Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-314

Proposal Title: Solar-Powered Pesticide Sensor Network for Water Monitoring

Project Manager Information

Name: Tianhong Cui

Organization: U of MN - College of Science and Engineering

Office Telephone: (612) 626-1636

Email: cuixx006@umn.edu

Project Basic Information

Project Summary: The project aims to develop a small, cheap, solar powered, wirelessly distributed sensor network to monitor pesticide pollutants in very large areas of lakes and rivers in Minnesota.

Funds Requested: $660,000

Proposed Project Completion: 2024-06-30

LCCMR Funding 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.

Chlorpyrifos is one of the most frequently used organophosphate pesticides used in agriculture. It can disrupt cholinesterase, leading to cholinergic toxicity and death. This endangers the health of both human and animals, and is a danger to children and seniors who are most vulnerable. People can be exposed to chlorpyrifos from breathing the dust from nearby fields or drinking water from impaired bodies of water. According to reports from the Minnesota Department of Agriculture, the detection of chlorpyrifos in water has appeared to increase since 2010, and nine bodies of water have been found to be polluted by chlorpyrifos. To effectively prevent and predict chlorpyrifos pollution, large-area and long-term chlorpyrifos monitoring is needed. Conventional chlorpyrifos analysis methods in laboratories such as mass spectrometry and atomic absorption spectroscopy, involve massive laboratory testing work and intensive labor effort. These limitations make the mentioned technologies impossible for onsite water monitoring and expensive for continuous pollutant monitoring. To overcome these limitations, we propose a new technology that is a small, cheap, and easily distributed sensor network self-powered by solar energy for chlorpyrifos concentration detection, which is capable of remote calibration, continuous monitoring, and remote reporting.

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

We propose a distributed pesticide sensor network self-powered via an integrated solar cell. This technique seeks to 1) design a self-powered, autonomous, on-site photoelectrochemical sensor that is suitable for on-line monitoring of chlorpyrifos in Minnesota's waters at low cost, and 2) build wireless sensor networks that provide pollutant data in lakes and rivers. The photoelectrochemical sensor exploits light and photocurrent as the excitation source and the recognition signal, respectively, which leads to lower background noise and higher sensitivity than conventional electrochemical sensors. Moreover, the heterojunction structure of the photovoltaic solar cell will have a higher optoelectronic conversion efficiency, while powering the detection circuit at same time. For long-term and large-area water pollutant monitoring, it is favorable to have low-power sensing and communication components. Given such requirements, a solar cell enabled backscatter communication network will be exploited. The radio frequency backscatter has very large range communication while consuming super low power for data transmission, which is achieved by modulating and reflecting the radio frequency interrogator signal rather than generating a radio frequency response signal using an on-board radio. Here the solar cell will power the whole device to achieve sensitive chlorpyrifos monitoring over a long-time in lakes and rivers.

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?

There are three deliverables proposed in this project, including (1) a prototype of a pesticide sensor suitable for self-powered, long-lasting, and on-site testing, (2) a backscatter wireless communication component integrated with sensor nodes that transmit data from the pesticide sensor, and (3) a backscatter communication network including sensor nodes, interrogators, remote data processing components and new protocols suitable for on-site testing applications. Furthermore, the sensing platform and networks build in this project will help the end-users including clean water agencies including MPCA, EPA, and other advocacy groups with continuous detection and monitoring of Minnesota waters to prevent against ecological contaminations.

