



पश्चिम बंगाल पश्चिम बंगाल WEST BENGAL

AF 987349

MEMORANDUM OF AGREEMENT (MOA)

This Memorandum of Agreement is made and entered into force this day 18th May of 2021 at New Delhi.

SL. No.-- 34

AMONG

The University Grants Commission, a Statutory Body established under the UGC Act, 1956 having its office at Bahadur Shah Zafar Marg, New Delhi - 110 002, represented by its Secretary (hereinafter referred to as "UGC") which expression shall unless the context requires otherwise, mean and include its successors, representatives and permitted assigns of the FIRST PART.

University of Burdwan, Bardhaman established on 15th June, 1960 having its office at the University of Burdwan, Rajbati, Bardhaman - 713104 West Bengal, represented by its Registrar (hereinafter referred to as "BU") Which expression shall, unless the context requires otherwise, mean and include its successors, representatives and permitted assigns of the SECOND PART.

[Handwritten signatures]

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AND

Suyro Chatterjee, the candidate selected as Associate Professor under the UGC- Programme on "Operation Faculty Recharge" (FRP) in the discipline of Biological Sciences and posted in the department/ School of Biotechnology, University of Burdwan, in the State of West Bengal and having his permanent residence at Janai, Hooghly, West Bengal (hereinafter referred to as "UGC-FRP-Faculty") forming the THIRD PART.

WHEREAS, the "UGC" has launched a novel scheme called, "Operation Faculty Recharge Programme (FRP)" for national level recruitment of faculty in Science, Engineering & Technology to strengthen high quality research in Science - related disciplines at internationally competitive levels and promote innovative teaching in the Universities through induction of fresh talent at the levels of Assistant Professors, Associate Professors and Professors.

Therefore, all the three to this Memorandum of Agreement agreed and undertake to abide by the following terms and conditions:

- (i) Qualifications for various faculty positions under the programme shall be the same as provided in the UGC Regulations on "Minimum Qualifications for appointment of teachers and other academic staff in Universities and Colleges and measures for the maintenance of standards in higher education, 2010" and as amended from time to time.
- (ii) The 'Faculty Recharge' position shall initially be for a tenure of five years. However, depending upon the peer group expert assessment report, the positions may either be extended or elevated to the next higher levels or in unsuccessful cases in peer group expert assessment could even be terminated.
- (iii) The period of appointment of the incumbents in these FRP-positions shall be the same as prescribed for teachers in the central universities by the UGC and the Government of India from time to time with the tenure of the FRP-Faculty may be extended every five years up to the age of 65 years subject to (ii) above.
- (iv) Nationally selected candidates under the "Faculty Recharge Programme" will be located/placed through harmonization of their own preference, response of the

host university and availability of infrastructure for discharge of the duties earmarked for these UGC-Faculty positions


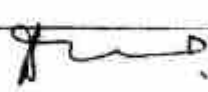

- (v) The recurrent financial implications of all the 'Faculty Recharge positions' shall be met by UGC. Such positions shall be made available to both Central and State Universities, which are eligible for receiving UGC funds under section 12-B of UGC Act, 1956, and which are signing this Memorandum of Agreement (MoA) with UGC.
- (vi) The "MOA" is intended to facilitate the legal and technical requirements for the recipient Universities to accept the Faculty - Recharge positions. The Universities shall also authenticate and undertake to UGC that all academic & administrative facilities will be extended to the appointees under the Faculty Recharge Programme as per the terms and conditions of appointment to be decided and communicated separately to both appointee and university.
- (vii) It shall also be mandatory for the recipient Universities to accept and implement all norms & guidelines pertaining to the "UGC' Operation Faculty Recharge Scheme" from time to time.
- (viii) It shall be incumbent on the part of the recipient Universities to provide teaching, research, co-curricular & extra-curricular facilities to the faculty recharge programme teachers.
- (ix) Subsequent to all the above conditions are agreed to by the recipient Universities, annual release of funds towards the faculty recharge positions provided will be made by UGC to the recipient Universities on a recurrent basis subject to the UGC - fund release norms applicable to Central/State Universities and the recipient Universities shall submit Utilization Certificates and Audited Statement of Accounts annually to UGC as per UGC norms.
- (x) The work load of each faculty in term of contact hours, presence on the campus and other activities relating to teaching, research, examination, evaluation, curricular development, self study and preparation for lectures with increased commitment on innovative research shall be as per the norms/service rules separately prescribed by the University Grants Commission under this

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"Faculty Recharge Programme"

- (xi) Every faculty member appointed under 'FRP' shall abide by the Code of Conduct framed by the University Grants Commission in its Regulations, 2010.
- (xii) Any faculty member in FRP may, at any time, terminate his contract by giving the University-UGC three month's notice in writing or on payment of three month's salary in lieu thereof.
- (xiii) Notwithstanding anything contained in this MOA, it is clarified between the "PARTIES" to this MOA that the detailed terms and conditions of service of persons to be appointed under the "FRP" shall be specified separately in the letter of appointment and through separate service rules for FRP to be communicated to the appointee and the University at the time of appointment of the faculty.

IN WITNESS THEREOF, the parties hereto have signed this Memorandum of Agreement on the 18th day of May Two thousand Twenty One.

For and behalf of University Grants Commission	For and on behalf of University
Signature 	Signature 
Name: Prof. Rajnish Jain Designation : Secretary, UGC Official Stamp प्रो. रजनीश जैन / Prof. RAJNISH JAIN सचिव / Secretary विश्वविद्यालय अनुदान आयोग University Grants Commission शिक्षा मंत्रालय, भारत सरकार Ministry of Education, Govt. of India New Delhi-110 002	Name: Dr. Debidas Mondal Designation : Registrar Official Stamp Registrar (Officiating) The University of Burdwan Rajbati, Burdwan-713104 West Bengal
Signature of this Party 	
Name: Suvro Chatterjee Designation : Associate Professor Permanent Address: Janai, Hooghly, West Bengal, 712304	

<p>Address for Communication: Department of Biotechnology University of Burdwan Golapbag Campus Bardhaman West Bengal 713104</p>	
<p>Name & Address of Witness 1..... 2.....</p>	<p>Name & Address of Witness 1. <i>Indrani Chandra</i> Dr. INDRANI CHANDRA Teacher-in-Charge Dept. of Biotechnology The University of Burdwan 2. <i>Chatterjee</i> University Engineer The University of Burdwan BURDWAN</p>



पश्चिम बंगाल पश्चिम बंगाल WEST BENGAL

AB 960366

MEMORANDUM OF AGREEMENT

This MEMORANDUM OF AGREEMENT is made on this **twenty seventh** day of **June** Two thousand and **nineteen** BY AND BETWEEN President of India, acting through **Advisor & scientist 'G'**, Department of Biotechnology, Ministry of Science and Technology, Government of India, New Delhi, hereinafter referred to as the 'DBT' (which expression unless excluded by or repugnant to the subject shall mean and include its successor-in-office and assigns) of the ONE PART;

AND

The **University of Burdwan** society under the Societies Registration Act – 1860, having its registered office in/at **Rajbati, Burdwan**, hereinafter referred to as **BU** (which expression shall where the context so admits include its successors and permitted assigns) of the OTHER PART;

WHEREAS DBT being desirous of **Research on Human Genetics & Genomics** decided to support a project submitted by **Prof. Anupam Basu** for the attainment of the objectives, hereinafter described in the Annexure I annexed hereto;

This Memorandum of Agreement (MoA) defines the role and responsibilities of the participating agencies, monitoring and other matters related to the "A Genetic Algorithm-Based Targeted Approach for Understanding the Phenotypic Heterogeneity of **Thalassemia Syndromes** in Northern and Eastern Indian Population"

02-02-19
Dr. B. Mondal
Joint Registrar
The University of Burdwan

Dr. Anupam Basu
PROFESSOR
Department of Zoology
University of Burdwan

20/1/19
only

NOW THE PARTIES HERETO AGREE AS FOLLOWS:-

1.0 . ROLE OF DEPARTMENT OF BIOTECHNOLOGY, NEW DELHI

To provide funds to the extent of 7379121.00 over a period of 3 years from the date of sanction of the project, to The University of Burdwan for undertaking activities as detailed in Annexure 1. Details of the funds to be provided are given in Annexure II.

