Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-124

Proposal Title: Sensors for Monitoring PFAS and DBP in Water

Project Manager Information

Name: Tianhong Cui

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: This project is to develop an electrochemical sensor for monitoring water pollutants including PFAS and DBP in Minnesota, which is small, simple, cheap, efficient, and accurate.

Funds Requested: $200,000

Proposed Project Completion: June 30, 2025

LCCMR Funding Category: Small Projects (H)
Secondary Category: Water Resources (B)

Project Location

What is the best scale for describing where your work will take place?
Statewide

What is the best scale to describe the area impacted by your work?
Statewide

When will the work impact occur?
During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

polyfluoroalkyl substances (PFAS) and disinfection byproducts (DBP) are two serious water pollutants. PFAS are a group of more than 5,000 man-made chemicals also known as “forever chemicals” because they do not degrade in the environment. Some are known to cause serious health problems. Water systems add chlorine to drinking water for killing or inactivating harmful organisms in a process called “disinfection.” During this process, chlorine reacts with naturally occurring organic matter that may present in drinking water. Chlorine disinfection byproducts can be formed during this chemical reaction. Scientists have identified hundreds of DBPs. Several DBPs have limits set by the U.S. Environmental Protection Agency (EPA): trihalomethanes (THMs), haloacetic acids (HAAs), chlorite, and bromate. EPA sets these limits by balancing the health benefits of water disinfection with the risk of exposure to disinfection byproducts. Chromatographic techniques are the current most often used method for detection of PFAS and DBPs in water. However, such method is very expensive, time-consuming, and requires to be operated in labs using large equipment. These shortcomings make it impossible to realize distributed real-time monitoring. As a result, a real-time monitoring system with integrated cheap accurate sensors needs to be developed.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

We propose a small water pollutant monitoring system with integrated electrochemical sensors. The proposed tiny sensor in the project is accurate and easy to fabricate at a very low cost. The sensors, which are mortified to specifically detect PFAS and DBPs, can be used in a distributed manner and enable real-time detection. The electrochemical sensors, namely a planar glassy carbon electrode array, are mass fabricated using carbonization of negative photoresist SU-8 process, which are much cheaper than the traditional precious metal electrodes. The selectivity of the sensor is achieved by molecularly imprinted polymer (MIP) technology, where target molecular (certain PFAS or DBPs that needs to be monitored) is used as the template during sensing electrode fabrication, and then be removed to the active specific binding site. The analyte of interest blocks a redox reaction when it associates with the MIP, resulting in a quantifiable signal change in a variety of electrochemical techniques. The electrical signal can be collected by a computer through a wired connection. Since the sensing component part includes simply electrodes on a substrate, it is convenient to arrange multiple distributed sensors using a multiplex exchanger.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state’s natural resources?

The outcome of this project aims to develop a cheap, fast, and real-time sensor for water monitoring. Advanced manufacturing techniques at the University of Minnesota allow the development of a reliable and efficient sensing platform at a very low cost. This sensor will help the state protect the natural and drinking waters by building up an alarming system for potential PFAS and DBP pollutions. Furthermore, the distributed sensing platform built in this project will help the end-users including clear water agencies, researchers, and advocacy groups for continuous detection and analyses of Minnesota waters and prevent from ecological contaminations.

Activities and Milestones

Activity 1: Development of small, low-cost, and accurate electrochemical sensors for simultaneous detection of PFAS and DBPs in Minnesota waters

Activity Budget: $99,920

Activity Description:
The objective of this activity is to develop a small sensor array for an electrochemical detection of PFAS and DBPs. Each sensing unit contains four glassy carbon electrodes: two working electrodes aiming to selectively detect PFAS or DBPs respectively, one counter electrode, and one reference electrode to establish an electrochemical sensing procedure. The glassy carbon electrodes are fabricated using carbonization of photoresist process, where the electrode is patterned by a photoresist using a photolithography method, then carbonized at high temperatures. The sensor's working electrode is modified with molecularly imprinted polymer using target PFAS or DBPs as the template. Once the template is removed with certain reagents, the polymer film can selectively bind to the analyte, resulting in a change of surface resistance that can be detected using the electrochemical method. Next, we will set up a testing facility to characterize the fabricated sensor with the electrochemical method. The testing facility consists of an electrochemical work station and a computer. The sensor will be tested in a standard solution of the analyte of interest. Based on the electrochemical response of the sensor, we will analyze the sensitivity, detection limit, response time, selectivity, and stability of the sensor.

