Annexures

Annexure 1

List of publications from thesis and associated works

1. ***Shubhangi**, Rohini Kumari, S.K. Rai, and **Pranjal Chandra***, Electrochemical Assembly of Nickel Metal Organic Framework-Decorated Nanoimprinted Gold Dendrites as Peroxidase Mimic for High-Performance Hydrogen Peroxide Sensing, **ACS Appl. Nano Mater**. 2024, 7, 1, 1388–1401.*

2. ***Shubhangi**, Indrani Nandi, S.K. Rai, **Pranjal Chandra***, MOF-based nanocomposites as transduction matrices for optical and electrochemical sensing, **Talanta**, 2024, 266 (2), 125124.*

3. ***Shubhangi,** Ruchita Chaudhari, S.K. Rai, **Pranjal Chandra***, Engineered Cobalt/Molybdenum Bimetallic MOF as Electrochemical Signal Transducer for Uric Acid Detection, 2024, **IEEE BioSensors Conference (BioSensors)**, Cambridge, United Kingdom, 2024, pp. 1-4, doi: 10.1109/BioSensors61405.2024.10712685.*

4. ***Shubhangi,** Divya, S.K. Rai, **Pranjal Chandra***, Shifting Paradigm in Electrochemical Biosensing Matrices Comprising Metal Organic Frameworks and their Composites in Disease Diagnosis, **WIREs Nanomedicine and Nanobiotechnology**, **2024;** 16:e1980. https://doi.org/10.1002/wnan.1980.*

5. ***Shubhangi,** Rohini Kumari, Kajal Kacchawaha, Sumit K Singh, S.K. Rai, **Pranjal Chandra***, Pristine Ni-MOF sandwiched between 1D and 3D engineered Au sensor for in vitro Folic acid sensing, 2024, (**ACS Anal. Chem.:** In Press; https://doi.org/10.1021/acs.analchem.4c03564).*

6. ***Shubhangi,*** *Rohini Kumari, Arkya Jyoti Ghosh, Supratim Mahapatra, S.K. Rai,* ***Pranjal Chandra*****, Layering pristine Ni and Co MOFs to develop transduction matrix for sensing Sodium Nitrite in water samples, 2024.(****revision submitted****).*

7. ***Shubhangi,*** *Ratul Paul, S.K. Rai,* ***Pranjal Chandra*****, Bimetallic MOFs as trend-shifters in electrochemical sensing modules, 2024.* ***(submitted).***

8. ***Shubhangi,*** *Niharika, Smridhi, Bhadra,* ***Pranjal Chandra*****, Deciphering the functional potential of dopants in 2D material matrix in sensors, 2024. (manuscript under preparation).*

9. ***Shubhangi,*** *Amisha Kushwaha, Ratul Paul,* ***Pranjal Chandra*****, Engineering Cobalt/Molybdenum Bimetallic MOF for Ultraswift detection of Uric Acid, 2024, (under preparation).*

10. ***Shubhangi****, *Marshal Dhayal, Substrate assisted formation of ZIF-8 crystals for tunable size and morphological characteristics: Investigating the role of temperature, method and solvent on the size of ZIF-8 crystals, In: Kumar, V., Dubey, B.K., D. Yadav, K. (eds) Technological Advancements in Waste Management: Challenges and Opportunities. TAWMCO 2023. Lecture Notes in Civil Engineering, vol 542.* ***Springer, Singapore.*** *https://doi.org/10.1007/978-981-97-6024-4_22.*

11. *Rohini Kumari,* ***Shubhangi,*** *Daphika S Dkhar,* ***Pranjal Chandra*****, Metallic Dendrites: How Far Can We Go?, (****ACS Anal. Chem.:*** *In Press; https://doi.org/10.1021/acs.analchem.4c06456).*

12. *Divya,* ***Shubhangi****,* ***Pranjal Chandra*****, Electrochemical Synthesis of Pristine MOF for High Performance Sensing of Caffeine in Beverages, 2024.* ***(revision submitted)****.*

13. *Divya, **Shubhangi**, **Pranjal Chandra***, Electrochemical Synthesis of Engineered Bimetallic Pristine MOF-MoS2 Nanocomposite for Sensing Application, 2024, **IEEE BioSensors Conference (BioSensors)**, Cambridge, United Kingdom, 2024, pp. 01-04, doi: 10.1109/BioSensors61405.2024.10712708.*