2.0. ROLE OF THE UNIVERSITY OF BURDWAN (Institute)

- 2.1. To provide their contribution of NIL for NIL years from date of sanction of the project as detailed in Annexure - II. *(if a jointly supported project)*
- 2.2. To provide existing facilities as mentioned in the project document.
- 2.3. To be responsible for accomplishing objectives identified and activities listed.
- 2.4. To allow the Scientists authorized by DBT to work with the Research & Development team of the center in all stages of process development and production.
- 2.5. To recruit all scientific and non-scientific staff as sanctioned by DBT.
- 2.6. To prepare and submit all periodical reports and other documents that would be required by DBT.
- 2.7. To maintain a separate audit head of account for the grants received from DBT for the project.
- 2.8. To submit an annual audited statement of expenditure incurred under the project.
- 2.9. To ensure effective utilization of the grant given by DBT for the purpose for which it was granted and to ensure timely progress of project work.
- 2.10. The manpower, both scientific and non-scientific, recruited shall be purely on contractual terms & conditions such that the contract for engagement of the manpower shall run concurrently with the said project period only.

3.0 DURATION OF PROJECT

- 3.1 Duration of project shall be 3 years from the date the Project has been sanctioned by DBT.

4.0 RIGHTS OF OWNERSHIP/TECHNOLOGY TRANSFER AND UTILIZATION

- 4.1 The know-how generated from the project by Prof. Anupam Basu will be the joint property of The University of Burdwan and DBT, Government of India. It shall be the responsibility of Prof. Anupam Basu & The University of Burdwan to take necessary action for protection of the intellectual property arising out of the PROJECT through proper instruments, such as, patents, copy rights, etc.

The know-how developed may be transferred to other entrepreneurs on a non-exclusive basis on such terms and conditions as may be determined by DBT.

02-08-19
Dr. D. Mondal
Joint Resident
The University of Burdwan
Burdwan-713104, W.B.

Dr. Anupam Basu
PROFESSOR
Department of Zoology
University of Burdwan

- 4.3 All the assets including the equipment and produce acquired will be the property of DBT and shall not be utilized for purposes other than those for which the grant has been sanctioned. The rights of **The University of Burdwan** under this MoA shall not be transferred to any other party without prior approval in writing of DBT.
- 4.4 It shall be the responsibility of **Prof. Anupam Basu** to ensure that support of DBT is suitably acknowledged in the publications (papers, reports, etc.) arising out of the PROJECT.

5. SECRECY

It is hereby agreed that the participating agencies shall keep information and data collected completely secret provided that the right to transfer the technology shall rest with the DBT.

6. MONITORING

- 6.1 The progress of implementation of the project and proper utilization of grant shall be reviewed by the DBT and by the Monitoring Committee set up by DBT.
- 6.2 The periodic progress of physical achievements and the utilization of funds, statement of expenditure shall be evaluated by the Monitoring Committee.
- 6.3 The Comptroller and Auditor General of India, at his discretion shall have the right of access to the books and accounts of **The University of Burdwan** for the grants received from DBT for this project.
- 6.4 The DBT may terminate the grant at any stage if it is convinced that the grant has not been properly utilized or appropriate progress has not been made. In the event, DBT terminates the grant, **Prof. Anupam Basu** shall hand over all documents including technical details and equipment purchased related to the project.

7.0 DURATION OF MEMORANDUM OF AGREEMENT

This MoA will remain in force for the duration of the project and until all claims are settled between DBT and **The University of Burdwan**.

8.0 ARBITRATION

In the event of any question, dispute or difference whatsoever arising between the parties to this Agreement out of or relating to the construction, meaning, scope, operation or effect of this Agreement or the validity of the breach thereof shall be referred to an Arbitrator to be appointed by mutual consent of both the parties herein. If the parties cannot agree on the appointment of the Arbitrator within a period of one month from the notification by one party to the other of existence of such dispute, then the Arbitrator shall be nominated by the Secretary, Department of Legal Affairs, Ministry of Law & Justice, Government of India. The provisions of the Arbitration and Conciliation Act, 1996 will be applicable and the award made thereunder shall be final and binding upon the parties hereto, subject to legal remedies available under the law. Such differences shall be deemed to be a submission to arbitration under the Indian Arbitration and Conciliation Act, 1996, or of any modifications or amendments thereof.

0208-19
Dr. D. Mondal
Joint Registrar
The University of Burdwan
Raibach, Burdwan-713104 W.B.
Dr. Anupam Basu
PROFESSOR
Department of Botany
University of Burdwan

9.0. GOVERNING LAW

This Contract shall be governed by the Law of India for the time being in force.

IN WITNESS WHEREOF the parties hereto have signed, sealed and delivered this Agreement on the day, month and year first above written in presence of:

Witnesses:

1.

Signed by -----

(Designation)

2.

For and on behalf of The President of India

Witnesses:

1.

Son
Dr. SOUMENOPAMATH CHATTERJEE
Associate Professor & Head
Dept.
The Un.
Golepara, Burdwan-713104

2.

Anupam Basu
27/6/19
Dr. Anupam Basu
PROFESSOR
Dept. of English
The Un.
Golepara, Burdwan-713104



Signed by -----

[Signature]
02.08.19

Dr. D. Mondal
Joint Registrar
The University of Burdwan
Belhail, Burdwan-713104, W.B.

For and on behalf of
The University of Burdwan

TERMS & CONDITIONS OF THE GRANT
(To be signed and enclosed with concern filled proforma)

1. Approval of the Research proposal and the grant released would be for the specific project mentioned in paras I to V of this proposal and grant should be exclusively spent on the project for which it has been sanctioned within the stipulated time. The Institute is not permitted to seek or utilize funds from any other organization (Government, Semi Government, Autonomous or Private) for this research project. Any unspent part of amount would be surrendered to the Govt. of India through an account payee demand draft drawn in favor of the "Drawing and Disbursing Officer, Department of Biotechnology, New Delhi", and carry forward of funds of the next financial year for utilization for the same project may be considered only with the specific approval of the Department of Biotechnology (DBT).
2. For permanent/semi-permanent assets acquired solely or mainly out of the grant, an audited record in the form of a register in the prescribed proforma (enclosed at **Appendix-'A'**) shall be maintained by the Institute. The term "assets" means (I) immovable property and (II) movable property of a capital nature, where the value exceeds Rs. 1000/- The grant will not be utilized for construction of any immovable property, Full facilities by way of accommodation, etc. for the project will be given by the Institute.
3. All the assets acquired from the grant will be the property of Govt. of India and should not without the prior sanction of the Dept. of Biotechnology, be disposed of, or encumbered or utilized for purpose other than those for which the grant has been sanctioned.
4. At the conclusion of the project, the Govt. of India will be free to sell or otherwise dispose of assets which are the property of the Government. The Institute shall render to Govt. necessary facilities for arranging the sale / disposal of these assets. **The Government may, however, consider the request of host institutions to retain the assets created under a project for carrying out similar work for the promotion of science.**
5. The implementing Institute/PI will furnish progress report of work on the project every six months. The progress of the project will also be reviewed/monitored at least once a year by the concerned Task Force/Project Monitoring Committee, etc. In addition the DBT shall designate Scientists/Specialists to visit the Institute periodically for reviewing the progress of work and for suggesting such measures as to ensure early realization of the objectives of the project. On completion of the project five copies of a consolidated report of the work done on the subject would be submitted to the Department of Biotechnology.
6. The Institute is required to send to DBT a list of assets referred to at Sl. No. 2 above at the end of each financial year as well as at the time of seeking further installments of the grant.
7. The Institute would furnish to the Dept. of Biotechnology a Utilization Certificate and an audited statement of expenditure duly signed by the P.I., the Head of the Institute and the Head of the Finance wing, pertaining to the grant at the end of each financial year as well as a consolidated statement of expenditure at the end of the completion of the project.

