
Southeastern Nanotechnology Infrastructure Corridor (SENIC)

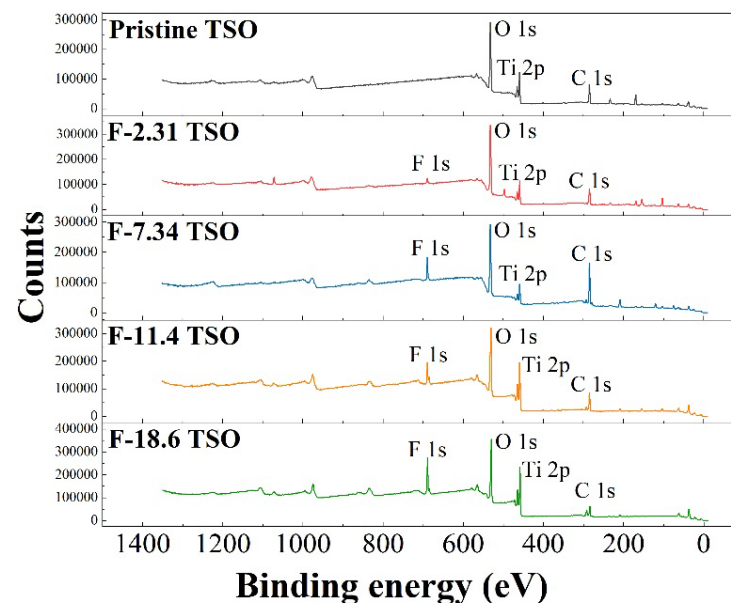
Research and Education Highlights

Year 6 (October 2020 – September 2021)



Treatment of per- and polyfluoroalkyl substances (PFASs) using novel reactive electrochemical membrane (REM) systems based on titanium suboxide (TSO) materials

The objective of this work is to provide a basis for design and optimization of the TSO-based REM systems for electrochemical treatment of PFAS-contaminated waters. Porous Magnéli phase TSO have been used as anode to degrade PFASs in electrochemical oxidation. Modification of the TSO materials by manipulating their porous structure and doping with selected elements using sintering and surface modification approaches can further improve the its efficiency towards PFAS degradation in REM processes and minimize its reactivity towards chloride to inhibit the formation of unwanted chlorate and perchlorate. Material characterizations performed at SENIC along with molecular simulations help to guide the design of the materials and explore the interactions of PFAS and chloride on the anodes.



XPS full scan of pristine and surface fluorinated TSO anode.

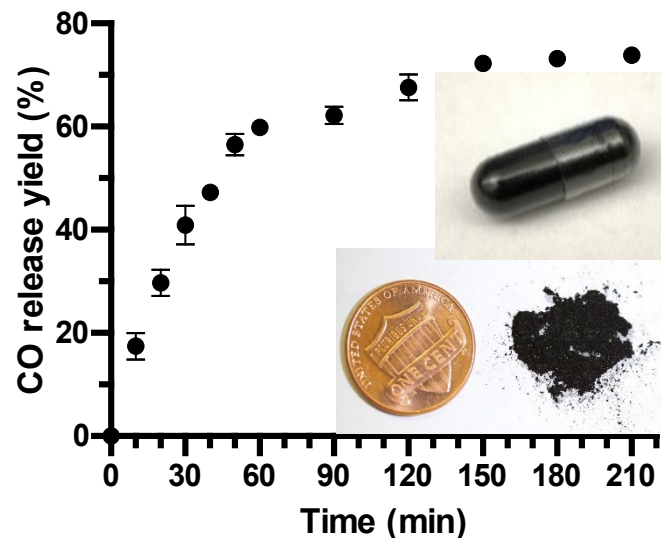
Qingguo Huang, College of Agricultural and Environmental Sciences, Department of Crop and Soil Sciences, University of Georgia. This work was partially performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by DoD SERDP ER-2717 and ER-1320 and EPA National Priorities Program Grant 840080. *Science of The Total Environment*, 788, 147723, 2(021).

National Research Priority: NAE Grand Challenge-Provide Access to Clean Water

Activated Charcoal-based Formulation for Oral Delivery Carbon Monoxide

A unique orally bioavailable formulation of carbon monoxide (CO) prodrug was developed by adsorbing oxalyl saccharin, a newly developed organic CO prodrug, in the activated charcoal (AC). The formed solid dispersion formulation addressed key developability issues of this CO prodrug. By taking advantage of the large surface area of AC, the paradox in the low water solubility of the prodrug and the requirement of hydrolysis to release CO is resolved, and the need for undesirable organic cosolvent is completely circumvented. The AC formulation also mitigates the adverse effect of low pH on the CO release yield, allowing steady CO release in simulated gastro and intestine fluid. It allows feasible encapsulation in normal and enteric-coated gel capsules, which enables controllable CO delivery to the upper or lower GI system. It also features an advantage of trapping CO prodrug and release product in the AC, therefore lowering systemic absorption of these chemicals. Through in-vivo pharmacokinetic study in mice, the AC formulation showed better CO delivery efficiency of delivering CO through oral administration compared to the prodrug dosed with organic cosolvent at the same dose. The formulation method has also been applied to address similar developability issues of a reported Diels-Alder reaction-based CO prodrug. We envision this formulation approach to facilitate the future development of CO therapeutics.



