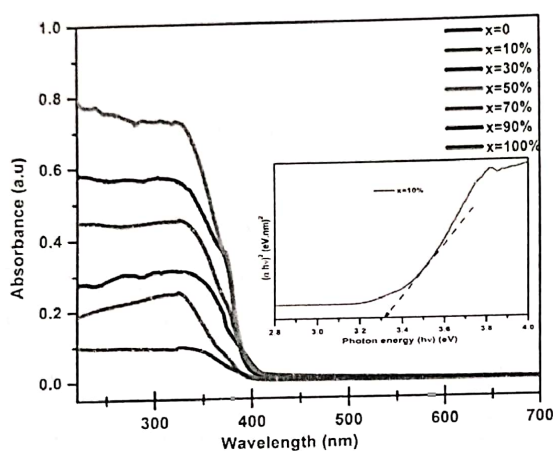


Fig. 5 UV-Vis absorption spectra of $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composites

The efficiency of catalysis is dependent on the surface morphology of nanoparticles. The fine spherical particle in anatase phase of TiO_2 in comparison with large, ragged and needle shape particle in rutile phase provided higher surface area [20]. Figure 4 shows FESEM images of the three typical composite electrodes ($x=0$, $x=50\%$ and $x=100\%$). From the images, it can be observed that the pure and composite electrodes exhibit the uniform spherical topography with high porous structure. This highly porous structure helps to attach more dye molecules on the surface of composite electrodes, and as on when the dye on the surface of particles of TiO_2 -ZnO absorbs the light (photons) it results in excitation of more electrons. The particle size of the pure and composite powders was determined using line intercept method and it is found to be in the range 45–80 nm.

Figure 5 shows the UV-Vis absorption spectra of TiO_2 -ZnO nanocomposite samples. In a semiconductor such

Table 1 Bandgap energy values of $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composite samples

Sample (%)	Bandgap energy (E_g)
$x=0$	3.26
$x=10$	3.28
$x=30$	3.30
$x=50$	3.31
$x=70$	3.36
$x=90$	3.39
$x=100$	3.24

as TiO_2 and ZnO, light is only absorbed if it has energy that is greater than the energy required to excite an electron from the valence band to the conduction band of the material. ZnO is a direct band gap semiconductor with bandgap energy around 3.3 eV. On the other hand, the TiO_2 is an indirect bandgap semiconductor with bandgap energy around 3.2 eV (387.5 nm) for anatase. From the figure, it can be observed that the present investigated samples are exhibiting transparent behaviour in the visible range (400–1000 nm). Moreover, for light wavelengths below 400 nm, the absorbance nature of samples are high and the percentage of absorption varies with composition and it is maximum for $x=30$ and 50% samples. In fact, the Zn atoms create distortion in TiO_2 lattice and in Ti-O bond length which causes shift in the absorption edge [21]. The average optical transmission of all the samples in the visible range part of the spectrum is found to be around 93%. Surface morphology has a significant effect on the optical properties of the sample. Larger pores of investigated samples result in the reduction of light scattering, which can decrease the absorbance of samples. From figure, it can also be observed that UV spectra of composite samples showing the two absorption edges which can be attributed to the optical absorption of two crystalline phases. The optical band gap (E_g)

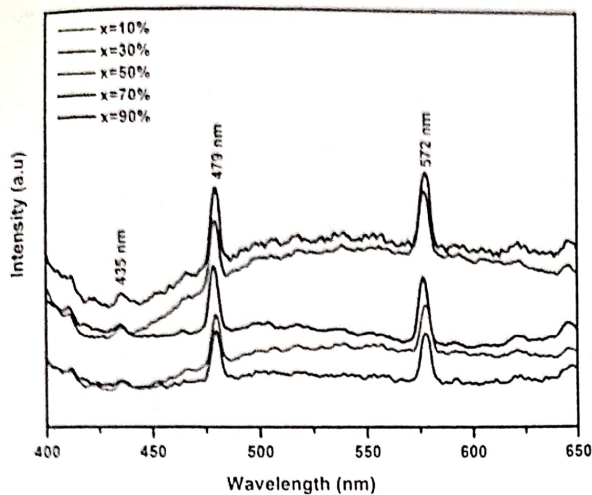


Fig. 6 PL spectra of $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composites

of investigated samples are measured from the plots $(\alpha h\nu)^2$ versus the photon energy ($h\nu$) and the obtained values of E_g are reported in Table 1. From the table, it can be seen that the composite samples band gap slightly higher compare to pure TiO_2 and ZnO samples.