02-08-19
Dr. D. Mondal
Joint Registrar
The University of Burdwan
Rajbati, Burdwan-713104.
Dr. Anupam Bhowmik
PROFESSOR
Department of Zoology
The University of Burdwan

A stamped receipt be sent to the Dept. of Biotechnology on receipt of the Cheque/ Demand draft towards each release.


9. The Comptroller and Auditor-General of India at his discretion shall have the right of access to the books and accounts of the Institute for the grant received from the Government.
10. The Institute would maintain separate audited accounts for the project. If it is found expedient to keep a part or whole of the grant in a bank account earning interest, the interest thus earned should be reported to the Dept. of Biotechnology.
11. Sale proceeds, if any, as a result of the development of the project arising directly from funds granted by the Dept. of Biotechnology shall be reported to the Govt. of India. The Govt. of India may at its discretion allow a portion of such receipt to be retained by the Institute for its utilization for the project activities.
12. Investigators/Institutes wishing to publish papers based on the research work done under Dept. of Biotechnology projects should acknowledge the financial support received from the Dept. of Biotechnology.
13. Investigators/Institutes may utilize various resources such as the Bioinformatics resources, experimental materials, reagents, cell lines, animals, etc. from the National facilities/Institutes/Centers established by this Department as per the terms of transactions followed by them. More information may be obtained about such facility from DBT websites: <http://www.dbtindia.org/> www.dbtindia.nic.in, www.btisnet.ac.in.
14. Investigators / Institutes shall follow the detailed instructions on technology transfer and Intellectual Property Rights (IPR) as given at Annexure - V. The same has the approval of the Ministry of Finance, Govt. of India vide Dept. of Expenditure, Plan Finance II - Division Letter No. 33 (5) /PF.II/99 dated 22nd February, 2000. Any deviation from these instructions may be brought to the notice of this Department.
15. Investigators / Institutes may file patents with the help of the Biotechnology Patents Facilitating Cell (BPFC) established at DBT on priority bases. The format for filing the patents may be seen at Annexure -VI.
16. The Govt. of India (Dept. of Biotechnology) will have the right to call for drawings, specifications and other data necessary to enable the transfer of know-how to other parties and the Institute shall supply all the needed information at the request of the Department of Biotechnology which will ensure confidentiality. The information required for commercializing Biotechnologies may be furnished to this Dept. as per the format enclosed at Annexure - VII. More information on commercialization can be found at the website www.ebc.nic.in.
17. The Institute may not entrust the implementation of the work for which the grant is being sanctioned to another institution and to divert the grant receipts as assistance to the latter institution. However, in such situations the express permission of DBT may be obtained. In case the grantee is not in a position to execute or complete the project, it may be required to refund forthwith to the Govt. of India (Department of Biotechnology) the entire amount of grant received by it.
18. The human resources that may be engaged for the project by the Institute are not to be treated as employees of the Govt. of India and the deployment of such human resource at the time of completion or termination of project, will not be the concern/responsibility of the Govt. of India. The Organization may make reservations for Scheduled Castes, Schedule Tribes etc. in the human resource to be engaged for the project in accordance with the instruction issued by the Govt. of India from time to time.

02.08.19

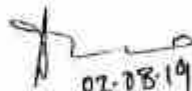
Dr. D. Mondal
Joint Registrar
The University of Burdwan
Rajbati, Burdwan-713104, W.B.


Dr. Anupam Basu
PROFESSOR
Department of Zoology
The University of Burdwan

19. The Dept. of Biotechnology reserves the right to terminate the grant at any stage and also to recover the amounts already paid if it is convinced that the grant has not been properly utilized or the work on the project has been suspended for any unduly long period or appropriate progress is not being made.
20. The project will become operative with effect from the date of release of the first installment for the project.
21. If the Investigator to whom a grant for a project has been sanctioned leaves the institution where the project is being implemented, he shall submit five copies of complete and detailed report of the work done by him on the project and the money spent till the date of his/her release and shall also arrange to refund the unspent balance, if any.
22. The organization should maintain subsidiary accounts of the Govt. of India grant and furnish it to the Audit Officer as and when the recurring and non-recurring expenditure exceeds the limits of Rs. 5.00 lakhs.


Signature of Project Coordinator
(Applicable only for multi-Institutional projects)

Date: 27/6/19
Dr. Anupam Basu
PROFESSOR
Department of Zoology
The University of Burdwan

✓ 
02.08.19
Signature of Registrar
of University of Burdwan
Joint Registrar
The University of Burdwan
Date: Burdwan-713104, W.B.


Signature and stamped of Principal Investigator
The University of Burdwan

Date: 27/06/19
Dr. Anupam Basu
PROFESSOR
Department of Zoology
The University of Burdwan





TECHNISCHE
UNIVERSITÄT
WIEN
Vienna University of Technology

Department of Geodesy and Geoinformation
A.o. Univ.-Prof. DI Dr. Guenther Retscher

Research Division Engineering Geodesy
Wiedner Hauptstrasse 8-10/E120-05
1040 Wien, AUSTRIA
Tel.: +43/1/58801-12847
<https://www.geo.tuwien.ac.at/>

To:

Whom It May Concern

Vienna, 19 August 2021

LETTER OF INTEREST

Dear Sir / Madam,

I am very pleased to invite Dr. Anindya Bose to collaborate and bring his expertise as advisor in the course of the Erasmus+ Capacity Building in Higher Education project entitled 'Curricula Enrichment delivered through the Application of Location-based Services to Intelligent Transport Systems / LBS2ITS'. The LBS2ITS project has a duration of 3 years and started on January 15, 2021. Participating Universities are the EU programme countries' Universities Technische Universitaet Dresden (TU Dresden), Germany, and National Technical University of Athens (NTUA), Greece, under the lead of Technische Universitaet Wien (TU Wien), Austria. The partner country in this project is Sri Lanka with the four Sri Lankan partner Universities Sabaragamuwa University of Sri Lanka (SUSL), University of Moratuwa (UOM), University of Sri Jayewardenepura (USJ) and General Sir John Kotelawala Defence University (KDU).

Location-based Services (LBS) are an important application in Positioning, Navigation and Timing (PNT) and especially for Intelligent Transport Systems (ITS). Global Navigation Satellite Systems (GNSS) play thereby a crucial role and for the LBS users in the Indian sub-continental region the Indian Regional Satellite Constellation NavIC and the Satellite Based Augmentation System (SBAS) GAGAN provide great opportunities for research and education. Due to the great expertise of Dr. Bose in the PNT field, the collaboration and exchange of research ideas can benefit all involved institutions. A train-the-teachers course on PNT technologies is held in early May 2022 in Sri Lanka at SUSL. We would like to invite Dr. Bose to contribute and participate in this course. Another starting point of our collaboration would be that Dr. Bose joins as a member of a supervisory panel for a master students from SUSL.