CO release yield of cellulose capsule loaded with the activated charcoal formulation of the CO prodrug (insert images) in simulated gastric fluid.

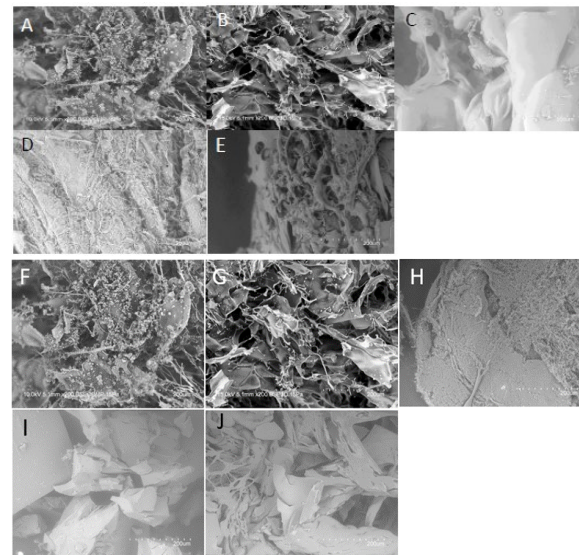
Xiaoxiao Yang, Wen Lu, Ladie Kimberly De La Cruz, and Binghe Wang, Department of Chemistry and Center for Diagnostics and Therapeutics, Georgia State University. Work was partially performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by National Institutes of Health (R01DK119202).

National Research Priority: NAE Grand Challenge-Engineer Better Medicines

Morphological evaluation of graft and crosslinked hydrogel using SEM

This work involve preparation of thermosensitive hydrogels with a variety of therapeutic nutraceuticals and characterization using SEMs. The development of biomaterials that retain structure/function properties, in addition a protective cellular approach via simultaneously controlling cell fate and ECM production is critical for advancing the new knowledge in improving tissue engineering strategies. We have used SEM at the SENIC facility for our research. The SEM images reveal that the morphology of pure PVCL hydrogel, and meHA200K have porous microstructure, and PVCL-g-meHA200K(AM), PVCL-g-meHA200K-g-ATP (AM) and PVCL-g-meHA200K-g-CURC(AM) has a denser microstructure and smaller pore size that characterize the completion of graft reaction. Sheet-like microstructure of PVCL-c-meHA200K-c-ATP (AM) and PVCL-c-meHA200K-c-CURC(AM) images reveal crosslinking results more compact and interlocking of reacting molecules.



SEM Images of lyophilized samples A. PVCL, B. meHA200K, C. PVCL-g-meHA200K(AM), D. PVCL-g-meHA200K-g-ATP(AM), E. PVCL-g-meHA200K-g-CURC(AM), F. PVCL, G. meHA200K, H. PVCL-c-meHA200K(AM), I. PVCL-c-meHA200K-c-ATP(AM), J. PVCL-c-meHA200K-c-CURC(AM) at 200-micron scale bar.

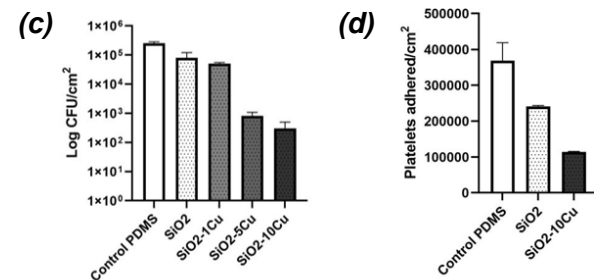
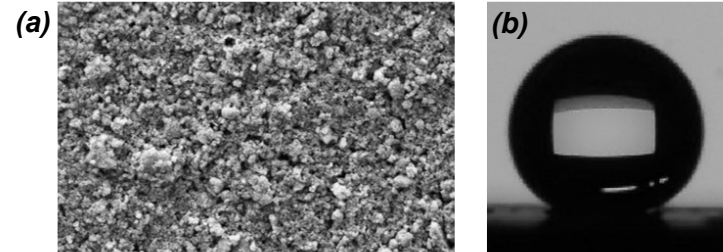
Samina Yasmeen and Juana Mendenhall, Department of Chemistry, Morehouse College. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by NSF (EiR 1900806).

National Research Priority: NSF-Understanding the Rules of Life

Superhydrophobic NO-Generating Coating

This work is the result of research into multifunctional superhydrophobic coatings to prevent biofouling in blood-contacting biomedical devices. A polymeric nanocomposite utilizes hydrophobic-modified nanoparticles to provide low surface energy micro-/nano-structures that yield a superhydrophobic state, where water droplets do not adhere. The inclusion of a copper catalyst gives the coating the ability generate nitric oxide, a therapeutic gasotransmitter with antimicrobial and antithrombotic potential, from molecules naturally endogenous to blood. The resulting coating reduced bacterial and platelet adhesion.