Figure 6 shows typical PL spectra for composite samples with a xenon lamp excitation as a source. It can be seen from the figure that all the composite powders having similar exciton PL peaks (435, 479 and 572 nm) behaviour however, the PL intensity varies with composition. The similar emission behavior of the PL spectra indicates that all the composite samples have a similar origin of PL emission. In general, PL spectra of TiO_2 materials are attributed to three types of physical origins: self trapped excitons, oxygen vacancies, and surface states [22]. The peak at around 435 nm in the blue-violet region originates from charge recombination in the surface state defects. These surface states are possible due to the interaction of ZnO and TiO_2 . The bands at around 479 nm in the blue area are due to different intrinsic defects in the TiO_2 lattice such as oxygen vacancies, titanium vacancies and interstitial defects. A green emission can be seen at around 572 nm which may be due to electron-hole recombination. The variation in PL intensity indicates that the rate of recombination of electron-hole varies from sample to sample. From the figure, it can be observed that the PL spectra intensity of $x = 10$ and $x = 30\%$ is low when it is compared to other samples, which indicates that the samples with $x = 10$ and $x = 30\%$ ZnO composite samples have low rate of recombination compare to other samples.

Figures 7 and 8 show the measured current density (J) and voltage (V) characteristics of the TiO_2 - ZnO composite photoanode DSSCs with *Syzygium cumini* and *Beta vulgaris* dyes respectively. Photovoltaic tests of DSSC with these natural dyes as sensitizers were performed by measuring the

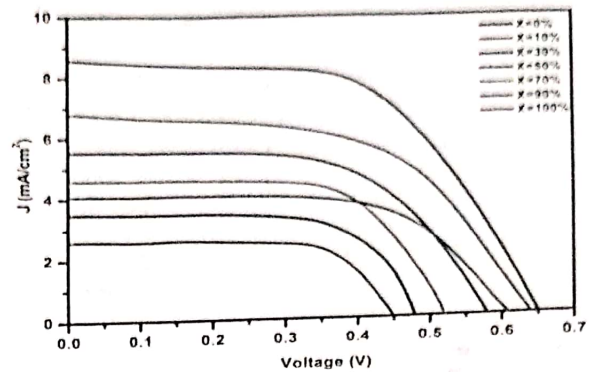


Fig. 7 J-V characteristics of the DSSCs made from $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composite photoanode and *Syzygium cumini* dye as photosensitizer

current density and voltage (J - V) characteristics under irradiation with white light (100 mW cm^{-2} from 300 W solar simulator). The performance of natural dyes as sensitizers in DSSCs was evaluated by short-circuit current (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and energy conversion efficiency (η) parameters and obtained results are listed in Tables 2 and 3. A η of 1.05% was achieved for the *Syzygium cumini* dye pristine TiO_2 photoanode DSSC, with a J_{sc} of 3.45 mA/cm^2 , a V_{oc} of 0.47 V and a FF of 63.83. Besides a η of 2.73% was achieved for the *Beta vulgaris* dye pristine TiO_2 photoanode DSSC, with a J_{sc} of 6 mA/cm^2 , a V_{oc} of 0.86 V and a FF of 52.9. From the table, it can be observed that with increasing of $\text{ZnO}(x)$ concentration in $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composites all the parameters (J_{sc} , V_{oc} , FF and η) vary and no systematic behaviour is observed. The increase in photocurrent with low amount ZnO concentration can be attributed to rapid electron transport and the