14. *Ankur Singh, **Shubhangi, Pranjal Chandra***, Molecularly Imprinted Polymers as Emerging Engineered Platforms for Precision Molecular Sensing **(under revision).***

15. *Marshal Dhayal, **Shubhangi,** Juhi Jaiswal, Electrodeposited folic acid platinum electrode for rapid detection of human hepatocellular carcinoma cells, **Electroanalysis, 2023,** e202200482 (https://doi.org/10.1002/elan.202200482)**.***

16. *Rohini Kumari, Aditi Sammi, **Shubhangi,** Ananya Srivastava, U P Azad, **Pranjal Chandra***, Emerging 3D Nanomaterials as Electrocatalysts for Water-Splitting Reactions, **International Journal of Hydrogen Energy,** 2024, 74, 214-231.*

Patents during Ph.D.

1. *Authors: Pranjal Chandra, **Shubhangi,** Rohini Kumari, S.K. Rai.*

*Title: **AN ELECTROCHEMICAL SENSOR AND A METHOD OF FABRICATION THEREOF, 2024, Status:*** Filed***, Patent Application No.:** 202411082613.*

2. *Authors: Pranjal Chandra, Divya, **Shubhangi.***

*Title: **A METAL ORGANIC FRAMEWORK BASED SENSOR AND A METHOD OF FABRICATION THEREOF, 2025, Status:*** Filed***, Patent Application No.:** 202511001234.*

3. *Authors: Pranjal Chandra, Divya, **Shubhangi.***

*Title: **HIGHLY CATALYTIC AND CONDUCTIVE BIOMETALLIC MOF FOR CAFFEINE SENSING APPLICATION, 2025, Status:*** Processed.

ACS APPLIED NANO MATERIALS

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Electrochemical Assembly of Nickel Metal Organic Framework-Decorated Nanoimprinted Gold Dendrites as Peroxidase Mimic for High-Performance Hydrogen Peroxide Sensing

Shubhangi, Rohini Kumari, S.K. Rai, and Pranjal Chandra*

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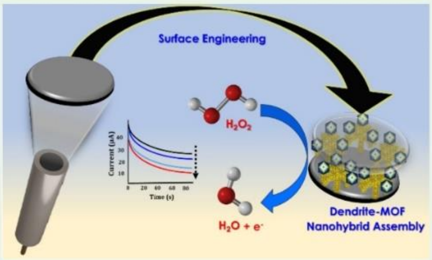

ABSTRACT: Hybrid nanomaterials with distinct properties and morphologies when clubbed within a sensor matrix can generate a synergistic effect on molecular sensing. In this work, creation of such nanohybrid platform has been attempted for rapid detection of hydrogen peroxide (H_2O_2), which has tremendous role in area of medical diagnostics. Conventionally, the peroxidase (POD) enzyme catalyzes H_2O_2; however, it is prone to inherent chemical and thermal instabilities reducing the overall stability and shelf life of sensor probe. A possible solution for this problem has been attempted in this work where a nonenzymatic peroxidase mimic nanohybrid probe comprising gold nanodendrites (AuND), nickel metal organic framework (Ni-MOF), and hydrazine has been synergistically deployed for rapid detection of H_2O_2. The developed sensor probe has been rigorously characterized through various characterization techniques, including scanning probe microscopy (SPM), scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX-mapping), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction analysis (XRD), X-ray photoelectron spectroscopy (XPS), cyclic voltammetry (CV), and electrochemical impedance spectroscopy (EIS). The probe demonstrated impressive analytical performance, possessing a linear dynamic range (LDR) between 1×10^{-8} M and 1×10^{-15} M and a limit of detection (LOD) of 0.34 ($\pm$0.05) $\times 10^{-15}$ M. The probe's average response time with changing H_2O_2 concentrations was 5.02 $\pm$ 0.42 s, making it an agile sensing platform for H_2O_2 detection. The nanohybrid probe displayed minimal response toward interferants such as superoxide radicals, ascorbic acid, cysteine, glucose, alanine, and citric acid, which usually coexist in a real sample matrix. In order to investigate the real-life applicability of the developed sensor probe, a real sample analysis involving synthetic serum was adopted, which yielded a current recovery between 90.20 and 94.14%. The probe fabrication time and on-chip synthesis procedure are facile, making it a robust and efficient sensing platform for H_2O_2 free radicals in clinical settings.