(a) SEM image of Coating (b) Contact Angle Image of Water Droplet on Superhydrophobic Coated Surface (c) *E. coli* adhesion of Coatings with Various Concentrations of Copper Catalyst (d) Platelet adhesion study of Coatings with/without Copper Catalyst

Divine Francis and Hitesh Handa, School of Chemical, Materials and Biomedical Engineering, University of Georgia. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by NIH (R01HL134899 and R01HL151473).

National Research Priority: NAE Grand Challenge-Engineer Better Medicines

Powering Internet-of-Things using the 5G Network

Researchers led by Prof. Manos Tentzeris at Georgia Tech have developed a method to use 5G networks as a “wireless power grid” for IoT devices that typically use battery power. The device is based on a flexible Rotman lens-based rectifying antenna (rectenna) for energy harvesting in the 28-GHz band.



Manos Tentzeris et al., School of Electrical and Computer Engineering, Georgia Institute of Technology. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This research was supported by the Air Force Research Laboratory and the NSF-Emerging Frontiers in Research and Innovation program. *Scientific Reports*, 11, 636, 2021.

National Research Priority: NSF-Growing Convergence Research

Low-cost, Fast Production of Solid-state Batteries for Electric Vehicles

Materials science researchers at Georgia Tech, led by Prof. Gleb Yushin, have developed a melt-infiltration technology to produce high-density composites for solid-state automotive lithium-ion batteries. At the lower temperatures for this procedure, fabrication is much faster and easier.



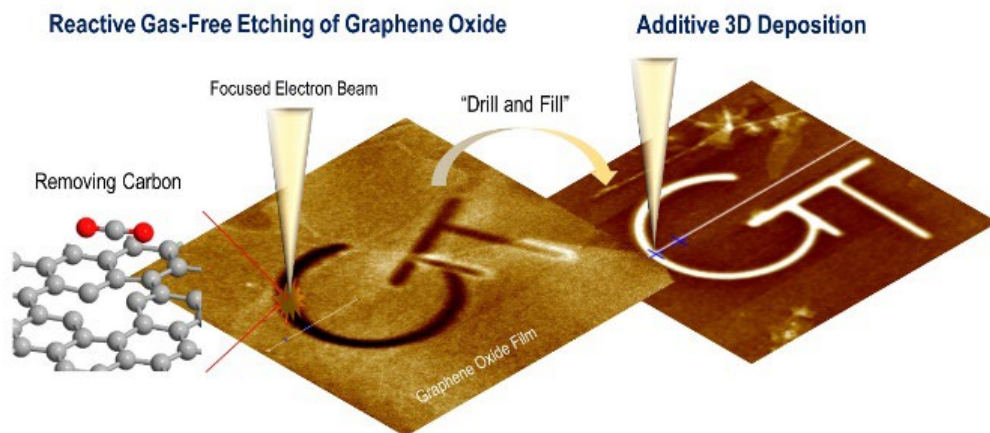
Gleb Yushin et al., School of Materials Science and Engineering, Georgia Institute of Technology. Characterization of the materials was performed at the Georgia Tech Materials Characterization Facility.

This research was supported by Sila Nanotechnologies Inc., a Georgia Tech startup company. *Nature Materials*, 2021.

National Research Priority: NSF-????

E-Beam Process for Quantum Nanodevices

A team at Georgia Tech led by Andrei Fedorov has developed a technique for etching and depositing high-resolution nanoscale patterns on two-dimensional layers of graphene oxide using focused electron beam-induced (FEBID) processing. This direct-write method with atomic-scale resolution may be used to produce 2D and 3D structures for quantum communications and sensing, among other applications.



Andrei Fedorov et al., School of Mechanical Engineering, Georgia Institute of Technology. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

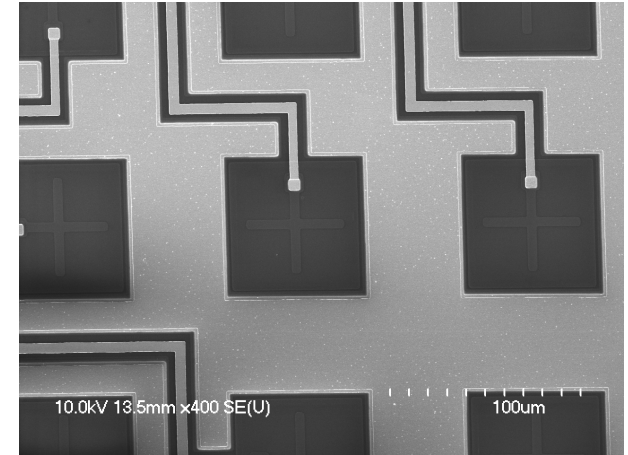
The research was supported by the DOE, Office of Science, Basic Energy Sciences and the National Research Foundation of Korea. *ACS Applied Materials & Interfaces*, 12, 39595–39601, 2020.

National Research Priority: NSF-Quantum Leap

Development of Micro UV LED Array for Compact DNA Data Storage Device

The goal of this project is to fabricate Micro LED device with UV light emission at wavelength of 365nm for medical applications, specifically for DNA synthesis. This project aims at developing a UV Micro LED, which can effectively serve as manipulation method on oligonucleotide (oligo) synthesis.