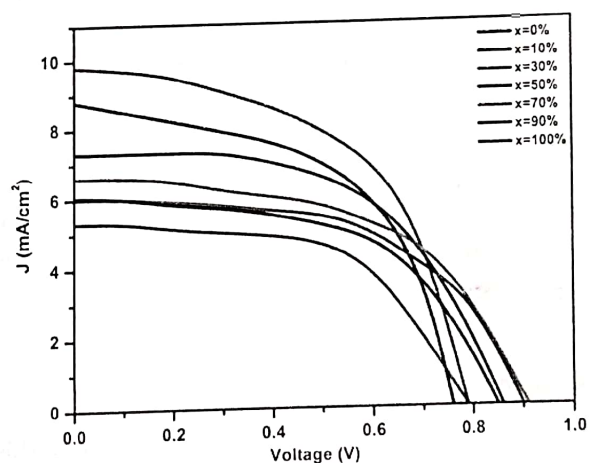


Fig. 8 J-V characteristics of the DSSCs made from $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composite photoanode and *Beta vulgaris* dye as photosensitizer

Table 2 Photovoltaic performances of the DSSCs made from $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composite photoanode and *Syzygium cumini* dye as photosensitizer

Sample (%)	J_{sc} (mA/cm ²)	J_{max} (mA/cm ²)	V_{max} (V)	V_{oc} (V)	FF (%)	η (%)
x = 0	3.45	3.0	0.35	0.47	63.83	1.05
x = 10	6.82	7.8	0.44	0.64	71.69	3.12
x = 30	8.3	8.0	0.42	0.65	62.22	3.35
x = 50	5.52	5.0	0.38	0.58	59.56	1.89
x = 70	4.57	4.25	0.36	0.52	65.38	1.53
x = 90	4.10	3.8	0.40	0.61	60.77	1.52
x = 100	2.65	2.1	0.35	0.45	72.59	0.85

Table 3 Photovoltaic performances of the DSSCs made from $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ composite photoanode and *Beta vulgaris* dye as photosensitizer

Sample (%)	J_{sc} (mA/cm ²)	J_{max} (mA/cm ²)	V_{max} (V)	V_{oc} (V)	FF (%)	η (%)
x = 0	6.0	4.2	0.65	0.86	52.90	2.73
x = 10	8.7	6.5	0.61	0.76	59.96	3.96
x = 30	9.8	7.1	0.63	0.79	57.77	4.47
x = 50	7.3	6.1	0.60	0.88	56.97	3.66
x = 70	6.5	4.8	0.68	0.90	55.79	3.26
x = 90	6.0	5	0.65	0.91	59.62	3.25
x = 100	5.4	4.2	0.59	0.80	57.36	2.48

shortened electron-transfer distance. Moreover, the V_{oc} improved with the ZnO concentration up to 30% owing to the suppression of electron recombination, consequently improving the conversion efficiency. However, when a higher ZnO concentration was introduced, J_{sc} decreased because higher ZnO concentrations formation of the Zn^{2+} /dye complexes, which hinder dye absorption, electron transport and electrolyte penetration. Consequently, the DSSCs that used $x = 10$ and $x = 30\%$ of $(100-x)\text{TiO}_2 + (x)\text{ZnO}$ photoanodes exhibited more than double efficiency compare to that of pure TiO_2 and ZnO based DSSC efficiency irrespective of dye. In both *Syzygium cumini* and *Beta vulgaris* dye based series, $x = 30\%$ photoanode DSSC showing the highest efficiency 3.35 and 4.47% respectively. The obtained efficiency values of present investigate TiO_2 -ZnO DSSC is superior compare to several composite photoanode reports. Tripathi and Chawla [23] noted that the efficiency of betacyanin sensitized CeO_2 - TiO_2 composite photoanode DSSC increases from 0.63 to 2.8% with CeO_2 concentration. Jiao et al. [24] deposited layers of nano-sized MgO on TiO_2 nanowires. According to their results, the short circuit current of the cell improved 35% and the efficiency of the cell rose from 1.11 to 1.37%.