KEYWORDS: *electrodeposition, hydrogen peroxide, nanodendrites, MOF, surface engineering, nanohybrid systems*

1. INTRODUCTION

H_2O_2, an intermediate in various biological reactions and signaling pathways, is difficult to detect in natural premises due to its instability. However, its excessive concentration can pose threat to cellular health by damaging vital proteins and DNA due to the generation of reactive oxygen species. In view of the importance of H_2O_2, a number of analytical techniques such as colorimetry, fluorescence,[1] gas chromatography, high-performance liquid chromatography (HPLC),[2] and HPLC-UV[3] have been used. Techniques like chromatography and colorimetry are highly skill-dependent ones with necessary preprocessing requirements incurring higher costs and labor for the target specimen detection.[4] Whereas, techniques such as fluorescence can have hindered outcomes due to involvement of interferants. Therefore, to avoid such limitations, electrochemical sensing approach could be a plausible solution due to its rapid response, ease of procedure, sensitivity, and low cost.[5,6]

Enzymatic sensors are widely being used nowadays for sensitive and selective sensing of H_2O_2. POD is a naturally occurring enzyme found in many plants as well as in a few animal cells. This enzyme is known to be highly selective toward combining with H_2O_2 and methyl or ethyl peroxides.[7] Horseradish peroxidase, a heme-containing enzyme of this class, is known to utilize H_2O_2 in order to oxidize a vivid

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analytical chemistry

pubs.acs.org/ac Article

Pristine NiMOF Sandwiched between 1D and 3D Engineered Au Particles on a Dendritic Platform for Ultraswift Folic Acid Sensing in Cellular Microenvironments

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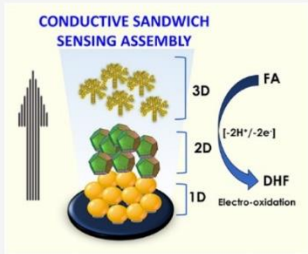
ABSTRACT: Catalytic metal-organic frameworks (MOFs)-based sensor matrices can act synergistically with Au metallic nanostructures to generate amplified signal readouts by causing the electro-oxidation of the target analyte. Folic acid (FA), an essential water-soluble vitamin and a precursor for enzymes, requires timely and precise monitoring in the serum of individuals with varying clinical diagnoses. An attempt has been made in this direction through our work, where the rapid detection of FA through its oxidation at metal centers from hybrid nanomaterials is deployed for signal generation. A nonenzymatic, nonimmunometric approach involving a sandwich model, comprising NiMOF layered between gold nanoparticles (AuNPs) and gold nanodendrites (AuNDs) incorporated within a sensor matrix, has been deployed for this purpose. The probe displayed great analytical performance with a linear dynamic range (LDR) from 1×10^{-11} M to 1×10^{-3} M and a limit of detection (LOD) of 0.43×10^{-11} M. The probe's average response time with respect to changes in FA concentration was recorded as less than 2.1 s, making it a rapid sensing platform for FA detection. The real-life applicability of the developed sensor was tested in serum, followed by analysis in a breast cancer cellular microenvironment, which yielded a current recovery between 95.11 and 98.17%. The *in vitro* analysis was further validated through live-cell imaging using the standard method of fluorescence. The shorter fabrication time of the developed sensor compared to existing ones makes it a facile and efficient sensing platform for FA detection in clinical settings. This study represents the first report on the conjunction of 1D, 2D, and 3D materials as a sensing matrix for molecular detection applications.