We are confident that the collaboration with the Dr. Bose and Burdwan University will be of mutual benefit for all involved partners. Further acquisition of funding for joint research projects forms an integral part of our intended collaboration and will be sought-after.

Yours sincerely,

Guenther Retscher
TU Wien - Vienna University of Technology
<https://lbs2its.net/>

SL. NO. 36

Her m.13

Dr. Arijit Chatterjee

Joint Director - Lifelong Learning

&

In Charge - Research Section



The University of Burdwan

Rajbati, Burdwan- 713104, W.B

M-9434740604

E-mail : jtdirector_III@buruniv.ac.in

No.R-Ph.D./Regn. / Sc/ Env. Sc/ 58

Dated: 26.06.2023

To:

Ms. Tanumita Pan

C/O- Prof. Srimanta Gupta,

Dept. of Environmental Science, B.U.

**Under UGC's New
Regulation - 2016**

**Sub: Grant of Registration as a candidate for Ph.D. degree in Environmental Science
with effect from 09.09.2021**

Sir/Madam,

I am to inform you that the Faculty Council for P.G. Studies in Arts/ Science at its meeting held on 06.06.2023 permitted you to get yourself registered as a candidate for Ph.D. degree, mentioned above, the title of your thesis being, "MEDICAL GEOLOGICAL APPRAISAL OF FLUORIDE CONTAMINATION IN GROUNDWATER OF SOUTH DINAJPUR DISTRICT, WEST BENGAL WITH THE DEVELOPMENT OF A MAGNETIC NANO-MATERIAL BASED DEFLUORIDATION TECHNIQUE" Subject to fulfillment of the requirements set forth in the University Ordinances relating to Doctoral Degrees and such terms and conditions as may be laid down by the appropriate authorities of the University from time to time.

You will now be required to deposit the Ph.D. Registration fee of Rs. 8,000/- (Eight thousand only) for enrolment of your name in the Register of candidates for Ph.D. degree, positively within a month from the date of issue of this letter, failing which your case will not be considered for Registration as a Ph.D. candidate and the relevant copy of the cash receipt should be submitted to the Ph.D Unit.

In this connection you are requested to note that ---

a) You have been permitted to do research work under Prof. Srimanta Gupta, Dept. of Environmental Science, B.U. & Prof. Rama Ranjan Bhattacharjee, Dept. of Chemistry, Sister Nivedita University, Kolkata (Co-supervisor) as your Supervisor / Co-Supervisors.

b) You will be required to get yourself registered as a student of this University on migration after completing all the necessary formalities prescribed in this behalf, unless you are already a registered student of this University.

c) You will be required to deliver one seminar talk before submission of the thesis pertaining to the project of your research you have undertaken within the period of your research work and before submission of the thesis.

d) i) You will have to published at least one research paper related to your research work in a referred journal / peer reviewed journal and ii) Make two presentation in Conference/Seminar before submission of the thesis and produce evidence for the same in the form of acceptance letter / reprint / certificate of presentation as applicable at the time of submission of your thesis.

e) You will have to submit your thesis within six years from the date of your registration for Ph.D. degree mentioned above, but not earlier than 09.09.2024 (three years including course work) in the prescribed manner along with the fee of Rs. 8,000/- (Eight thousand only) or as may be fixed by the Executive Council from time to time towards submission of thesis.

- f) i) You will be required to appear before **Research Advisory Committee** once in six months to make a presentation of the progress of his/her work for evaluation and further guidance. This six-monthly report shall be submitted by the Research Advisory Committee to the Board of Research Studies with a copy to the research scholar.
- ii) In case the progress of the research scholar is unsatisfactory, the Research Advisory Committee shall record the reasons for the same and suggest corrective measures. If the research scholar fails to implement these corrective measures, the Research Advisory Committee may recommend to the Faculty Council for PG Studies concerned through the Board of Research Studies with specific reasons for cancellation of the registration of the research scholar.
- g) The women candidate & persons with disability (More than 40%) may be allowed a relaxation of two years for Ph.D Programme in the maximum duration. The women candidates may avail **Maternity Leave/Child care Leave once in the entire duration of Ph.D Programme upto 240 days** with the permission of the Chairman, Doctoral Committee.
- h) In your case, **four/five copies** of the thesis along with a **C.D. in PDF format** (containing the Synopsis and the Thesis) be submitted and one copy be retained by you as a reference copy.
- i) At the time of submission of thesis, a certificate in the prescribed form furnished by your Supervisor(s) will have to be pasted on all the copies of the thesis.
- j) **The registration granted under this letter will remain valid for six years from the date of registration.** In the event of failure of submission of the thesis within the stipulated period, re-registration may be sought for and the same may be granted after observing all the formalities required in this behalf and on the receipt of the prescribed fee(s). Application for re-registration may be sought within the stipulated period i.e. within six years.
- k) The registration granted herein may be cancelled by the concerned authority/ body of the University in the event of failure of the candidate to fulfill any of the prescribed requirements at any stage.
- l) Residential requirements should be fulfilled and maintained.
- m) While submitting for evaluation, the thesis shall contain an undertaking from the research scholar and a certificate from the research Supervisor(s) attesting to the **Originality of the work, vouching that there is no Plagiarism and that the work has not been submitted for the award of any other degree/diploma of the University or to any other institution.**
- n) You will be required to submit six typed copies of Synopsis/Abstract of the thesis (not exceeding ten pages) along with the certificate mentioned in Clause(l) above and a certificate of delivering Seminar talk(s) and the Clearance Certificate from the Librarian of the Central Library, Burdwan University at the time of submission of thesis.

Yours faithfully,

Bhattacharjee

In Charge

Research Section

No. R/Ph.D./Regn./ *sc/Env.sc/5811(4)*

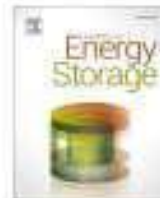
Dated: *26.06.2023*

Copy forwarded for information to:

- 1) The Head of the Department of Environmental Science, B.U.
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Research Section



Research Paper

Mn-doped NiWO₄ quantum dots with superior electrochemical and conductivity performance for energy storage application

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ABSTRACT

Monoclinic amorphous Ni_{1-x}Mn_xWO₄ ($x = 0.00, 0.02$) compounds have been successfully synthesized by hydrothermal technique for achieving better capacitive and conductive performances. Different characterization techniques like X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), ultraviolet-visible (UV-Vis) and photoluminescence (PL) spectroscopy have been employed to investigate their structural, microstructural, and optical properties. Mn-ion incorporation in the NiWO₄ lattice reduces the particle size of the sample to ~4.5 nm, compared to the pure undoped NiWO₄ sample (~18 nm), confirmed from the transmission electron microscopy image and Brunauer-Emmett-Teller analyses (BET). Tauc plot of Ni_{0.98}Mn_{0.02}WO₄ sample exhibits a significant increase in bandgap energy, compared to pure undoped NiWO₄ sample due to the quantum confinement effect. The electrochemical performance of electrodes made with these materials has been revealed by cyclic voltammetry (CV), galvanostatic charge-discharge (GCD) properties and electrochemical impedance spectroscopy (EIS). Moreover, the addition of 2 % Mn in NiWO₄ causes an increase in specific surface area (117.390 m²/g) due to the reduced particle size of the material, resulting in excellent specific capacitance of 463 F g⁻¹ at 0.5 A g⁻¹ current density. The detailed charge storage mechanism for the improvement of conductivity and electrochemical performance of the Mn-doped NiWO₄ has been revealed in different studies. An asymmetric supercapacitor device (ASC) has been fabricated using Mn-doped NiWO₄ electrode material as positive electrode. The device shows superior cyclic stability upto 5000 cycles, can retain 88.4 % of its initial value.