Activities and Milestones

Activity 1: Development of a small, cheap, sensitive photoelectrochemical sensor self-powered by a solar cell for monitoring pesticide in water

Activity Budget: $436,980

Activity Description:
This activity is to develop a self-powered sensor based on a perovskite solar cell. Perovskite is a cheap material used for low-cost but high-performance solar cells. Graphene, BiOCl and Bi2O3 nanoparticles are deposited on the gold electrode of a perovskite solar cell. With light illumination, the photoactive heterojunction of BiOCl/graphene/Bi2O3 induces electron-hole pairs. The spatial separation of the electron-hole pairs in the BiOCl/graphene and graphene/Bi2O3 interfaces retards their recombination, while photo-electrons are smoothly transferred. Meanwhile, the photon-excited holes from the device migrate to the gold electrode, and combine with photon-electrons, which facilitates the transfer of electrons from Bi2O3 to the gold electrode interface. Furthermore, the inner potential drop from the solar cell applied to the photoelectrochemical sensor improves electron-hole separation inside Bi2O3. Together, this integrated structure leads to the generation of an enhanced photocurrent signal for a very high sensitivity. Through adding chlorpyrifos, the BiOCl nanoparticles form the Bi-chlorpyrifos complex on the sensor surface which achieves good selectivity, inhibiting the separation electron and yields to return electron transfer on the surface due to steric effect as the formation of C=N and P=S bonds. Increasing chlorpyrifos concentration therefore leads to decreasing photocurrent intensity.

Activity Milestones:

Description	Completion Date
Develop a sensitive, selective, and stable photoelectrochemical sensor for detection of chlorpyrifos	2022-06-30
Integrate the chlorpyrifos photoelectrochemical sensor with a fabricated perovskite solar cell for self power	2022-06-30
Self-powered chlorpyrifos photoelectrochemical sensors will be improved and tested in comparison with conventional lab results	2023-06-30

Activity 2: Development of backscatter wireless sensor communication networks and field testing in lakes and rivers in Minnesota

Activity Budget: $223,020

Activity Description:
To reduce the power consumption and complexity of the photoelectrochemical sensor, we propose developing backscatter communication and building a sensor networks. By modulating the reflection wave of an externally generated carrier, only a single radio frequency switching element is required in the sensor node for data transmission, vastly reducing complexity and power consumption when compared to a conventional radio. We propose a newly distributed interrogator network along with sensor nodes using backscatter and significant processing gain to overcome the path loss at the expense of spectral efficiency and data-rate. Multiple interrogators will be deployed over the area where sensors are deployed with the ability to provide a carrier that can transmit to and receive signals from the backscatter chlorpyrifos sensors, as well as conventional radios, GPS (operating in a different band) to backhaul data to the cloud and communicate with one another. We will deploy the sensor nodes and interrogator networks at Buffalo River Watershed for instance, where several water bodies have reported near or above acceptable chlorpyrifos concentration by MPCA. We will closely work with MPCA to compare the results from our sensor networks with respect to their lab tested ones.

Activity Milestones:

Description	Completion Date
The prototype will be built on a water site and data transmission will be tested	2024-06-30
Data networking protocol and hardware will be developed	2024-06-30
A prototype of sensing network with tiny sensors unit will be developed	2024-06-30

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 be funded?
The pesticide sensor will be developed and tested with a portable instrument for lab tests and field detection in lakes and rivers in Minnesota. Next, we will build up a wireless sensor network, and test the distributed sensor network in natural waters in high contamination environments. We need funding from LCCMR to support this effort. We plan to file patents on the proposed sensors and sensor networks for commercialization in Minnesota. In addition, we can also use the sensors or sensor networks for monitoring pollutants in soil. We will also apply for funding from USDA, NSF, EPA, and private foundations.

Project Manager and Organization Qualifications

Project Manager Name: Tianhong Cui

Job Title: Professor

Provide description of the project manager's qualifications to manage the proposed project.
Dr. Tianhong Cui is currently 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 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 is a Distinguished Visiting Fellow at the University of Cambridge, and a Distinguished Visiting Professor at the University of Paris East in France. He is a Fellow of American Society of Mechanical Engineering (ASME).

Dr. Cui is an international leading expert on micro devices and advanced manufacturing. He has more than 320 publications in scientific journals and prestigious conferences. He has 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 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. He is also the founding Editor-in-Chief for the first AAAS/Science Partner Journal titled Research.