■ INTRODUCTION

Folic acid (FA), commonly known as pteroylglutamic acid, is an essential water-soluble vitamin (vitamin B9) of the B-complex category. Its primary essentiality revolves around important bodily functions, serving as a precursor for various coenzymes such as ferroheme and contributing to the synthesis of purines and pyrimidines. Consequently, it plays a vital role in the repair, methylation, and synthesis of DNA.[1,2] It is a synthetic substitute for vitamin B9 or folacin, chemically known as (2S)-2-[[4-[(2-amino-4-oxo-1H-pteridin-6-yl)-methylamino]benzoyl]amino] pentanedioic acid. It gained prominence at the beginning of the century as understanding of its deficiency grew.[3,4] A decrease in its body fluid concentration ($34.4 \pm 10.4 \times 10^{-9}$ M) has been linked to various diseases such as mental deconvolution, leucopoenia, gigantocytic anemia, and increased possibilities for heart attacks and cancer.[5] While its supplementation reduces the occurrence of neural tube defects such as spinal bifida in women and decreases carcinogenesis due to its involvement in nucleotide synthesis, the overexpression of its receptors on cancerous cells makes them classic tumor markers due to the increased metabolic FA uptake by these cells.[6−8] There have been conflicting reports on its role in suppressing as well as increasing carcinogenesis in clinical subjects with varying clinical diagnoses.[9−11] This makes its judicious supplementation and quantitative detection through selective and sensitive sensing modules the need of the hour. While it is naturally synthesized in green leafy plants, algae and microbes such as yeast and bacteria, its deficiency is coped up in humans through dietary or pharmaceutical supplementation.[12]

FA detection has been practiced through various methods including the traditional spectrophotometry,[13] colorimetry,[14] mass spectroscopy,[15] and electrophoretic[16] methods along with sophisticated methods like high-performance liquid chromatography,[17] flow injection chemiluminescence,[18] ELISA,[19] and many others. The major drawback of these methods is that they require expensive setups and expertise in operations and are time-consuming. To overcome these challenges, newer and more sensitive tools such as electro-

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MOF-based nanocomposites as transduction matrices for optical and electrochemical sensing

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ABSTRACT

Metal Organic Frameworks (MOFs), a class of crystalline microporous materials have been into research limelight lately due to their commendable physio-chemical properties and easy fabrication methods. They have enormous surface area which can be a working ground for innumerable molecule adhesions and site for potential sensor matrices. Their biocompatibility makes them valuable for *in vitro* detection systems but a compromised conductivity requires a lot of surface engineering of these molecules for their usage in electrochemical biosensors. However, they are not just restricted to a single type of transduction system rather can also be modified to achieve feat as optical (colorimetry, luminescence) and electro-luminescent biosensors. This review emphasizes on recent advancements in the area of MOF-based biosensors with focus on various MOF synthesis methods and their general properties along with selective attention to electrochemical, optical and opto-electrochemical hybrid biosensors. It also summarizes MOF-based biosensors for monitoring free radicals, metal ions, small molecules, macromolecules and cells in a wide range of real matrices. Extensive tables have been included for understanding recent trends in the field of MOF-composite probe fabrication. The article sums up the future scope of these materials in the field of biosensors and enlightens the reader with recent trends for future research scope.

1. Introduction

MOFs are a diverse class of multifunctional, crystalline and porous materials with their evolution dating back to late 1990s [1]. These porous materials often referred to as 'coordination polymers', are formed through coordination of organic linker molecules with metal ions by their self-assembly [2,3]. They find their applications in a plethora of fields ranging from gas storage [4–7], gas separation [8], catalysis [9–12] to drug delivery, theranostics and sensing [13–17]. For example, Cu-based MOFs are often used as nanozymes like proteases, peroxidases and laccases [18–20]. The applications of these MOFs are supported by their commendable properties such as uniform and tunable pore sizes, large accessible surface area, high thermal and chemical stabilities [1]. Some MOFs have intrinsic properties like low toxicity, inherent stability and good biocompatibility such as Zr-based MOFs [21]. However, for expansion and enrichment of their properties, further, these MOFs are often decorated with functional species to form composite materials with synergistic or improved features [22–24]. For example, Wen et al. in their recent work improved the electron-transfer efficiency of ZIF-8 by conjugating it with graphene for fabrication of a pesticide biosensor matrix [25]. Similarly, in a work by Lai et al. [26], a porphyrin-based MOF was doped with Mn^{2+} ions to selectively detect glutathione. In another study by Kulandaivel et al. [27], copper-based MOF nanozymes after being doped with Cu^{2+} ions, were found to be catalytic with oxidoreductase activity which helped in enhanced colorimetric paper-based detection of Cr^{6+}. Apart from doping, the key to MOF's reticular design lies with binding of metal nodes to different linker molecules yielding MOF structures of varying pore sizes and morphology. There is liberty for precise control of preferred topology by change in the molecular building blocks [28]. The guest accessible voids can be exploited as per needs for the development of optical, electromechanical, electrochemical, chemicapacitor sensors, and sensor arrays. For sensing applications, the target moiety's counter molecule can be either encapsulated or adsorbed on the MOF surface making its physical