1. Introduction

Electrochemical storage devices such as supercapacitors, fuel cells, and Li-ion batteries are more sustainable clean energies to deal with the global warming issues [1–3]. Among all three renewable energy sources, a supercapacitor is more promising than Li-ion batteries due to its fast charging, longer recyclability, better power density, and easy maintenance. Supercapacitors are classified into two categories, (i) electric double-layer capacitors (EDLC) and (ii) pseudocapacitors [2–5]. Researchers are continuously trying to improve the energy density of

[6,7]. However, some drawbacks of using metal oxides in electrochemical applications include poor conductivity, low energy density, and poor cycle stability [8,9]. It has been revealed from recent works that the electrochemical properties of some complex oxides (such as NiCo₂O₄ and MnCo₂O₄) are superior to single oxides like NiO, MnO₂, and Co₂O₄ because of multiple oxidation states of different metal cations [10–12]. The NiWO₄ compound is an attractive material in the electrochemical field because of its high electrical conductivity of 10^{-2} – 10^{-3} S cm⁻¹ [13–15], which is higher than NiO (10^{-13} S cm⁻¹), and CoWO₄ compounds [16]. It was reported that the incorporated W



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journal homepage: <http://www.elsevier.com/locate/jalcom>Advanced asymmetric supercapacitor with NiCo₂O₄ nanoparticles and nanowires electrodes: A comparative morphological hierarchyMahasweta Chatterjee^a, Samik Saha^b, Sachindranath Das^b, Swapan Kumar Pradhan^{a,*}^a Department of Physics, The University of Burdwan, Burdwan-713104, West Bengal, India^b Department of Instrumental Science, Jadavpur University, Kolkata-700032, India

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ABSTRACT

In the present work, hydrothermal and wet chemical methods are adopted to fabricate NiCo₂O₄ nanowires (NiCo-NW) and NiCo₂O₄ nanoparticles (NiCo-NP) respectively. Owing to the mesoporous nature of these subunits, fast and convenient electron-ion transport and redox reaction, NiCo-NW achieves excellent electrochemical performance. Structure and microstructural characterizations of these samples are carried out by analyzing X-ray diffraction data employing the Rietveld method of structure refinement method and analyzing HRTEM, FESEM images and FTIR spectra. The low dimensional NiCo-NP is found to provide superior electrochemical performance than the NiCo-NW (~13 nm) due to its smaller particle size (~9 nm). This porous structure effectively helps in better transport of ions in the electrolyte. It manifests high specific capacitance 1066.03 F g⁻¹ and enormous areal capacitance up to 5.96 F cm⁻² whereas NiCo-NW exhibits specific capacitance up to 880.72 F g⁻¹ and high areal capacitance of 4.93 F cm⁻². An asymmetric supercapacitor (ASC) has been fabricated with NiCo-NP and activated carbon as positive and negative electrodes respectively in 1 M Na₂SO₄ electrolyte medium. This device offers maximum specific energy 59.56 Wh Kg⁻¹ and maximum power density 3403 W kg⁻¹ with a high energy density of 4.197 Wh Kg⁻¹ and shows excellent cyclic stability.

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1. Introduction

In recent years, enormous attention has been drawn to develop novel materials and devices for the new renewable and sustainable energy sources with high efficiency, high reliability and high energy density. The supercapacitor has been used massively in last few decades as a green energy storage device combining the features of the conventional capacitor (high power density, long cycling life) and rechargeable batteries (high energy density) [1–8]. Based on the charge storage mechanism supercapacitors are of two types: (i) electric double-layer capacitor (EDLC), and (ii) pseudocapacitors. For EDLCs electric energy is stored by separation of charge in Helmholtz double-layer and for pseudocapacitor storage of electric energy is achieved by a faradaic redox reaction with charge transfer [8–10]. Various carbonaceous materials like activated carbon, CNT, graphene are being used as electrode materials for EDLCs for their higher surface area with a porous surface and electrically intercalated networks. EDLCs show high power density, better cycle life

than pseudocapacitor but possess very low specific capacitance. However, due to fast multi electro-redox reaction, pseudocapacitors possess higher specific capacitance, higher energy density than observed in EDLCs [11,12], but it leads to deficient cycle stability because of redox reaction like a battery.

The primary focus of the present work is to improve cell voltage and energy density by developing an ASC device in which (EDLC) electrode has been used as the negative electrode and redox-active transition metal oxides as a positive electrode. The maximum operating voltage in the cell system can be reached by using different potential windows of the two-electrode system. Primarily, activated carbon has been used as the negative electrode and transition metal oxides as a positive electrode. So, the main focus of ASC is to develop better metal oxides for advanced positive electrode [3,13].

Various metal oxides and hydroxides with their variable valence states had been widely used for electrode materials in pseudocapacitors [14,15]. Attempts had been made to prepare inexpensive metal oxides like Co₃O₄ [16,17], NiO [10,18], MnO₂ [19], V₂O₅ [20], Fe₂O₃ [21] for high theoretical capacitance and low toxicity. Both Ni and Co-based materials were considered to be the most admirable

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Enhanced electrochemical properties of Co_3O_4 with morphological hierarchy for energy storage application: A comparative study with different electrolytes

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ABSTRACT

A facile hydrothermal route synthesizes Co_3O_4 nanocrystals with urchin spine-like morphology. Structure and microstructural characterizations of the sample are carried out. Electrochemical properties have been explored in the presence of different electrolytes. In order to find out the best electrolyte, three electrolytes (Na_2SO_4 , NaOH and Na_2SO_4 with Hq) of fixed concentration (1 M) are used to record the cyclic voltammetry data. In the presence of Na_2SO_4 as an electrolyte, specific capacitance becomes 218 F g^{-1} , possibly because of low ionic conductivity of SO_4^{2-} , higher charge transfer resistance. When NaOH and Na_2SO_4 (with Hq) are used as electrolytes, high specific capacitances of 1720 F g^{-1} and 2433 F g^{-1} respectively are obtained due to extra pseudocapacitive effect of redox reaction. It is worth noting that the semicircle diameter in the EIS plot is highest for Na_2SO_4 and lowest for Na_2SO_4 (with Hq) electrolyte. The R_{ct} value depends on the type of electrode and the interaction between electrolyte ions with the electrode.

1. Introduction

Nowadays, one of the primary focuses of the scientific community is to harvest new sustainable energy materials to cope up with the continuous changes in the global climate. The demand for energy, however, is increasing day by day. It becomes very urgent for a scientist to develop new renewable energy sources with high power and better efficiency. It is now well known that supercapacitors have emerged as an alternative energy storage device with better efficiency than a rechargeable battery [1,2]. Supercapacitors exhibit higher energy efficiency, excellent reversibility, higher energy density than a conventional capacitor. Generally, supercapacitors can be classified into three types based on the charge storage mechanism: (i) electrical double-layer capacitor (EDLC), (ii) pseudocapacitors, and (iii) hybrid system. The energy storage mechanism in the electrochemical capacitor is of two types: faradaic and non-faradaic. The non-faradaic reaction arises in the EDLC due to ion adsorption at the electrode/electrolyte [3]. Various carbonaceous materials such as activated carbon, carbon nanotube (CNT), graphene oxide belong to the EDLCs. Such carbonaceous

materials possess a large surface area with a porous surface with the interlaced network [4]. However, EDLCs cannot fulfill the requirement for the peak power assistance in the vehicle since EDLC offers low energy density. Instead, the faradaic pseudocapacitors are based on the fast reversible redox reaction within electroactive materials on the electrode, and its energy density is at least one order of magnitude higher than EDLCs [3,4].