A GaN-based Micro LED array on sapphire substrate was fabricated. Ion implantation was used as device isolation and leakage suppress technique. ICP etching was used to form mesa structures. The device was passivated with Spin-on-Glass (SOG). The Micro LED array overall gains uniformity with 32 out of 36 devices achieve uniform forward IV curves in a 6-by-6 array with mesa size of $60\mu\text{m} \times 60\mu\text{m}$.



SEM image of Micro LED array devices

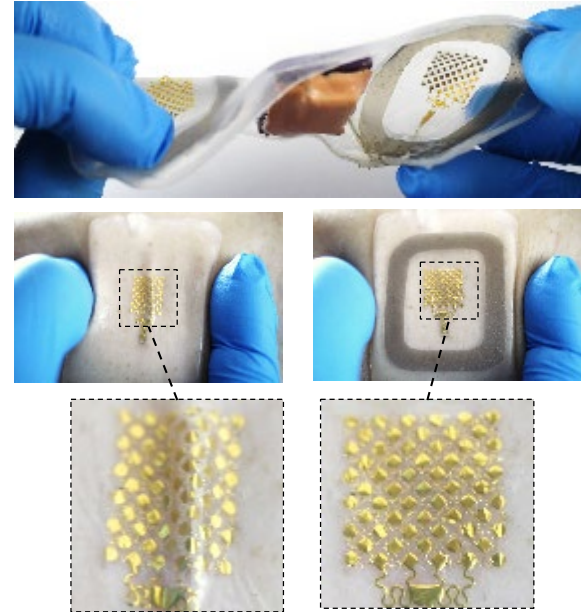
Zhiyu Xu, Minkyu Cho and Shyh-Chiang Shen, School of Electrical and Computer Engineering, Georgia Institute of Technology. Work was performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was partially supported by a SENIC Seed Grant (NSF ECCS-2025462).

National Research Priority: NSF-Growing Convergence Research

Skin-Conformal, Wireless, Wearable ECG Biopatch with Minimized Motion Artifacts

The miniaturization of electronics continues to incorporate wearable devices into our daily lives to improve health and fitness monitoring. The benefit of this progress is that a smaller device is less cumbersome, enabling freedom of movement without restriction. A simultaneous limitation is that more movement increases the opportunity for noise in the signal. Most wearable electronics measure signals through contact with the skin's surface, which stretches and flexes during movement. Here, we show a non-invasive device with measurable increased integration between the sensor and the skin. Limiting skin strain and electrode deformation is shown to reduce motion artifacts by 20% in ECG recordings during heavy jogging. Further developing wearable systems that conform to the skin will move wireless monitoring beyond the currently popular wrist-strap paradigm.



ECG device using skin friendly soft materials for long-term signal monitoring. Strain isolation layers shield electrodes from buckling and deformation that causes signal noise.

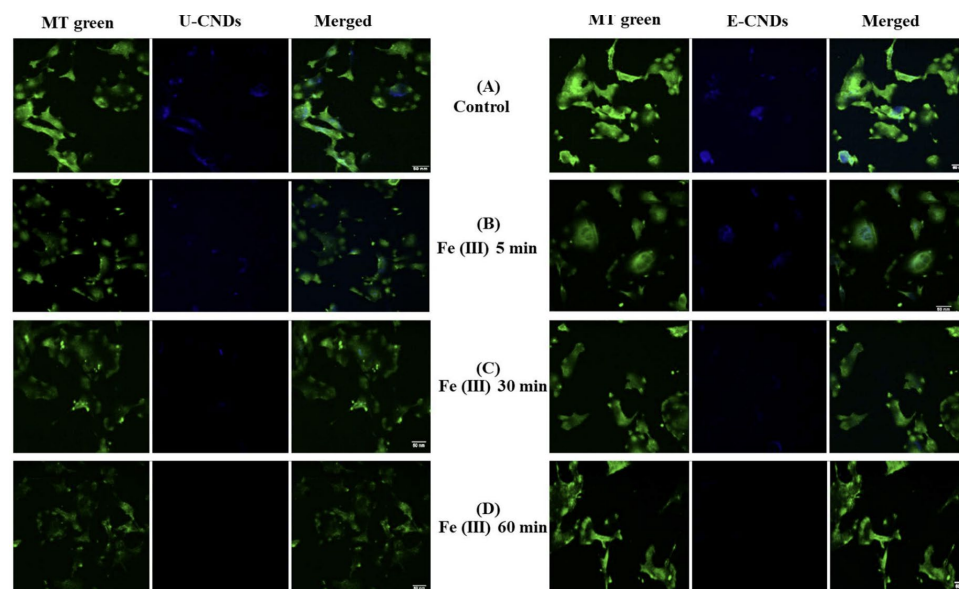
Nathan A. Rodeheaver and W. Hong Yeo, School of Mechanical Engineering, Georgia Institute of Technology
Work performed at Georgia Tech's Institute for Electronics and Nanotechnology

This work was partially supported by a SENIC Seed Grant (NSF ECCS-2025462).