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ADVANCED REVIEW

WIREs NANOMEDICINE AND NANOBIOTECHNOLOGY WILEY

Shifting paradigm in electrochemical biosensing matrices comprising metal organic frameworks and their composites in disease diagnosis

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Abstract

Metal Organic Frameworks (MOFs) are an evolving category of crystalline microporous materials that have grabbed the research interest for quite some time due to their admirable physio-chemical properties and easy fabrication methods. Their enormous surface area can be a working ground for innumerable molecular adhesions and site for potential sensor matrices. They have been explored in the last decade for incorporation in electrochemical sensor matrices as diagnostic solutions for a plethora of diseases. This review emphasizes on some of the recent advancements in the area of MOF-based electrochemical biosensors with focus on various important diseases and their significance in upgrading the sensor performance. It summarizes MOF-based biosensors for monitoring biomarkers relevant to diabetes, viral and bacterial sepsis infections, neurological disorders, cardiovascular diseases, and cancer in a wide range of real matrices. The discussion has been supplemented with extensive tables elaborating recent trends in the field of MOF-composite probe fabrication strategies with their respective sensing parameters. The article sums up the future scope of these materials in the field of biosensors and enlightens the reader with recent trends for future research scope.

This article is categorized under:
Diagnostic Tools > Biosensing
Diagnostic Tools > Diagnostic Nanodevices

KEYWORDS
diagnosis, disease, electrochemical biosensors, metal organic frameworks, nanobioengineering

1 | INTRODUCTION

In recent times, the convergence of nanotechnology, materials science, and bioengineering has led to revolutionary progress in the advancement of biosensors, heralding a new age of accurate diagnosis and personalized healthcare (Borse et al., 2022; Chandra & Prakash, 2020; Huang, Zhu, & Kianfar, 2021). The increasing worldwide prevalence of infectious and fatal diseases, including those that can be transmitted and others that cannot, highlights the dire need for diagnostic methods that are simple, fast, accurate, and affordable (Mahato et al., 2016). Conventional

Engineered Cobalt/Molybedum Bimetallic MOF as Electrochemical Signal Transducer for Uric Acid Detection

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***Abstract*—**

Electrochemical signal transduction systems involving metal organic frameworks (MOFs) are new buzz words in sensing due to their astounding functional capabilities and catalytic potential. In this work, creation of one such novel sensing platform comprising of cobalt/molybdenum (Co/Mo) bimetallic MOF has been attempted for the sensitive detection of uric acid (UA) in clinical ranges. Conventionally, UA is detected through an enzyme called uricase which converts UA to allantoin. However, the enzyme-based diagnostic solutions are prone to chemical and thermal instabilities making the process cumbersome and tedious. To eliminate such challenges, the developed non-enzymatic detection system uses a highly catalytic bimetallic sensing module which electrochemically facilitates conversion of UA to allantoin, and yields electrochemical signal outcomes. The developed sensing probe was characterized through physical and electrochemical techniques such as scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR) and, cyclic voltammetry (CV). Here, UA has been used as the sample target analyte to validate the efficacy of the bimetallic system using differential pulse voltammetry (DPV) and chronoamperometry (CA). The preliminary results hold immense promise for the developed system in application for sensing a wide range of analytes through electrochemical methods in clinical settings.