Activity Milestones:

Description	Completion Date
Design of fabrication procedures for electrodes used in pollutant detection	December 31, 2023
Fabrication of carbonized photoresist glassy carbon electrodes	December 31, 2023
Electrode modification with molecular imprinted polymer	June 30, 2024
Electrochemical detection and calibration of pollutants with selectivity	June 30, 2024

Activity 2: Development of distributed water monitoring systems with embedded sensors, and optimization of the monitoring systems for better performance

Activity Budget: $100,080

Activity Description:
The objective of this activity is to develop a water pollutant monitoring system with multiple integrated electrochemical sensors. We will optimize the sensor modification as well as the electrochemical readout technology to achieve better sensitivity, selectivity, repeatability, and stability. Meanwhile, we will design, fabricate, and test a multiplex exchanger to connect multiple sensors and a computer (sensors and the exchanger are connected by thin wires of a certain length). The sensing component only contains wired electrodes on a tiny substrate without any mechanical components, electronic or energy storage elements, which is suitable for integration into distributed sensing probes. By using a computer-controlled distributed sensor array, the system can monitor water pollution in multiple locations simultaneously in real-time. Moreover, this process can be automatically operated without manual sampling. Finally, the system needs to be evaluated in field tests (e.g., natural water, wastewater, and tap water) and optimized by comparing the results with the conventional detection method.

Activity Milestones:

Description	Completion Date
Optimization of sensitivity and selectivity of the electrochemical sensing electrode	December 31, 2024
Buildup of multi-channel and real-time monitoring sensor system	June 30, 2025

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
This project will provide low-cost, but high-performance sensors for monitoring Minnesota's water pollutants such as PFAS and DBPs. Upon completion, this project will realize distributed sensor network for continuous detection of pollution levels. The knowledge learned throughout this project will provide a solid foundation for further research and development that may lead to the eventual implementation of this sensing technique, for broader monitoring of Minnesota's waters. In addition, we plan to file patents on the proposed distributed sensors for commercialization in the future. If needed, we will apply for funding from NSF, EPA, USGS, and other funding agencies.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Develop Small and Inexpensive Purification System for Community Drinking Water	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 04e	$425,000
Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 07c	$300,000

Project Manager and Organization Qualifications

Project Manager Name: Tianhong Cui

Job Title: Distinguished McKnight University Professor

Provide description of the project manager's qualifications to manage the proposed project.
Dr. Tianhong Cui is a Distinguished McKnight University Professor at the University of Minnesota. He is a Professor in Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in Department of Electrical and Computer Engineering and Department of Biomedical Engineering. He joined the faculty of the University of Minnesota in 2003. From 1995 to 2003, he held research or faculty positions at Tsinghua University, University of Minnesota, National Laboratory of Metrology in Japan, and Louisiana Tech University. He was a Distinguished Visiting Fellow at the University of Cambridge in UK, and a Distinguished Visiting Professor at Gustave Eiffel University in France. He is a Fellow of American Society of Mechanical Engineering.