4 Conclusions

Dye sensitized solar cells are successfully fabricated with TiO_2 -ZnO composite photoanode and natural (*Syzygium cumini* and *Beta vulgaris*) sensitizers. Then the cell performance of sensitized solar cell is investigated using J_{sc} , V_{oc} ,

FF and η parameters. From these studies, it may be concluded that the addition of ZnO to TiO_2 enhances the cell performance due to the reduced recombination of photoinjected electrons. The *Beta vulgaris* dye has higher photosensitized performance compare to *Syzygium cumini* due to the better charge transfer between the betacyanin dye molecule and the TiO_2 -ZnO surface that is related to a dye structure. Hence, this dye provides a more efficient incident photon to electron conversion.

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SYNTHESIS OF TiO₂ NANOPARTICLES AND ITS APPLICATION IN DYE SENSITIZED SOLAR CELLS

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ABSTRACT: Dye-sensitized solar cells (DSSCs) based on a TiO₂ photoanode have been considered as an alternative source in the field of renewable energy resources. In DSSCs, photoanode plays a key role to achieve excellent photo-to-electric conversion efficiency. The surface morphology, surface area, TiO₂ crystal phase, and the dispersion of TiO₂ nanoparticles are the most important factors influencing the properties of a photoanode. We have successfully synthesized nanoparticles of anatase TiO₂ using microwave-hydrothermal method and characterized. Anatase phase and average particle size of 10 nm were confirmed from XRD pattern. From TEM, it was noticed that particles were of varying size and shape and aggregation with average particle size of 12nm. FTIR spectra reveal Ti-O bond corresponding to 483 cm⁻¹. A photoanode have been fabricated using nanoparticles of anatase TiO₂. Photocurrent density (J) - photovoltage (V) characteristic of DSSC of different thicknesses of TiO₂ were obtained.

1. INTRODUCTION

Recently research has been focused on TiO₂ nanomaterials which include nanoparticles, nanorods, nanowires and nanotubes [1]. The movement of electrons and holes in semiconductor nanomaterials is governed by the well-known quantum confinement, the transport properties related to phonons and photons, and these three key parameters are largely affected by the size and geometry of the materials, and the specific surface area and surface to volume ratios increases dramatically as the size of material decreases. TiO₂ which is a semiconductor utilizes these size dependent properties in the conversion of solar energy [2]. The use of nanoparticles for the TiO₂ semiconductor, which provides an extended surface area, sufficient dye and can be retained on a given area of electrode to provide absorption to the incident light. In this paper, we are reporting the synthesis and characterization of TiO₂ nanoparticles using microwave-hydrothermal method and a photo anode have been prepared using nanoparticles of anatase TiO₂.

2. EXPERIMENTAL

Titanium (IV) n-butoxide was added slowly into the acetic acid (2 M) solution. The solution was stirred for 3-4 days until obtaining a transparent white solution. Then, the mixture was microwave-hydrothermally treated at 150°C for 45 min. The obtained white precipitate was cooled to room

temperature, centrifuged, and washed with distilled water and with ethanol. Then, the white precipitate was dispersed into 40 mL of anhydrous ethanol and kept stirring for 24hrs. Thus, obtained nanopowder of TiO₂ was collected.

The particle size and the morphology of the TiO₂ nanoparticles were analyzed by Transmission electron microscopy (TEM, JEM, 1200EX). X-ray diffraction (XRD, PAN Analytical) measurement was carried out with Cu K α radiation. The surface area analysis of the TiO₂ nanoparticles was obtained using Brunauer-Emmett-Teller (BET, Micromeritics, Gemini V, ASAP-2010) surface area analyzer. FTIR spectrometer (Bruker Tensor 27 DTGS TEC detector) used in the present investigation. Differential thermal analysis (DTA) and thermo gravimetric analysis (TGA) on as synthesized nanopowder was carried out using SII TG/DTA 6200.