National Research Priority: NAE Grand Challenge-Advance Health Informatics

High quantum yield fluorescent carbon nanodots for detection of Fe (III) ions

In this work, two types of fluorescent carbon nanodots (CNDs) are synthesized economically from ethylene diamine (E-CNDs) or urea (U-CNDs) in a single step microwave process. Both E-CNDs and U-CNDs demonstrate high selectivity towards Fe (III) ions among different metal ions, by fluorescence quenching in a dose dependent manner. The limit of detection of E-CNDs and UCNDs is observed to be 18 nM and 30 nM, respectively, in the linear response range of 0-2000 μM . Cellular internalization studies confirm the localization of the CNDs and the optical imaging sensing of Fe (III) ions inside living cells. In overall characteristics, E-CNDs provides a sensing platform for highly sensitive and selective detection of Fe (III) ions.



Fluorescence images of EA. hy926 cells incubated with E-CNDs (0.1mg mL⁻¹, right) and U-CNDs (0.3mg mL⁻¹, left) in the absence of Fe (III) ions and in the presence of 10 μM of Fe (III) for different time intervals of 5 min (B), 30 min (C) and 1 hour (D)

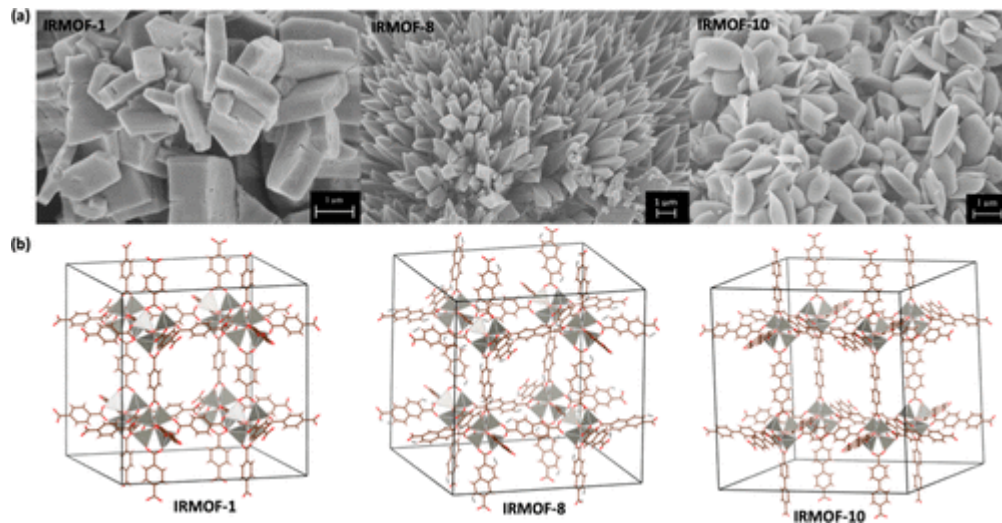
Durga Arvapalli, Jianjun Wei et al., Department of Nanoscience, University of North Carolina at Greensboro. Work was performed at the Joint School of Nanoscience and Nanoengineering (JSNN).

This work was supported by NSF Award #1832134. *Talanta*, 209, 120538, 2020.

National Research Priority: NSF-Growing Convergence Research

Semiconducting MOFs using Bloch mode analysis and spectroscopic measurements

A rapid and simple analytical approach is developed to screen the semiconducting properties of metal organic frameworks (MOFs) by modeling the band structure and predicting the density of state of isorecticular MOFs (IRMOFs). By solving Schrödinger's equation with a Kronig–Penney periodic potential and fitting the computed energy spectra to IRMOFs' experimental spectroscopic data, we model electronic band structures and obtain densities of state. The band diagram of each IRMOF reveals the nature of its electronic structures and density of state. This novel analytical approach serves as a predictive and rapid screening tool to search the MOF database to identify potential semiconducting MOFs.



(a) SEM images of microstructures of IRMOF-1, IRMOF-8, and IRMOF-10. (b) Crystal structures of the three IRMOFs. (Crystal structures were retrieved from CCDC and rendered using VESTA.)

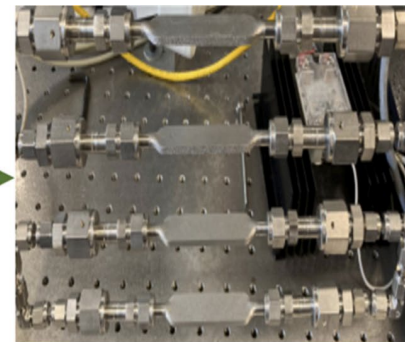
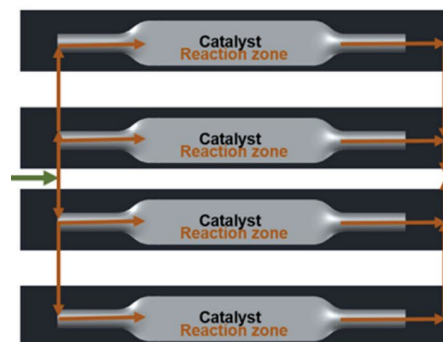
Hemali Rathnayake, Sujoy Saha, Sheeba Dawood, Shane Loeffler, Joseph Starobin, Department of Nanoscience, University of North Carolina at Greensboro. Work was performed at the Joint School of Nanoscience and Nanoengineering.