Keywords—metal organic framework; uric acid; nanocomposite; electrochemical; biosensing

I. Introduction

MOF, a class of self-assembled coordination complex-based porous materials, comprise of metal centre coordinated with organic linker moieties to form two or three-dimensional structures [1]. They have been designated as materials with high specific surface area, tunable mesoporosity, diverse catalytic metal centers linked to organic ligands with good adsorption affinities and superior redox behaviour [2]. These porous materials have found their utility in innumerable applications ranging from gas storage to catalysis and now to analytical applications like sensors and drug delivery systems [3]. However, the major challenges with working on these materials lies primarily with their wide band gap resulting into compromised electrochemical conductivity, heavily aggregated morphology and high resistance to diffusion [1]. Such phenomena have usually been observed in MOFs synthesized through the conventional solvothermal route which are now being replaced by newer synthesis protocols involving microwave, sonochemical and electrochemical methods [3]. MOFs have been projected as plausible solutions towards replacing enzyme-based sensors due to their catalytic metal centers imparting them with electrocatalytic potential [4]. Co-based MOFs have been recently reported as sensitive electrode matrix components for detection of analytes like UA [5].

Uric acid, a bio-compound also known as 2,6,8-trihydroxypurine, is often linked to various biophysiological pathways like purine (adenine and guanine) metabolism and decomposition [1],[5]. An abnormally high concentration or low concentration of UA is regarded as a causative factor for diseases like gout, hypertension, hyperuricemia, cardiovascular and chronic renal diseases, and oxidative stress [4],[6]. The clinical range of UA lies between 0.13-0.46 mM in blood serum and 1.49-4.46 mM in urine samples within healthy individuals [7],[8]. Therefore, a timely check on its physiological concentration holds enormous clinical significance in disease diagnosis. UA is routinely detected through enzyme-based assays or alternatively through spectrometry and chromatography-based methods [6]. However, electrochemical non-enzymatic methods hold great promise for sensing UA due to faster response time, greater selectivity and cheaper operations. Although there always lies a scope for an alteration in sensor components which can improvise sensitivity and contribute towards realistic applications of the sensors.

In this work, we have attempted to fabricate a novel combination of Mo and Co-based bimetallic MOF within a sensor matrix for the selective and sensitive detection of UA through the electrochemical approach. The novelty lies in conjugation of two highly conductive metal centers conjugated with methyl imidazole linker moiety. The

Bimetallic Copper/Zinc Metal Organic Framework-MoS_2 Nanohybrid based Electrochemical Sensor

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***Abstract*— Acetaminophen is a globally used antipyretic analgesic drug to relieve pain. The excess usage of acetaminophen leads to various health implications including cardiovascular ailments, asthma, liver and kidney damage. Bimetallic MOFs are emerging materials in the field of electrochemical sensing domain utilizing the synergistic effect of both the metal ions present within. In this study, we report a sensing matrix comprising of an electrochemically fabricated novel bimetallic MOF (CoZn) conjugated with MoS_2 nanosheets to form an electroconductive nanocomposite. Layer-by-layer characterization of CoZn-MOF/MoS_2 modified electrode surface was done through different electrochemical analytical techniques like CV and EIS. The composite (GCE/CoZn-MOF/MoS_2) can find its applications in sensing a plethora of analytes based on the catalytic potential of the metal nodes. In this work we have attempted the application of the developed nanocomposite probe in the electrochemical oxidation and thereby detection of acetaminophen. The developed nanocomposite was able to detect acetaminophen with enhancement in signal, proving the improved electroconductivity of the surface due to synergistic effect of CoZn-MOF and MoS_2.**

Keywords*—metal organic framework; bimetallic; nanocomposite; electrochemical; sensing

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I. Introduction

Metal-organic frameworks (MOFs), often referred to 'porous coordinate polymers', are a class of recently developed porous materials that are multifunctional, crystalline compounds made up of clusters of metal ions coordinated to organic linkers to form one, two, or three-dimensional structures [1]. The high specific surface area, adjustable pore size, diversity in metal centres, organic ligands, and easy tunability in their morphology has contributed to their current significance in sensing applications [2][3]. The eminence of these structures have resulted to their potential applications in a number of industries, including batteries, supercapacitors, gas separation, adsorption, energy storage, and electrochemical sensors [4]. Contrary to this, a high electron transfer energy barrier of these materials when synthesized through a variety of routes, including the most common solvothermal one makes their usage challenging in electrochemical biosensing [5]. A novel way to tackle this problem could be incorporation of a second metal ion in the MOF's lattice nodes or doping with a highly conductive metal within the MOF cavity or the sensor matrix. The first approach is a lesser transversed route that can be explored to achieve the synergistic effect of metal nodes in the developed bimetallic MOF. This could possibly be induced by lattice distortions, interfacial electronic coupling interactions, and increased porosity through combinational effects between distinct metal ions. Bimetallic MOFs are useful for catalyzing electron transfer-driven reactions because of their exposed active sites and great stability [6][7]. The common method of MOF synthesis can be replaced by electrodeposition-based methods which have been explored in recent times [8]. A range of bimetallic MOFs based on Ni/Cu catalytic bimetals [9], Cu/Co [10] for glucose, Fe/Ni for dopamine [11], Co/Ni for miRNA 126 [12], Cu/Ce for malathion [13], Mn/Fe for organophosphates [14], Ag/Zn for HCV-RNA [14] have been reported for a range of target analytes belonging to varied molecular strata. These research findings preach that bimetallic MOF are becoming one of the major areas which need to be explored more to utilize the potential lies in bimetallic MOFs for electrochemical sensing.