3. RESULTS AND DISCUSSION

Fig.1 shows the XRD patterns of M-H synthesized TiO₂ powders. XRD peaks can be indexed to the anatase structure of standard TiO₂ (JCPDS 21-1272). Within the detection limit of XRD, no extra characteristic peak of any impurity was found in the as-synthesized powder, indicating that the as-synthesized powder was a pure anatase TiO₂ phase. The crystallite size of the synthesized powder was calculated from the X-ray peak broadening of the (101)-diffraction peak using the Scherer formula. The calculated average crystallite size of presently synthesized powder is 10 \pm 0.01 nm.

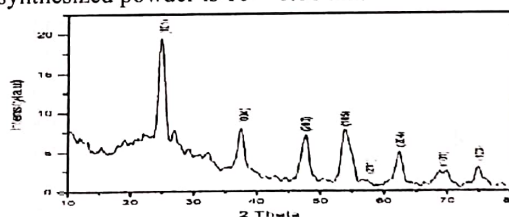


Fig.1 XRD pattern for as synthesized TiO₂ nanopowder

TEM image of as synthesized nanopowder is shown in Fig. 2. Clear spherical and non-homogeneous structures can be seen in the figure having diameter ~ 12 nm. Selected area diffraction is shown in inset of figure which clearly indicates that the TiO₂ nanoparticles are highly crystalline in nature. TEM image and selected area diffraction pattern of the microwave hydrothermal method given us nanoparticles. Selected area diffraction pattern of the nanoparticles indicates that the TiO₂ nanoparticles

prepared via microwave-hydrothermal method are crystalline in nature.

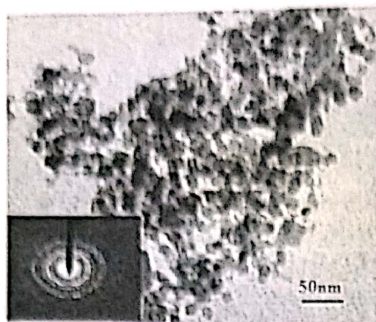


Fig2. TEM picture of as synthesized TiO2 nanopowder

Fig.3 shows the FTIR spectra for synthesized powder of TiO₂. The band centered at 3153 cm⁻¹ is a characteristic of ν-OH stretching and δ-H₂ H₂O bending respectively. The Ti-O vibration appears as a broad envelope between 1000-400cm⁻¹. Since there is no C-H vibration band from 3000 to 2700 cm⁻¹, the TiO₂-NPs are free of adsorbed organics. We can thus consider that the hydrolysis reaction leads to Ti (OH)₄ n.H₂O precursor. Thus, the FTIR spectra results are also in good agreement with the results that of XRD patterns. With addition of these three metal-oxygen characteristic bands some more bands are observed at other wave numbers. Sharp bands at 1625cm⁻¹ and 1402 cm⁻¹ were assigned to the O-H group, and NO₃⁻ ions respectively.

The dried as prepared powder was characterized by differential thermal analysis (DTA) and thermo gravimetric analysis (TGA) using SII TG/DTA 6200. TGA curve of TiO₂ nanopowder is shown in Figure 4. The degradation has occurred in three steps. The first degradation at 100°C is attributed to the removal of water from the surface (mass loss of about 10%). The second degradation is from 180 °C to 300 °C. 13% mass reduction has been observed in this region. This is due to the dehydration and removal of organic residues. The third degradation from 500 °C to 600 °C results in an additional mass loss of about 10%. Above 700°C, an essentially constant mass (67% sample) has been found indicating the thermal stability of the sample.

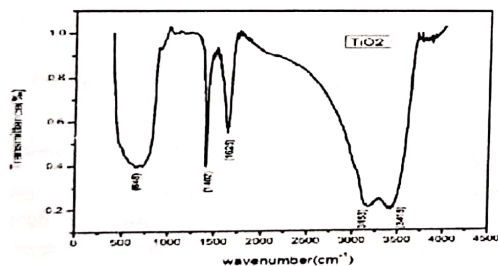


Fig. 4: FTIR spectra on as synthesized TiO2 nanopowder

After characterization of TiO₂ nanoparticles, a paste was prepared by taking 0.30 gram of synthesized TiO₂ nanopowder in a crucible containing 200 ml and 300 ml acetyl acetone and ethanol respectively.