Dr. Cui is an international leading expert on micro sensors and advanced manufacturing. He has more than 360 archived papers, and he holds 6 issued US patents. He received awards including the STA & NEDO Fellowships in Japan, the Alexander von Humboldt Fellowship in Germany, the Richard & Barbara Endowed Chair and the Distinguished McKnight University Professorship from the University of Minnesota, the Distinguished Visiting Professorship from University of Paris East, the Distinguished Visiting Fellowship from the Royal Academy of Engineering in UK, the Global Chair at the University of Bath, the Outstanding Editor Award from Nature Publishing Group, and numerous best paper awards. He is the founding Executive Editor-in-Chief for a Nature journal, Microsystems & Nanoengineering.

Dr. Cui will serve as the PI and the project manager, responsible for overseeing the project, all reports, and deliverables. He will supervise one graduate research assistant to work on design, fabrication, and characterization of the sensors for monitoring PFAS and DBP in water. He will hold weekly meetings with his graduate assistant to ensure good progress of this proposed work, in addition to some daily technical discussion with his research assistant.

Organization: U of MN - College of Science and Engineering

Organization Description:
This work will be performed at the University of Minnesota in the Technology Integration & Advanced Nano/Microsystems Laboratory (TIAN Lab), located in the Mechanical Engineering Building. Professor Tianhong Cui is the director of TIAN Lab equipped with the state-of-the-art instruments and facilities to conduct the proposed research, with a variety of fabrication and characterization equipment and tools, sufficient for Professor Cui and his graduate research assistant to design, fabricate, characterize and analyze the proposed sensors.

Some fabrication work will be partially done in Minnesota Nano Center, a state-of-the-art facility for research in nanoscience and applied nanotechnology. It is located at the University of Minnesota in a 7000 square foot facility, including 3000 square feet of class 10 clean room. The Lab contains all of the major pieces of processing equipment. Minnesota Nano Center well maintains these systems, keeps safe operating procedures, and trains students. State support, support from NSF through the NNCI network, and industry usage allows Minnesota Nano Center to offer academic rates that are normally less than half of the actual cost of operation. In addition to clean room tools available, the center will also operate two new non-cleanroom labs on nanomaterials and nanotechnology.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineli gible	% Bene fits	# FTE	Class ified Staff?	$ Amount
Personnel								
Tianhong Cui		Principal Investigator			33.5%	0.16		$50,774
Research Assistant		Graduate Student			23.6%	2		$109,507
							Sub Total	**$160,281**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Silicon wafers, polymer substrates, chemicals, and components for testing set-up.	Materials and supplies required to fabricate and characterize the sensors and for testing setup.					$28,719
							Sub Total	**$28,719**
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
							Sub Total	-
Travel Outside Minnesota								
							Sub Total	-

Printing and Publication								
							Sub Total	**-**
Other Expenses								
		Lab Space	University of Minnesota's Minnesota Nano Center for fabrication costs of the sensors and the University of Minnesota's Characterization facility for characterization of the electrochemical sensors					$11,000
							Sub Total	**$11,000**
							Grand Total	**$200,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	Unrecovered F&A of 55% MTDC	Unrecovered F&A of 55% MTDC	Secured	$91,750
			Non State Sub Total	**$91,750**
			Funds Total	**$91,750**

Attachments

Required Attachments

Visual Component

File: f78b29fc-3c9.pdf

Alternate Text for Visual Component

Comparison of current and new technologies; Future applications of proposed new technology....

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, or sale of products and assets?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

No

Does your project include original, hypothesis-driven research?

No

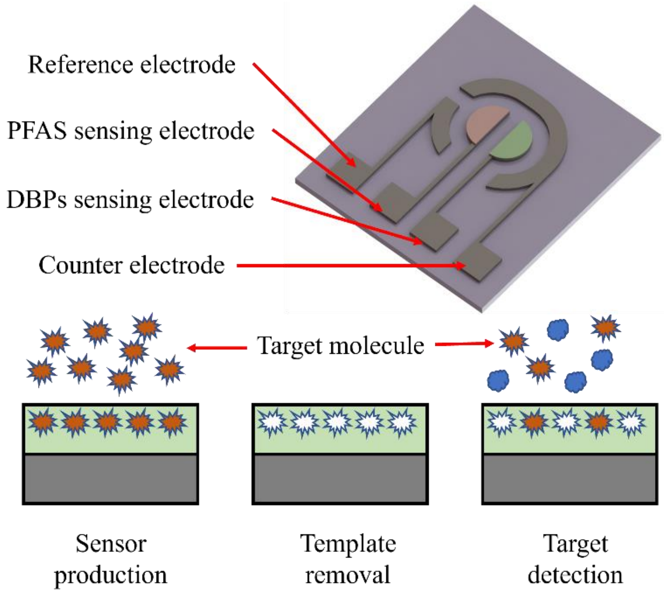
Does the organization have a fiscal agent for this project?