Dr. Cui will serve as PI and project manager for this work, responsible for the overall project, all reports, and deliverables. He will supervise one post-doc and one Ph.D. student to work on the design, fabrication, and characterization of solar-powered sensor networks. He will hold weekly meetings with his advisees to ensure good progress of this proposed work, in addition to some daily technical discussion with his post-doc and graduate 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 Cui is the director of TIAN Lab equipped with the state-of-the-art instrument and facilities to conduct the proposed research, with a variety of fabrication and characterization equipment and tools, sufficient for Professor Cui, his post-doc, and Ph.D. student to design, fabricate, characterize and analyze the proposed sensor networks.

Some fabrication work will be partially done in the Minnesota Nano Center (www.nfc.umn.edu), 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 NNCI, 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 also operates two new non-cleanroom labs in nanomaterials and nanotechnology.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineli gible	% Bene fits	# FTE	Class ified Staff?	$ Amount
Personnel								
Principle Investigator		To manage the overall project and to conduct overall research of this project			36.5%	0.24		$99,818
1 Postdoc		To set up characterization facility, to design, fabricate, test, and evaluate the sensor networks, and conduct field tests			25.4%	3		$249,454
1 Graduate Research Assistant		To design, fabricate, and characterize sensors			19.9%	1.5		$156,019
							Sub Total	**$505,291**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Materials and supplies, instrument and equipment consumables, supplies for setting up lab and field experimental systems, equipment repairs and calibration costs	To build and test the sensors and sensor arrays in labs and in fields (lakes and rivers)					$74,709
	Tools and Supplies	To use the facility of the Minnesota Nano Center and Characterization Facility	To fabricate and test the sensors and the sensor arrays					$71,000
							Sub Total	**$145,709**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**

Travel In Minnesota								
	Miles/ Meals/ Lodging	Travel for collecting samples and field test	Per University of Minnesota travel policy, this is for researchers to travel to collect samples in fields, and between campus and demonstration sites over the 3 years project period.					$9,000
							Sub Total	**$9,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$660,000**

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				
In-Kind	In kind: Indirect Cost at the University of Minnesota (55% MTDC)	In-kind support at the University of Minnesota	Secured	$335,896
			State Sub Total	**$335,896**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$335,896**

Attachments

Required Attachments

Visual Component

File: 171fb51d-080.pdf

Alternate Text for Visual Component

This visual component shows current technology, proposed technology, sensor scheme, and sensing mechanism.

Optional Attachments

Support Letter or Other

Title	File
University SPA Supporting Letter	84648f88-b80.docx

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

- Patent, Copyright, or Royalty Potential

Does your project include research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