Later, it was grinded by adding distilled water gradually until distilled water reaches 800 ml. Without stopping the grinding at this point, 80 ml of triton -X100 was added to obtain a fine paste of TiO₂. In order to prepare photo-anode FTO glass was cleaned with soap water, distilled water and dry ethanol respectively. Then, TiO₂ paste was coated on FTO glass using doctor blading technique. Traces of solvents and additives, as a result of cleaning and coating on FTO glass, were removed by annealing FTO at 550°C for 45 minutes. Total three films were prepared with different thickness i.e. 2 μm (MH1), 4.3μm (MH2), and 5.5μm (MH3). Thickness of the TiO₂ film was measured by using an Olympus microscope. The photo-anode was sensitized by raspberry dye in ethanol for 12 hours.

It is important to note that the desirable dye molecule should meet certain criteria such as matching with the solar spectrum, having a long-term operational stability and roughness of the semiconductor surface as well as a high redox potential. For our case, we used natural dye from raspberries juice. We started with crushing raspberries. Then we added 12 ml of 95% ethanol to the crashed berries as well as 12 ml of acetic acid. We then filter the dye until we end up with an evenly red liquid.

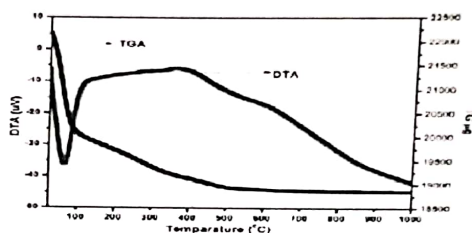


Fig. 4 DTA & TGA curves on as synthesised TiO2 nanopowder

The electrolyte is prepared with pure chemicals of acetonitrile (ACN) containing a mixture of 0.5 M Lithium Iodide (LiI), 0.05 M Iodine (I₂), 0.5 M 4-tert-Butyl Pyridine (4-TBP) and 0.6 M Di Methyl 3-Propyl Imidazolium Iodide (DMPII). The photo-anode sensitized by respective dye as mentioned above was placed on the platinum counter electrode so that the TiO₂ film was sandwiched between the two conducting sides of the FTO glass plates. The glass plates were held tight by binder clips on the two lateral edges. Liquid electrolyte was then injected using small syringe at the interface of two glass plates (electrodes) until electrolyte spreads and adsorbed on the TiO₂ nano porous film by capillary forces.

(J-V) characteristics was monitored and measured by using a Keithley 276 source measurement unit. J-V measurements were generated using a self-written LabVIEW program. A solar simulator equipped with xenon lamp (AM 1.5, Solar Light Company, Model 16S-300, USA) was used as light source and light intensity was measured with a pyrometer (PMA2144,

USA). The ultraviolet and infrared portion of the spectrum is eliminated by using a filter. The incident light intensity is tuned using neutral density filters (Eastman Kodak Company, USA).

Photocurrent density (J) versus photo voltage (V) of fabricated DSSCs sensitized with dye as a function of TiO₂ film thickness was measured. The short circuit current density (J_{sc}) and open circuit voltage (V_{oc}) of DSSCs as a function of TiO₂ film thickness are shown in Table 1 for raspberry dye. Efficiency (η) of DSSCs as a function of TiO₂ film thickness is shown in Table 1. It can be seen from the table that the value of J_{sc} increases to a peak value at 3.44 μm and 4.3 μm thicknesses for present dye and after wards decreases. The increase of J_{sc} may be as a result of more absorption of photons as the film thickness increases. But, when the film thickness is more than the light penetration depth, the number of photons useful for electron photo-generation will reach the limit and therefore, J_{sc} cannot be increased further since increase in the thickness more than the light penetration depth may yield more recombination centers which results higher electron loss and decrease in J_{sc}. It is evident from the figures that the V_{oc} decreases with an increase of the film thickness. This may be due to charge recombination and restricted mass transport in the thicker film as a result of augmentation of surface area [3-5].