The Journal of Physical Chemistry Letters, 12(2), 884-891, 2021.

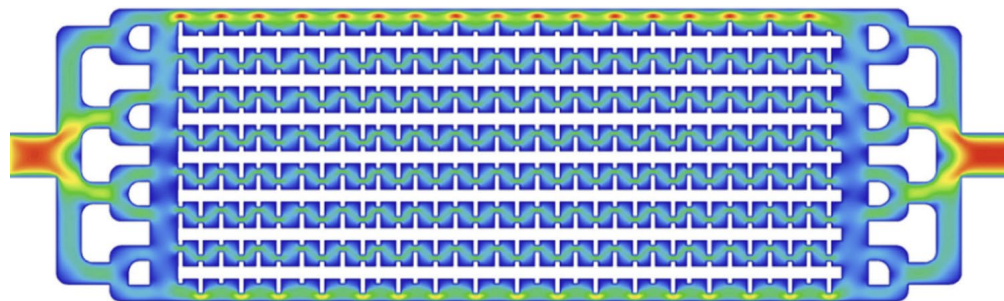
National Research Priority: NSF-Quantum Leap

Scale-up of high-pressure F-T synthesis in 3D printed microchannel microreactors

Scale-up of Fischer-Tropsch (F-T) synthesis using microreactors is very important for a paradigm shift in the production of fuels and chemicals. The scalability of microreactors for F-T Synthesis was experimentally evaluated using 3D printed stainless steel microreactors. The performance of catalysts was evaluated for three different scale-up configurations (stand-alone, two, and four microreactors assembled in parallel) at both atmospheric pressure and 20 bar at F-T operating temperature of 240 °C using a syngas molar ratio ($H_2:CO$) of 2. A CFD model was used to investigate the effect of different design features and numbering up approaches on the performance of the microchannel reactor.



Schematic and actual reactor assembly of scale-up experiments.



CFD results of effect of microreactor with a straight inlet, original mixing internals and channel design 3:: velocity contour

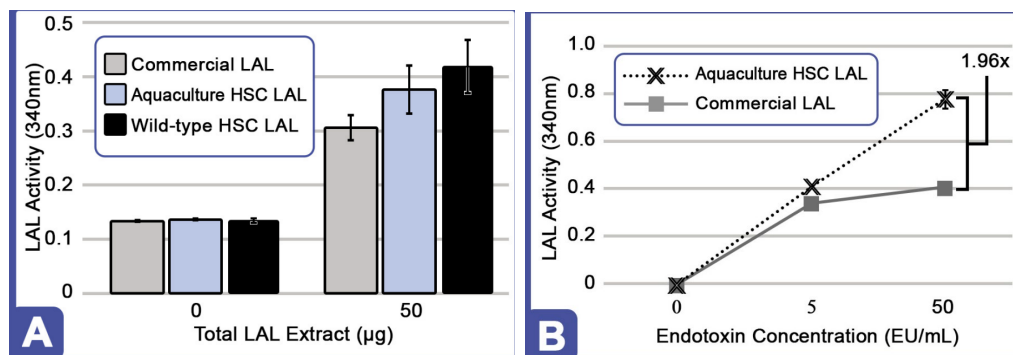
Nafeezuddin Mohammad, Debasish Kuila, Department of Chemistry, North Carolina A&T State University.
Work was performed at the Joint School of Nanoscience and Nanoengineering.

This work is supported by NSF-CREST Award #260326. *Catalyst Today*, 2021.

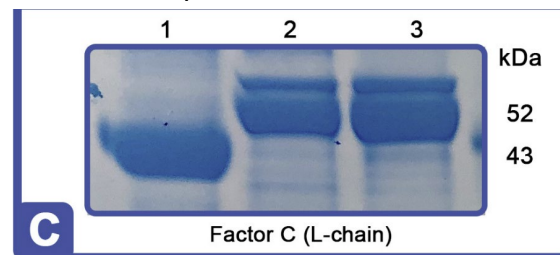
National Research Priority: NSF-Growing Convergence Research/Sustainable Nanomanufacturing

Horseshoe crab aquaculture as a sustainable endotoxin testing source

Horseshoe crab (HSC) hemolymph is the source of Limulus ameocyte lysate (LAL), a critical component in sterility testing that ensures drug and medical device safety for millions of patients every year. We designed a controlled aquaculture habitat to husband HSCs and evaluated the effects of captivity on health markers (e.g., ameocyte density, hemocyanin levels, and LAL activity). We found HSC aquaculture to be practicable, with routine hemolymph harvesting resulting in high LAL quality, while safeguarding animal well-being with 100% HSC survival. We report the development of a new LAL-based assay that can detect gram-negative bacteria and endotoxins in human blood without interference using aquaculture-derived LAL.



Evaluation & protein analysis of aquaculture-derived LAL at Day 88. A) Degree of gel clot formation - total protein of ameocyte extracts. B) Degree of clot formation of aquaculture HSC and commercial LAL.



Coomassie blue staining of crude protein lysate, commercial LAL (Lane 1), aquaculture LAL (Lane 2), and wild-type LAL.