Acetaminophen is an antipyretic analgesic medication that is extensively used globally to relieve mild to moderate pain brought on by post-operative treatments, arthritis, headaches, and back pain [15][16]. Furthermore, it lowers fever in cases of viral and bacterial illnesses. An appropriate dosage of acetaminophen has no negative side effects; however, exceeding beyond this limit might result in a build-up of toxic acetaminophen metabolites, which can induce a variety of adverse effects, including skin rashes, pancreatic inflammation, hepatoxicity, and nephrotoxicity. Specifically, the latter two effects may cause harm to the human body's kidneys and liver [17]. Numerous techniques, including titrametry, UV–vis spectrophotometry, spectrofluorometry, and high-resolution liquid chromatography, have been used to measure acetaminophen in biological fluids, wastewater, and pharmaceutical formulations [18][19]. The evaluations become more challenging because of high expenses, prolonged processing time, and complex sample preparation requirements.

Annexure 2

Conference presentations

1. **Shubhangi**, Rohini Kumari, S.K. Rai, **Pranjal Chandra***. **Title:** *Rapid High-Performance Sensing of Hydrogen Peroxide using Nickel MOF adorned Au dendrites in electrochemical settings* in ETID-2024: National Conference on Emerging Trends in Implants and Diagnostics. Organized by Center of Excellence, at **NIPER-Ahmedabad**, India**.** Date: 1-2 February, 2024. **(BEST POSTER PRESENTATION)**

2. **Shubhangi**, Rohini Kumari, S.K. Rai, **Pranjal Chandra***. **Title:** *Electrochemically Nanoengineered MOF- dendrite Composite as Rapid Sensing Platform for Hydrogen Peroxide*, in the National Conference on Technological Advancements in Waste Management: Challenges and Opportunities-2023, at **IIT (ISM) Dhanbad**, India. Date: 4-5 December, 2023. **(BEST POSTER PRESENTATION)**

3. **Shubhangi,** Ruchita Chaudhari, S.K. Rai, **Pranjal Chandra***, **Title:** *Engineered Cobalt/Molybdenum Bimetallic MOF as Electrochemical Signal Transducer for Uric Acid Detection*, in the IEEE BioSensors Conference (BioSensors 2024), at **Cambridge, United Kingdom,** Date: 28-30 July, 2024**. *(***Awarded with the **IEEE BIOSENSORS WISE TRAVEL GRANT 2024,** by the IEEE SENSORS COUNCIL and **DST-SERB Travel Support Grant**, Govt. of India).

4. **Shubhangi**, Rohini Kumari, S.K. Rai, **Pranjal Chandra***. **Title:** *Conjugation of MOF with Dendrites: A Novel Platform Exhibiting Peroxidase Mimicking Activity in the* 3rd International Conference on Electrochemical Science and Technology-2024, organized by the CSIR-National Physical Laboratory, New Delhi & The

Electrochemical Society, India Indian Institute of Science Campus, Bengaluru, at **CSIR-NPL, New Delhi**, India. Date: 18-20 September 2024.

5. **Shubhangi**, Marshal Dhayal, **Sanjay Kumar Rai***, **Title:** *Rapid Quantification of HepG2 Cells aided by Electrochemically Deposited Folic Acid on Platinum Electrode, in the* NATIONAL SYMPOSIUM ON ELECTROCHEMICAL SCIENCE AND TECHNOLOGY [NSEST - 2023] by THE ELECTROCHEMICAL SOCIETY OF INDIA, Indian Institute of Science Campus, Bengaluru and International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), **Hyderabad**, Date: September, 2023.