The J-V curve of a solar cell yields important photovoltaic properties [6], these include the short-circuit photocurrent density J_{sc}, the open-circuit potential V_{oc}, and the maximum power point, P_{max}. The fill factor, FF and conversion efficiency, are the other factors used to characterize a solar cell. The short-circuit current, I_{sc} is the current due to generation and collection of light generated carriers. The open-circuit voltage of a solar cell corresponds to amount of forward bias of the solar cell junction due to the light generated current. FF, the ratio of the maximum output power from the solar cell to the theoretical maximum power is calculated as [6]:

$$FF = I_m V_m / V_{oc} I_{oc}$$

Where I_m and V_m are solar cell photocurrent and voltage at maximum power point, respectively.

The fill factor reflects the electrical and electrochemical losses occurring during the operation of the DSSC. The conversion efficiency of the solar cell reflects the performance of the solar cell itself. It is defined as the ratio of energy output from the solar cell to input energy from the sun. The efficiency depends on the spectrum and intensity of the incident sunlight and can be calculated as [7];

$$\eta = FF \cdot V_{oc} \cdot I_{oc} / I$$

where I is the solar radiation intensity, W/m².

Table 1: Data on DSSCs from J-V curves

Thickness (μm)	J _{sc} (mA/cm ²)	V _{oc} (V)	Efficiency (η) %	FF
2	3.42	0.76	1.32	0.62
4.3	3.44	0.72	2.49	0.62
5.5	3.2	0.71	1.52	0.62

From Table 1, it can be seen that DSSC sensitized with raspberry exhibit the highest measured open-circuit photo voltage of 0.76 V. The highest current density was obtained for raspberry (3.44 mA/cm²). The value is close to that reported for ruthenium complex N3 by Moustafa et al. [8]. The difference in the current densities of the cells may be attributed to the difference in the structure of the dyes, and how fast the charge is injected into the conduction band of the TiO₂ film. The photo energy conversion efficiency of raspberry, red are 1.32%, 2.49%, and 1.52% for different thickness of photo anode films, respectively. The MH2 sample proved to be a better than their counterpart. MH1 and MH3 samples gave the lowest efficiency, despite the highest absorbance value. This may be understood by a thorough analysis of the chemical properties of the dye and electron reactions between the dye and TiO₂ which is not well understood now.

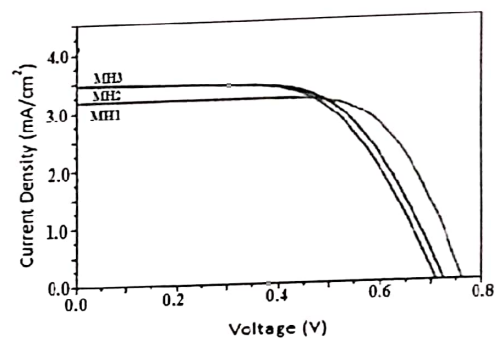


Fig. 5. Plots of J-V for different thicknesses of DSSCs films

In the present investigation, the obtained efficiencies are lower than those usually reported [9-21] for organic dye based DSSCs using ruthenium complexes. Low efficiencies may be attributed to poor adsorption of dye molecules onto the TiO₂ particle. Nanostructures of TiO₂ provide paths for the electrons while maintaining high surface area for dye absorption. Therefore, non-availability of bonds between the dye and TiO₂ molecules through which electrons can transport from the excited dye molecules to the TiO₂ film has been reported to result in low efficiencies [9]. Despite the low efficiencies, the DSSCs exhibit promising photo-electrochemical conversion potential. The merits of natural extracts DSSCs stem from reduced cost/Watt and environmental friendliness as compared to the ruthenium complexes based solar cells.

4.0 CONCLUSIONS

Nanoparticles of TiO₂ has been successfully synthesized using microwave hydrothermal method. A photo anode have been prepared using nanoparticles of anatase TiO₂. Photocurrent density (J) - photo voltage (V) characteristic of DSSC of different thicknesses of TiO₂ were obtained, it was observed that optimum solar energy to electricity conversion efficiency (η) for raspberry dye is 2.49 % and with TiO₂ thickness of 4.3 μ m.

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