In contrast, various inexpensive transition metal oxides such as Co_3O_4 [1,5–8], NiO [4,9], MnO_2 [10], and Fe_3O_4 [11], NiCo_2O_4 [12] are mainly used as electrode materials for pseudocapacitors. They provide enhanced electrochemical performance over EDLCs because of their higher specific capacitance generating from rapid and productive redox reaction. Finding cheap material with superior pseudocapacitive performance has thus attracted enormous attention. Among all these transition metal oxides, Co_3O_4 has been studied extensively for its supercapacitor application due to its high surface area, easily tunable surface area, multiple oxidation states and tunable structural properties. The Co_3O_4 is a p-type direct optical bandgap semiconductor that shows the high theoretical capacity, excellent corrosion stability and can act as

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Superior photocatalytic performance and photo disinfection of bacteria of solvothermally synthesized mesoporous La-doped CeO₂ under simulated visible light irradiation for wastewater treatment

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ABSTRACT

A simple, cost-effective, and facile solvothermal approach has been adopted to synthesize mesoporous CeO₂ nanostructures with varying La-doping (2, 4, and 6 mol%) concentrations. Photocatalytic and antibacterial performances are investigated against the inactivation of *Escherichia coli* and *Bacillus licheniformis* bacteria cells. Structural and microstructural characterizations of La-doped CeO₂ nanostructures are performed by analyzing X-ray diffraction (XRD) data employing the Rietveld refinement method, scanning electron (SEM) and transmission electron microscopy (TEM) images, Brunauer-Emmett-Teller (BET), energy-dispersive X-ray (EDX), and X-ray photoelectron spectroscopy (XPS) spectra. Among three doped samples, the 4 mol% La-doped CeO₂ (LCe4) has exhibited high oxygen and Ce³⁺ concentrations, high microstrain, small crystallite size, and lowest band gap energy, as are revealed by the analysis of XPS, UV-VIS absorption spectra,

Ultrastable Asymmetric Supercapacitor Device with Chemically Derived and Mechanically Activated NiCo_2O_4

Mahasweta Chatterjee, Adwaita Kundu, Sachindranath Das, and Swapan Kumar Pradhan*

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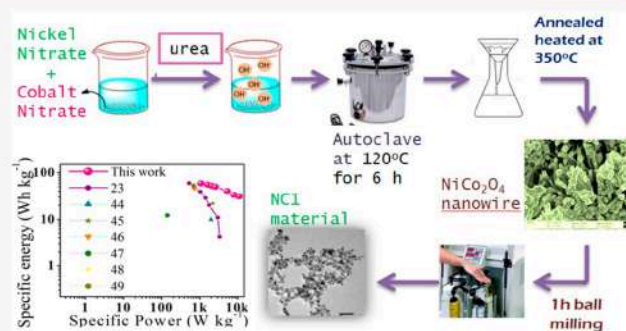
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ABSTRACT: We report the effect of mechanical alloying on the chemically synthesized NiCo_2O_4 nanowire for better electrochemical performance. The nickel cobaltite nanowires (NC) were successfully synthesized via the hydrothermal method without any surfactant. Then they were milled for 1 h (NC1) and 2 h (NC2) to boost the electrochemical performance. The structural and microstructural parameters, shape, size, and morphology of these samples are revealed by X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR) and transmission electron microscopy (TEM) techniques. The Brunauer–Emmett–Teller (BET) characterization and Barrett–Joyner–Halenda (BJH) model reveal that the NC1 sample offers the highest specific surface area among all three samples with its one-dimensional mesoporous structure (pore diameter, ~ 7 nm). The NC1 sample displays an excellent specific capacitance and rate capability (1234 F g^{-1} at a scan rate of 2 mV s^{-1}). However, upon further milling (2 h) the electrochemical performance of the sample decays rapidly due to an increase in particle size and reduction in specific surface area. A remarkable specific capacity of 1196 F g^{-1} is achieved in the 1 h milled sample at the lowest current density of 12 A g^{-1} , and at 40 A g^{-1} and 129.2 F g^{-1} specific capacitance can be retained. We further demonstrate an asymmetric device based on the NC1 sample as a positive electrode, which produces an excellent energy density of $59.221 \text{ Wh kg}^{-1}$ at a power density of 1065.4 W kg^{-1} . The assembled device can attain an outstanding power density of $10.992 \text{ kW kg}^{-1}$ at an enormous high current density of 13.33 A g^{-1} and demonstrates an excellent cyclic performance of 91.7% retention after 5000 cycles.



INTRODUCTION

Due to the rapid growth of portable energy storage systems, mobile systems, and other electronic gadgets, the main interest of scientists in these fields is to develop advanced new generation high energy and power density devices.^{1–3} Various transparent energy storage systems are used in commercial and industrial areas. A supercapacitor can be recognized as an efficient, clean energy storage candidate due to its excellent cycle life, high power density, and better cycle stability. Typically, the charge storage mechanism of a supercapacitor is of two types: one is the capacitive type and the other is the pseudocapacitive type. Generally, the charge storage process of the capacitive type is an electric double-layer capacitor that relies on electrostatic charge storage separation of ions at the electron electrolyte interface.^{4,5}

In contrast, in a pseudocapacitor, capacitance is produced by a fast multielectron faradaic surface redox reaction. The capacitance performance is much better than the electric double-layer capacitor (EDLC), especially in energy density. Several transition metal oxides (NiO , NiCo_2O_4 , CoFe_2O_4 , MnO_2 , and Co_3O_4) and sulfides are vastly used and studied as positive electrodes for their different pseudocapacitive nature.^{6–10} The binary oxides manifest extraordinary electro-

chemical performance than a single metal oxide because of their redox reaction between valence states, large electrode–electrolyte contact surfaces, and many defects, which improves pseudocapacitance as well as the energy density of the material.^{11–13} The crucial parameters which regulate the electrochemical performance are the porosity, particle size, specific surface area, oxygen vacancy, and surface defects. Scientists these days try to incorporate an optimized amount of oxygen vacancy and surface defects to balance the electrochemical performance of the material in a well-mannered way.^{14–16} Since metal oxide with a higher oxygen vacancy ensures a higher CV current and higher positive potential, forming an oxygen vacancy becomes one of the main choices for getting higher electrochemical performance by an easy and economical technique. In metal oxides or ceramics with

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Superior photocatalytic performance and photo disinfection of bacteria of solvothermally synthesized mesoporous La-doped CeO₂ under simulated visible light irradiation for wastewater treatment

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ABSTRACT

A simple, cost-effective, and facile solvothermal approach has been adopted to synthesize mesoporous CeO₂ nanostructures with varying La-doping (2, 4, and 6 mol%) concentrations. Photocatalytic and antibacterial performances are investigated against the inactivation of *Escherichia coli* and *Bacillus licheniformis* bacteria cells. Structural and microstructural characterizations of La-doped CeO₂ nanostructures are performed by analyzing X-ray diffraction (XRD) data employing the Rietveld refinement method, scanning electron (SEM) and transmission electron microscopy (TEM) images, Brunauer–Emmett–Teller (BET), energy-dispersive X-ray (EDX), and X-ray photoelectron spectroscopy (XPS) spectra. Among three doped samples, the 4 mol% La-doped CeO₂ (LCe4) has exhibited high oxygen and Ce³⁺ concentrations, high microstrain, small crystallite size, and lowest band gap energy, as are revealed by the analysis of XPS, UV–VIS absorption spectra, photoluminescence (PL) spectra, and Rietveld refinement result. The LCe4 sample with the highest number of oxygen vacancies and high surface area shows superior photocatalytic activity (~95% Rhodamin B (RhB) degradation in 130 min, ~70% Methylene Blue (MB) degradation within 30 min, and ~95% phenol degradation in 180 min under solar radiation). It shows a striking photo-disinfection effect and enhanced antibacterial activity (almost identical to a pure drug) against gram-positive and gram-negative bacteria under visible light irradiation. This novel disinfection and catalytic property of the LCe4 sample is attributed to the mesoporous structure of materials and surface activity, which lowers the electron-hole recombination rate and transports more photogenerated electrons and holes. The nanostructured mesoporous LCe4 material has been used as an effective visible light-activated photocatalyst and photo disinfection for treating wastewater containing organic dyes and gram-negative and gram-positive bacteria.