6. Presented my work at the 6^{th} edition of World Nanotechnology Conference (**hybrid mode**) held at **Orlando**, USA, Date: **April 24-26, 2023**.

7. Scientific Writing Workshop by ACS Publications in collaboration with Indian Institute of Technology (BHU), Varanasi. Date: **29^{th} June, 2023**.

8. Presented talk on our work titled, "*Optimizing conditions for solvothermal syntheses to obtain precise hexagonal crystals of ZIF",*in **AFMFP- Advanced Functional Materials: Future Perspectives,** held and organized by Dr BR Ambedkar National Institute of Technology, Jalandhar, India. Date: **6-8 August, 2022.**

9. Attended webinar on "The development and application of Trupath biosensors to the study of GPCR pharmacology and functional selectivity, by Dr Reid Olsen. Date: **15^{th} July, 2021.**

10. Attended the **4th Annual Drug Discovery & Development Virtual Conference**. Date:**24^{th} February, 2021.**

11. Attended seminar on "Trends in Publishing" by Dr. Harry Blom, Vice President - Journals, Development, Policy & Strategy, **Springer Nature**. Date: **16th June 2020.**

12. Attended the "**Immuno-Oncology & Cancer Biology Virtual Conference**", Global Event. Date: **29th July 2020.**

13. Attended the science webinar on "Deciphering the cell cycle: The role of cell cycle control in cancer." By the **Science/AAAS Custom Publishing Office**. Date: **8th July 2020.**

14. Attended the webinar on "Exploring and Preventing cell culture contamination", organized by ***Thermofischer Scientific***. Date: **15th July 2020.**

15. Attended the webinar on "Understanding Genomics and Genetic Testing in Cancer Immunotherapy ", by the **Cancer Research Institute**. Date: **24th June 2020.**

IEEE Women in Sensors

IEEE BIOSENSORS 2024
CAMBRIDGE, UK || JULY 28-30, 2024

IEEE BioSensors 2024
WiSe Travel Grant

awarded to

Shubhangi

presenting

Engineered Cobalt/Molybedum Bimetallic MOF as Electrochemical Signal Transducer for Uric Acid Detection

Ruchi Gupta *WiSe Co-Chair IEEE BioSensors 2024*	Ashleigh Ruane *WiSe Co-Chair IEEE BioSensors 2024*	Paola Saccomandi *WiSe Chair IEEE BioSensors 2024*	Elena Gaura *WiSe Co-Chair IEEE BioSensors 2024*

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BEST POSTER PRESENTATION AWARD

ETID 2024, NIPER Ahmedabad

BEST POSTER PRESENTATION AWARD

Biography

SHUBHANGI

Research Profile: https://scholar.google.co.in/citations?hl=en&user=HtfQsVsAAAAJ

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Shubhangi has pursued her Ph.D. from the Indian Institute of Technology (BHU), jointly from the School of Biomedical and Biochemical Engineering. She is a B.Tech (Biotechnology) from Lovely Professional University and M.Tech (Molecular Engineering and Advanced Chemical Analysis) from National Institute of Technology, Kurukshetra. She has excelled academically throughout, with a gold medal in her M.Tech for her work on drug development and computational simulation studies, furnishing an early granted patent. Her Ph.D. research work has been detailed on the engineering of Metal Organic Frameworks (MOFs) and fabrication of nano-sensing platforms for diagnostic applications, yielding more than a dozen articles published in highly reputed journals. Her research areas include devising novel synthesis strategies for fabrication of MOFs and development of highly sensitive electrochemical sensors for a range of analytes such as free radicals, folic acid, uric acid and environmental pollutants. She has presented her research works on various national and international platforms which have been critically acclaimed and awarded with best posters like the ones at TAWMCO-2023 in IIT (ISM) Dhanbad, and in ETID-2024 at the Centre of Excellence, NIPER-Ahmedabad. She also grabbed the prestigious Women in Science (WISE) travel grant (IEEE Sensor Council, USA) and the DST-SERB travel grant (Govt. of India), 2024, to present her lecture at the IEEE Biosensors Conference held at Cambridge, U.K.