No

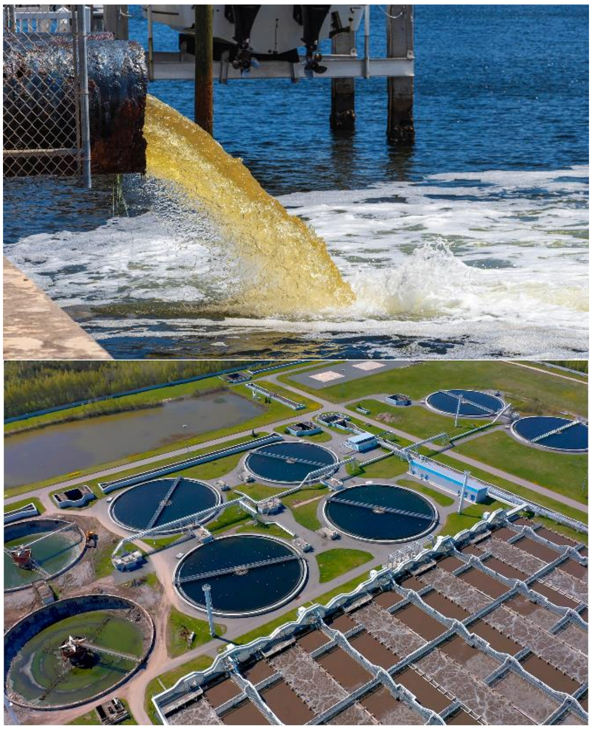
PI/PD: Tianhong Cui, University of Minnesota

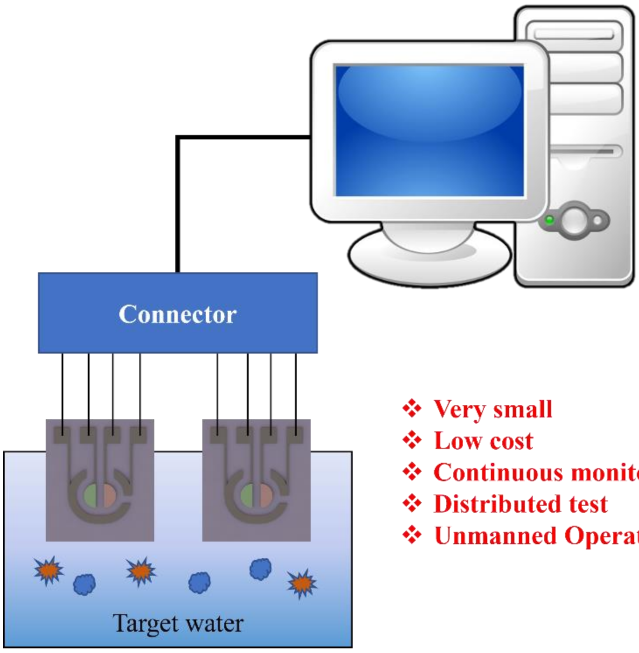
Project Title: Sensors for Monitoring PFAS and DBP in Water

Current Technology



New Technology Proposed





- Very small
- Low cost
- Continuous monitoring
- Distributed test
- Unmanned Operation

Future applications to continuous pollutants monitoring in Minnesota waters