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1. Introduction

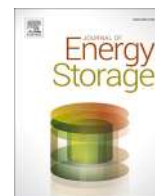
Water pollution from mixing hazardous materials and heavy metals has become a serious global issue. Because of water pollution, various water-born diseases become vulnerable to humanity in most developing countries due to the lack of adequate purifier systems like UV radiation and chlorofication, particularly in rural areas. Thus, the availability of purified drinking water becomes a critical issue for the increasing population. Photocatalytic degradation of pollutants is a facile green chemical, sustainable and cost-effective method to

remove contaminants from wastewater containing organic dyes [1–3].

CeO₂ is considered one of the most abundant rare earth oxides frequently used in electrochemical cells, energy storage and optical devices, photocatalysis, and as a biomaterial. CeO₂ is an n-type semiconductor material with various chemical and physical properties, like pollutant elimination with non-toxicity [5–7]. The main feature of CeO₂ is the transformation of the Ce⁴⁺ to Ce³⁺ valence state, which causes oxygen vacancies and a high stoichiometry deviation, consequently increasing visible light absorbance [4–8]. Various reports on CeO₂ as a photocatalyst with different morphologies, like nanocube, nanowire, and nanodisc, using different templates are available. The present study intends to develop CeO₂ nanomaterials with an optimum mesoporous structure and

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Research Paper

Mn-doped NiWO₄ quantum dots with superior electrochemical and conductivity performance for energy storage applicationMahasweta Chatterjee^a, Samik Saha^b, Tuli Chatterjee^c, Sachindranath Das^b, Swapan Kumar Pradhan^{a,*}

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ABSTRACT

Monoclinic amorphous Ni_{1-x}Mn_xWO₄ (x = 0.00, 0.02) compounds have been successfully synthesized by hydrothermal technique for achieving better capacitive and conductive performances. Different characterization techniques like X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), ultraviolet-visible (UV-Vis) and photoluminescence (PL) spectroscopy have been employed to investigate their structural, microstructural, and optical properties. Mn-ion incorporation in the NiWO₄ lattice reduces the particle size of the sample to ~4.5 nm, compared to the pure undoped NiWO₄ sample (~18 nm), confirmed from the transmission electron microscopy image and Brunauer-Emmett-Teller analyses (BET). Tauc plot of Ni_{0.98}Mn_{0.02}WO₄ sample exhibits a significant increase in bandgap energy, compared to pure undoped NiWO₄ sample due to the quantum confinement effect. The electrochemical performance of electrodes made with these materials has been revealed by cyclic voltammetry (CV), galvanostatic charge-discharge (GCD) properties and electrochemical impedance spectroscopy (EIS). Moreover, the addition of 2 % Mn in NiWO₄ causes an increase in specific surface area (117.390 m²/g) due to the reduced particle size of the material, resulting in excellent specific capacitance of 463 F g⁻¹ at 0.5 A g⁻¹ current density. The detailed charge storage mechanism for the improvement of conductivity and electrochemical performance of the Mn-doped NiWO₄ has been revealed in different studies. An asymmetric supercapacitor device (ASC) has been fabricated using Mn-doped NiWO₄ electrode material as positive electrode. The device shows superior cyclic stability upto 5000 cycles, can retain 88.4 % of its initial value.

1. Introduction

Electrochemical storage devices such as supercapacitors, fuel cells, and Li-ion batteries are more sustainable clean energies to deal with the global warming issues [1–3]. Among all three renewable energy sources, a supercapacitor is more promising than Li-ion batteries due to its fast charging, longer recyclability, better power density, and easy maintenance. Supercapacitors are classified into two categories, (i) electric double-layer capacitors (EDLC) and (ii) pseudocapacitors [2–5]. Researchers are continuously trying to improve the energy density of supercapacitors without hampering their power density and cycle life. Pseudocapacitor materials store more energy than an electric double-layer capacitor.

For this reason, various binary and ternary metal hybrid oxides with different morphologies were synthesized for supercapacitor applications

[6,7]. However, some drawbacks of using metal oxides in electrochemical applications include poor conductivity, low energy density, and poor cycle stability [8,9]. It has been revealed from recent works that the electrochemical properties of some complex oxides (such as NiCo₂O₄ and MnCo₂O₄) are superior to single oxides like NiO, MnO₂, and Co₃O₄ because of multiple oxidation states of different metal cations [10–12]. The NiWO₄ compound is an attractive material in the electrochemical field because of its high electrical conductivity of ~10⁻⁷–10⁻³ S cm⁻¹ [13–15], which is higher than NiO (10⁻¹³ S cm⁻¹), and CoWO₄ compounds [16]. It was reported that the incorporated W atoms had improved the electrical conductivity and electrochemical activity of the compound [17]. Recent reports on core-shell heterostructures with multi-component, such as MnCo₂O₄/NiWO₄, Ni₂Co₂O₄/NiWO₄, and NiWO₄/NiCo₂O₄ grown on nickel foam showed enormous high electrochemical performance than the NiWO₄ lattice

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Synthesis and characterization of a novel nanocarrier for biocompatible targeting of an antibacterial therapeutic agent with enhanced activity

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ABSTRACT

This study reveals a new strategy to enhance the activity of an antibacterial drug by conjugating it with a Cu–Ag–based nanocarrier. The Cu–Ag–Co₃O₄–TiO₂ nanocomposite is successfully synthesized by mechanical alloying and applied for biocompatible targeting of an antibacterial drug by conjugating the drug (10 wt%) with the nanocarrier. The samples have been well-characterized by the Rietveld refinement of the XRD pattern and by analyzing TEM, FESEM images, and FTIR spectra. The successful formation of the drug conjugated nanocomposite sample has also been verified from the EDS and UV–Vis absorption spectra. Both the samples are non-toxic to the normal human cells which have been confirmed by cell viability assay on human normal lung fibroblast WI38 cells. Antibacterial activities of both the samples against the bacteria *E. coli* have been investigated by the agar cup diffusion method and minimum inhibitory concentration (MIC) study. The 10 wt% amoxicillin conjugated nanocomposite shows the same effect as the pure (100 wt %) drug. The enhanced activity of the drug conjugated nanocomposite is due to the more significant interaction of the drug conjugated nanocomposite with the cell wall and membrane of the bacteria as compared to the pure drug. It is confirmed by measuring the change of conductivity and total protein leakage in the culture filtrate of the nanocomposite, pure drug, and drug conjugated nanocomposite treated culture of *Bacillus subtilis*. This strategic protocol is found to have great importance for enhancing the efficacy of a standard antibiotic drug.

1. Introduction

In recent days, the world faces a growing antimicrobial resistance problem, as some pathogens have become resistant to a comprehensive class of antibiotics [1,2]. The overuse of antibiotic drugs is the most significant driver of this antimicrobial resistance [3]. The bacterial resistance against these β -lactam antibiotics is due to the production of β -lactamases primarily produced by gram-negative bacteria. It breaks the β -lactam ring of the antibiotic and provides antibiotic resistance [4]. This kind of resistance can be overcome by conjugating the antibiotic with nanostructured composite materials [5]. These nanoparticles are reported to possess antibacterial activities and can be used in targeted drug delivery. The potency of a large number of antibiotics is limited due to low membrane transport. The drug conjugated

nanoparticle/nanocomposite (ND) can enter the cell by endocytosis, thus facilitating intracellular entry [6]. The interactions with the surface lipids help to achieve membrane penetration. Thus they provide physical protection against the various mechanism of bacterial resistance [7].