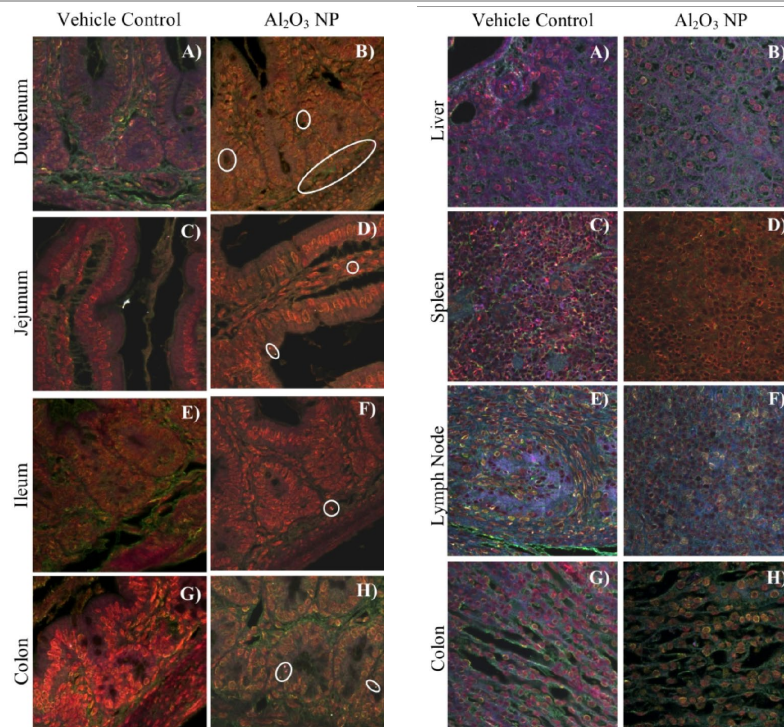
Rachel Tinker-Kulberg, Anthony Dellinger et al, Kepley Biosystems. Partial work was performed at the Joint School of Nanoscience and Nanoengineering.

This work is supported by NSF (SBIR #1819562). *Frontiers in Marine Science*, 7, 153, 2021.

National Research Priority: NSF-Growing Convergence Research/Sustainability

Response of aluminum oxide nanoparticles in juvenile rats following oral administration

Little is known about the uptake, biodistribution, and biological responses of nanoparticles (NPs) and their toxicity in developing animals. Here, male and female juvenile Sprague–Dawley rats received four consecutive daily doses of 10 mg/kg Al₂O₃ NP or vehicle control (water) by gavage between postnatal days (PNDs) 17–20. The biodistribution of Al₂O₃ NP in tissue sections of the intestine, liver, spleen, kidney, and lymph nodes were evaluated using enhanced dark-field microscopy (EDM) and hyperspectral imaging (HSI). EDM/HSI indicates intestinal uptake of Al₂O₃ NP. Al₂O₃ NP altered neurotransmitter/metabolite concentrations in juvenile rats' brain. These data suggest that orally administered Al₂O₃ NP interferes with the brain biochemistry in both female and male pups.



Hyperspectral images of H&E stained vehicle control and Al₂O₃ NP dosed (left) A-B) duodenum, C-D) jejunum, E-F) ileum, and G-H) colon. (right) A-B) liver, C-D) spleen, E-F) lymph node, and G-H) kidney

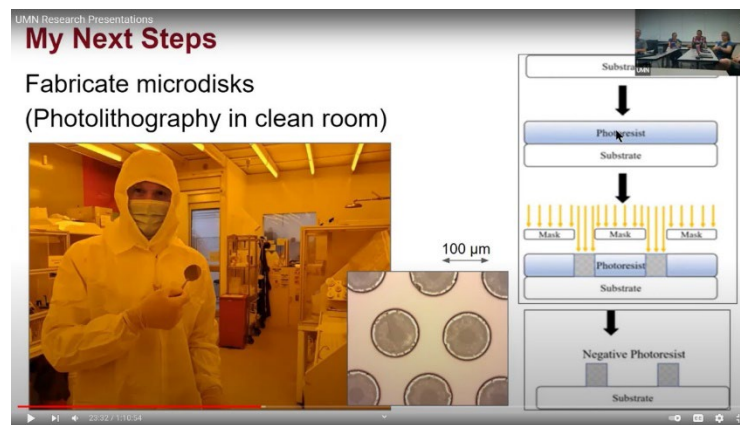
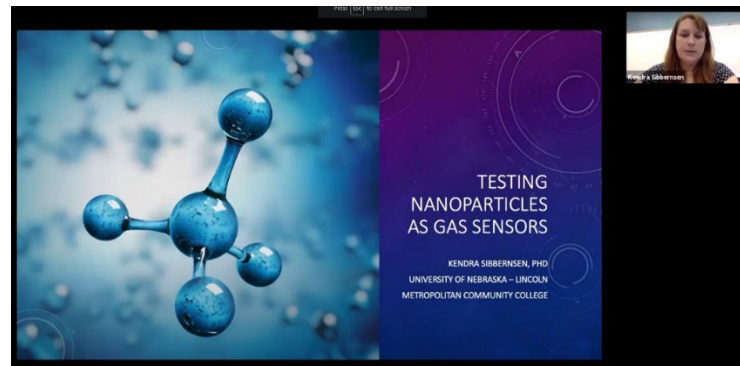
Mortensen, Fennell et al., RTI International, Research Triangle Park, NC. Partial work was performed at the Joint School of Nanoscience and Nanoengineering.

