Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Research and Education Highlights

Year 3 (October 2017 – September 2018)

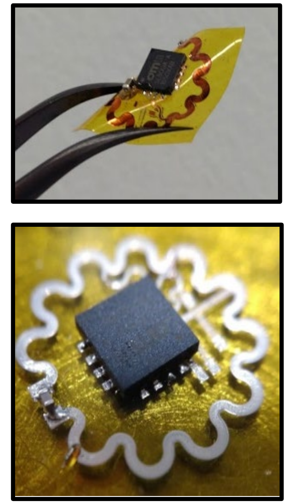
Stretchable Hybrid Electronics for Wireless Monitoring of Salivary Electrolytes

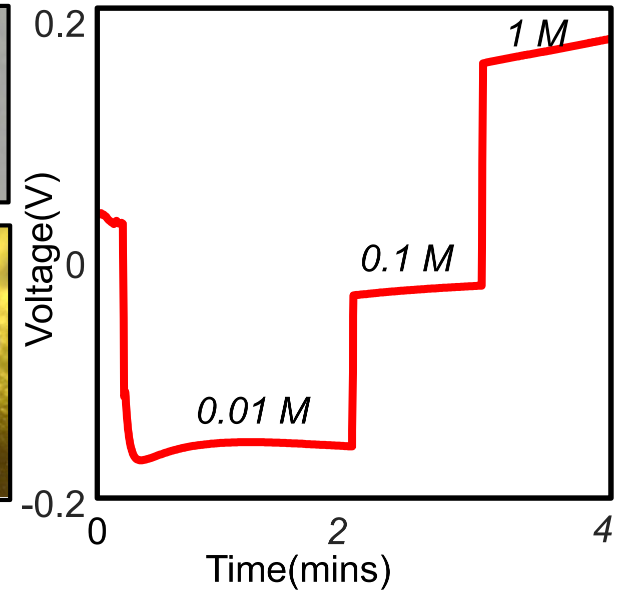
This project developed a batteryless, hybrid electronic sensor platform for analyzing salivary electrolytes.

The device was fabricated by using two different process methods, including aerosol jet printing and material transfer printing. The IC chip allowed for configuration of potentiometric sensors.

The RFID tag fits on a Hawley retainer and reads up to 1 meter in free space.

The current sensor design was electroplated with palladium and Ag/AgCl for measurements of potassium electrolytes. Current sensor configuration could successfully detect potassium as small as 0.01 Mol/L.





Optical images (left) of fabricated hybrid electronics via the combination of microfabrication, transfer printing, and direct writing methods. The graph (right) shows the sensor response according to various solutions with potassium analytes.

Saswat Mishra and Woon-Hong Yeo, School of Electrical and Computer Engineering, Georgia Institute of Technology. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by SENIC Seed Grant (NSF ECCS-1542174).

Y. Lee, et al., *Proceedings of the National Academy of Sciences*, **115**, 5377 (2018)

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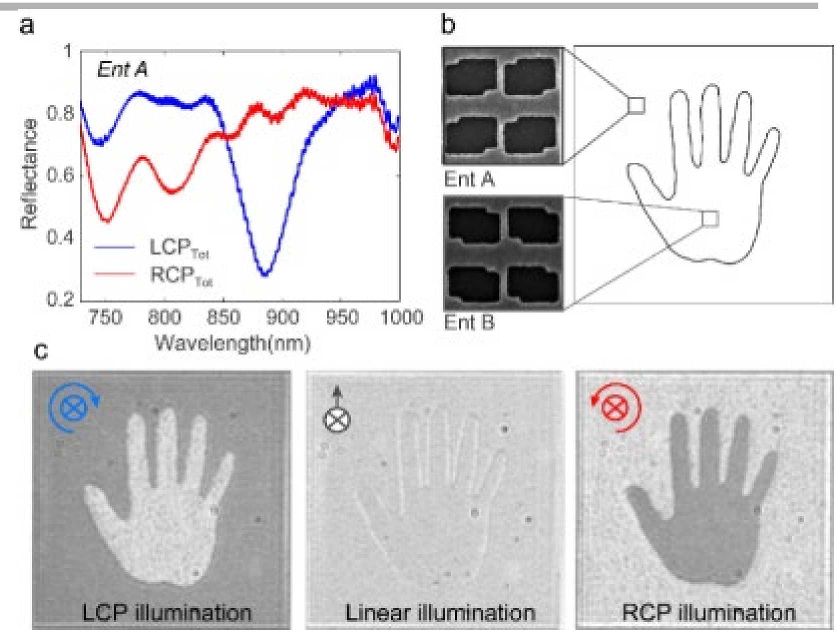
Chiral Metamaterials for Optical Modulation and Signal Processing