Nanoparticles inhibit bacterial growth by multiple mechanisms, which are as follows: (a) they interact with the bacterial cell wall, (b) damage the bacterial cell membrane by ROS generation, (c) the biofilm formation can be inhibited due to the effect of nanoparticles [8,9]. The main advantage of nanoparticles is their small size and the large surface-to-volume ratio [10]. They can protect antimicrobial compounds against enzymes that can break the structure of the drugs. Thus they can deliver the antibiotics actively to the desired site.

Amoxicillin is a β -lactam antibiotic. It inhibits the cell wall synthesis of bacteria. The transpeptidation process can be inhibited due to the

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Phase crossover induced by dynamical many-body localization in periodically driven long-range spin systems

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Dynamical many-body freezing occurs in periodic transverse field-driven integrable quantum spin systems. Under freezing conditions, quantum dynamics causes practically infinite hysteresis in the drive response, maintaining its starting value. We find similar resonant freezing in the Lipkin-Meshkov-Glick (LMG) model. In the LMG, the freezing conditions in the driving field suppresses the heating postulated by the *eigenstate thermalization hypothesis* (ETH) by inducing *dynamical many-body localization*, or DMBL. This is in contrast to many-body localization (MBL), which requires disorder to suppress ETH. DMBL has been validated by the inverse participation ratio (IPR) of the quasistationary Floquet modes. Similarly to the TFIM, the LMG exhibits high-frequency localization only at freezing points. IPR localization in the LMG deteriorates with an inverse system size law at lower frequencies, which indicates heating to infinite temperature. Furthermore, adiabatically increasing frequency and amplitude from low values raises the Floquet state IPR in the LMG from nearly zero to unity, indicating a phase crossover. This occurrence enables a future technique to construct an MBL engine in clean systems that can be cycled by adjusting drive parameters only.

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I. INTRODUCTION

In the past few years, periodically driven quantum many-body systems have been of considerable theoretical and experimental interest [1,2]. Under certain conditions in the drive parameters, they can experience dynamical many-body freezing (DMF), which causes the response to freeze completely to its initial value at all times [3–5]. This arises as a consequence of additional approximate symmetries that occur at the freezing points [6]. DMF has been demonstrated via the rotating wave approximation (RWA) in the driven transverse field Ising model (TFIM) with nearest-neighbor interactions [7] and is shown to be protected when translational invariance is explicitly broken (say, by disorder) [8,9].

The utilization of Floquet theory simplifies the analysis of time-periodic systems. For closed quantum systems governed by the time-dependent Schrödinger equation, the *Floquet Hamiltonian* allows for a mapping of the time-dependent dynamics into the dynamics of a time-independent effective Hamiltonian, provided the system is strobed at integer multiples of the time period of the drive. The time-independent eigenstates of the effective Hamiltonian correspond to quasistationary *Floquet Modes* of the original Hamiltonian. The temporal progression of the system comes from phase coefficients that capture the dynamics [10,11].

Any sufficiently complex nonintegrable many-body system is expected to thermalize according to the eigenstate thermalization hypothesis (ETH) despite the fact that closed quantum dynamics preserves the memory of the initial state

of the system. This arises due to the properties of the matrix elements of observables in typical states [12]. The ETH can be readily adapted to time-periodic systems using Floquet theory (the Floquet-ETH, or FETH [13–16]). Nonetheless, the conditions for ETH to hold are not particularly strong, and the density matrix of the system can fail to approach one that is described by a thermal expression. Thermal systems must conduct because they exchange energy and particles internally during thermalization. Thus, insulating systems can be naturally athermal; many-body localization (MBL) is a well-studied case [17]. This phenomenon is stable against local perturbations, and constitutes an exotic state of matter with far-reaching implications in theoretical physics, as well as in practical applications [18].

The addition of disorder has been identified as a crucial component in the onset of MBL. In that case, thermalization is prevented by disorder-induced localization. Nonetheless, alternative approaches to MBL in strongly interacting disorder-free systems [19–21], inhomogeneous systems [22–25], and by inducing disorder in the emergent physics [26] and by other effective means [24] (albeit with strong finite-size effects), have been reported. An alternative approach to realizing MBL in disorder-free *homogeneous* many-body systems involve *Floquet engineering*, where a time-periodic drive is introduced, and the drive parameters tuned to introduce a clustering of quasistationary energies in a manner similar to localization [12].

In this article, we use the fact that emergent approximate symmetries can be engineered in Floquet systems [6,27] and apply it to long-range interactions. This results in *dynamical many-body localization* (DMBL) at specific values of the drive parameters, and complete thermal behavior at other values.

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PAPER

Time crystal embodies chimera-like state in periodically driven quantum spin system

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E-mail: mrahaman@scholar.buruniv.ac.in and daneel@utexas.edu**Keywords:** chimera in a quantum system, time crystal, dynamical many-body localization, periodic drive

Abstract

Chimera states are a captivating occurrence in which a system composed of multiple interconnected elements exhibits a distinctive combination of synchronized and desynchronized behavior. The emergence of these states can be attributed to the complex interdependence between quantum entanglement and the delicate balance of interactions among system constituents. The emergence of discrete-time crystal (DTC) in typical many-body periodically driven systems occurs when there is a breaking of time translation symmetry. Coexisting coupled DTC and a ferromagnetic dynamically many-body localized (DMBL) phase at distinct regions have been investigated under the controlled spin rotational error of a disorder-free spin-1/2 chain for different types of spin-spin interactions. We contribute a novel approach for the emergence of the DTC-DMBL-chimera-like state, which is robust against external static fields in a periodically driven quantum many-body system.

1. Introduction

The phenomenon of a *chimera state* is observed in coupled systems of identical nonlinear oscillators, when spontaneous synchronized and desynchronized dynamics coexist simultaneously [1, 2]. Kuramoto *et al* first detected this phenomena in a network of non-locally coupled phase oscillators in 2002. Two domains of coherent oscillations with unique frequencies and incoherent oscillations with distributed frequencies were observed. [1]. These patterns were called ‘chimera states’ by Strogatz [3]. Chimeras have been widely explored in classical systems over the last decade [4–6]. The origin of the chimera lay in the symmetry-breaking bifurcation in the Kuramoto model, which led to a breakdown of global synchronization. This gave rise to a chimera state where spatially distinct regions exhibit different synchronization behaviors [7]. The coexistence of synchronized and desynchronized states in a chimera state can be considered a manifestation of spontaneous symmetry breaking in the context of nonlinear dynamics [8]. In the physical realm, chimera states serve as a possible explanation of unihemispheric slow wave sleep (UHSW) in migrating birds, seals and domestic chicks [9–11]. Chimeras have also been observed in models of electrical power grids, where a synchronous state can be stabilized by tuning the parameters of the generator [12, 13].

Eventually, chimera states were realized in the quantum regime as an ordered phase of matter [14]. However, it has been difficult to extend classical chimeras, which are heavily reliant on nonlinear dynamics, to purely quantum systems with linear unitary dynamics. As a result, quantum chimeras have had to be described in the semi-classical realm. Nonetheless, the possibility of chimeras in closed quantum systems remains, although one needs to take a different approach to create a quantum system where two different dynamics coexist. In fact, states in which two different dynamics coexist in the same quantum system have already been proposed and reported [15–17].

Interest in the formation of chimeras in magnetic systems has recently increased. Curie-Weiss-type models, such as the Ising model [18], are used to represent systems of interacting quantum spins where order