This work was supported by NIH (U01ES027254) and NSF (CBET 1604647). *J. Appl. Toxicol.* 41, 1316, 2021.

National Research Priority: NAE Grand Challenge-Engineer Better Medicines

Research Experiences for Teachers Across the NNCI

Awarded in spring 2020, the NSF-supported RET hosted the first cohort of educators in summer 2021. SENIC (lead), MINIC, NNF, and SHyNE welcomed 5 high school teachers or technical/community college faculty on their campuses for 6 weeks of hands-on research. As a networked program, everyone met virtual 1-2 times a week to share their research and receive feedback on their proposed original lessons. In addition to research, teachers participated in a nano-careers webinar series featuring industry speakers who are also users of site facilities. The educators will present on their experience and lessons at the 2022 annual National Science Teachers Association Meeting. Their lessons will also be posted on the NNCI's searchable database and nanoHUB, and the teachers are recording short videos intended to help their peers implement their lessons.

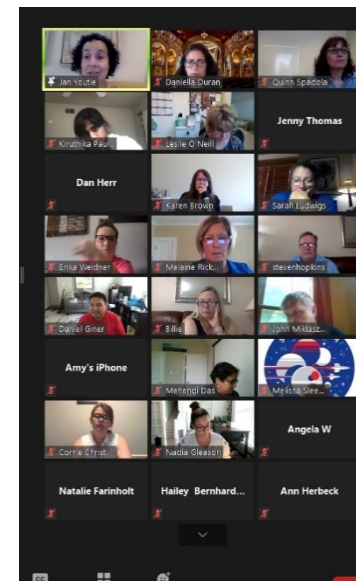
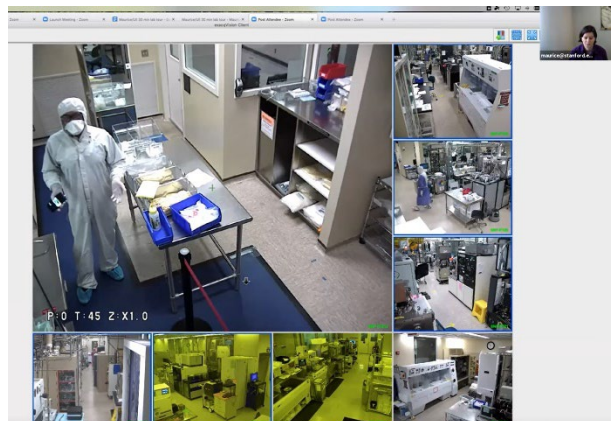


This work was supported by NSF RET (#1953418 at SENIC)

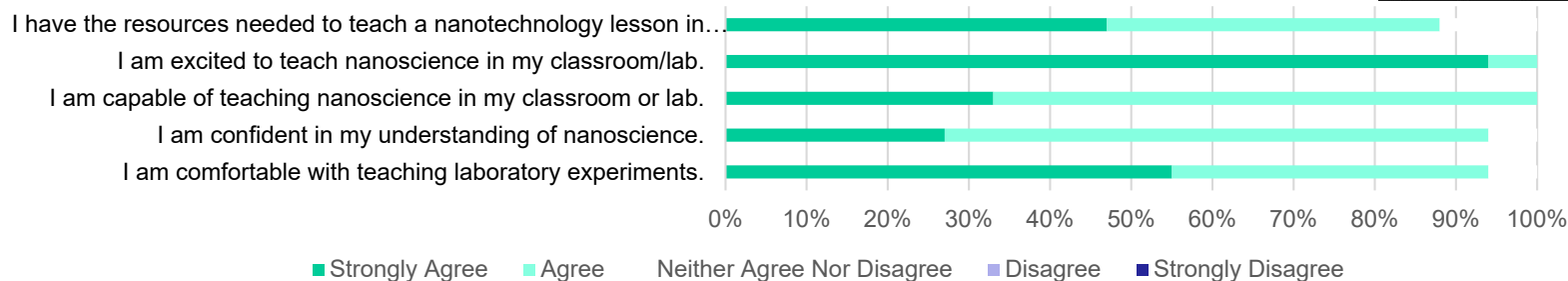
National Research Priority: NSF-INCLUDES

Nano Summer Institute for Middle School Teachers (NanoSIMST)

SENIC hosted a week-long virtual NanoSIMST in June 2021. Due to personnel changes at nano@Stanford, SENIC included their 15 teachers in the program. The 30 teachers (15 from NC, 15 from Stanford) learned about nanotechnology and careers, worked through hands-on demos, heard from experts, went on virtual lab tours, and developed their own ideas for implementing nanotechnology in their classrooms.



2021 Post-Program Assessment



This work was supported by the SENIC NNCI funding (NSF ECCS-2025462).

National Research Priority: NSF-INCLUDES