PI/PD: Tianhong Cui, University of Minnesota

Project Title: Solar-Powered Pesticide Sensor Network for Water Monitoring

Fig 1. Current Technology

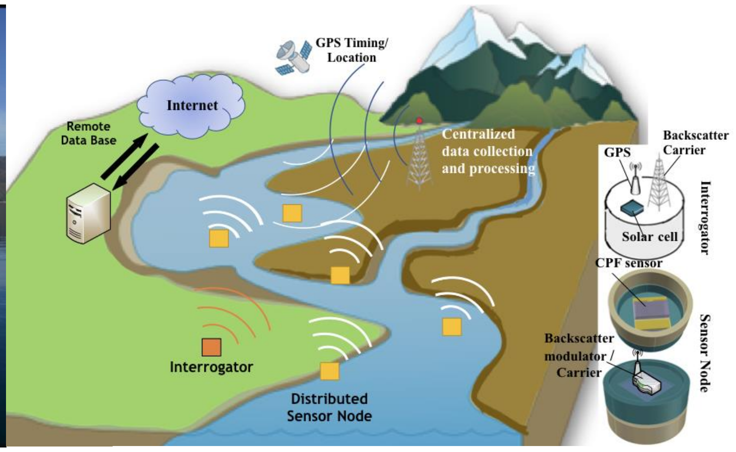

Fig 2. Proposed New Technology

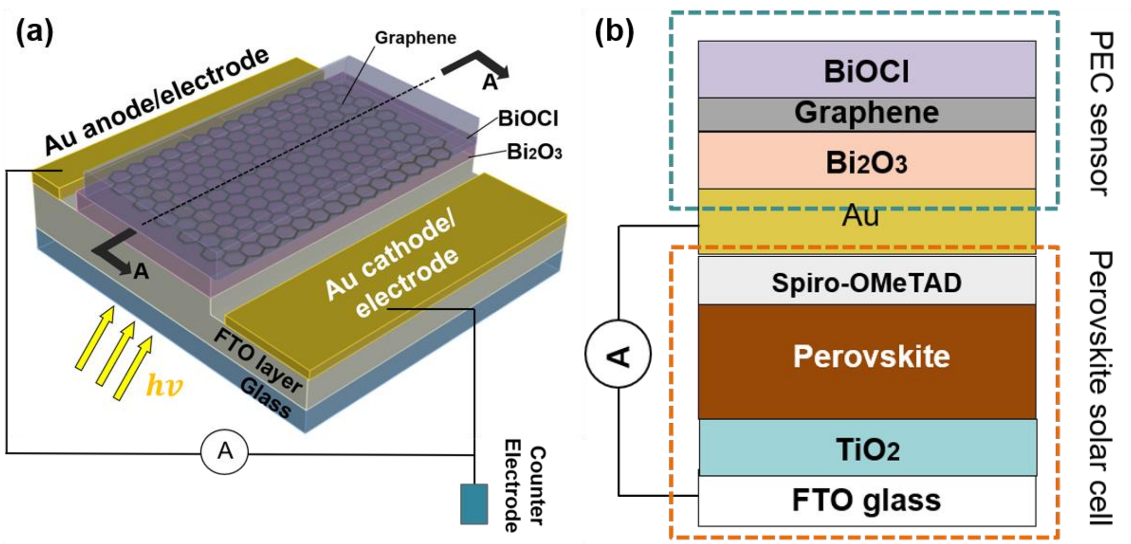

Fig 3. Photoelectrochemical (PEC) sensor (sensor node) scheme; (a) 3D view of a sensor node; (b) cross-sectional view at A-A

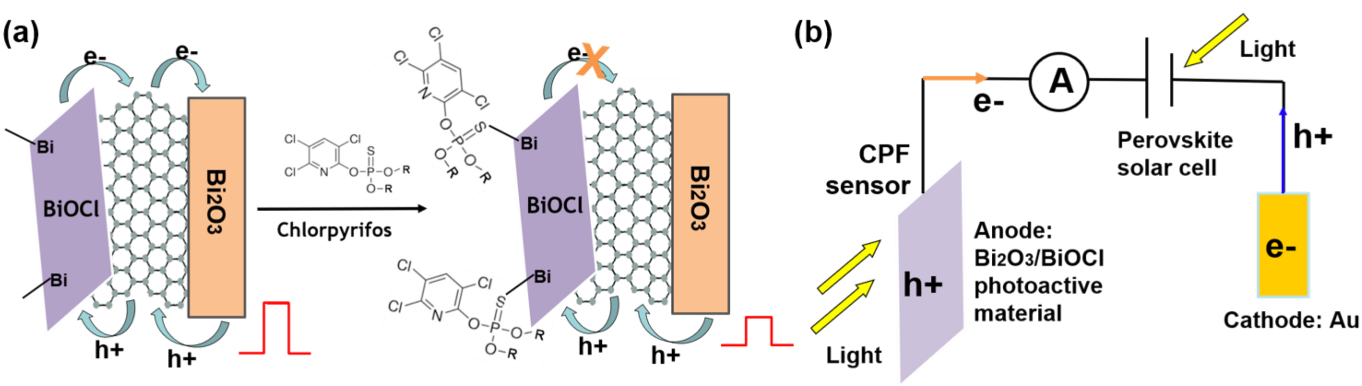

Fig 4. (a) Chlorpyrifos (CPF) PEC sensing illustration; (b) Equivalent PEC sensor circuit