Metamaterials can be designed to exhibit extraordinarily strong chiral responses. We realized a set of photonic metamaterials that possess pronounced chiroptical features in the nonlinear regime. In additional to the gigantic chiral properties such as the circular dichroism and polarization rotation, the metamaterials demonstrate a distinct contrast between second harmonic responses from the two circular polarizations. These structures are further exploited for chiral-selective two-photon luminescence from quantum emitters, photon-drag effect with helicity-sensitive generation of photocurrent, and all-optical modulation of chiroptical responses under a modest level of excitation power.



(a) Measured circular dichroism spectra of a chiral metamaterial. (b) Schematic of enantiomeric placement in the pattern. (c) Imaging of the chiral pattern under linear and circularly polarized lights.

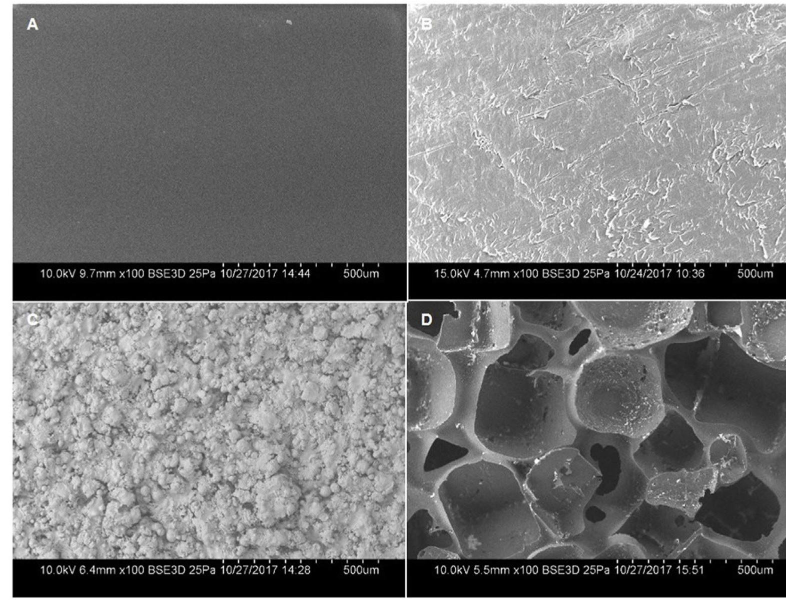
S. P. Rodrigues, L. Kang, and W. Cai, School of Electrical and Computer Engineering, Georgia Institute of Technology. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

Project supported by NSF (ECCS-1609567) and ONR (N00014-17-1-2555).

S. P. Rodrigues et al., *Nature Communications*, Vol. 8, 14602 (2017). L. Kang et al., *Nano Letters*, Vol. 17, No. 11, 7102-7109 (2017)

Porous PEEK Improves the Bone-implant Interface Compared to Plasma-sprayed Titanium Coating on PEEK

Polyether-ether-ketone (PEEK) is one of the most common materials used for load-bearing orthopaedic devices due to its radiolucency and favorable mechanical properties. However, current smooth-surfaced PEEK implants can lead to fibrous encapsulation and poor osseointegration. This study compared the in vitro and in vivo bone response to two smooth PEEK alternatives: porous PEEK and plasma-sprayed titanium coatings on PEEK. Overall, porous PEEK was associated with improved osteogenic differentiation in vitro and greater implant fixation in vivo compared to smooth PEEK and Ti-coated PEEK. These results suggest that not all PEEK implants inherently generate a fibrous response and that topography has a central role in determining implant osseointegration.



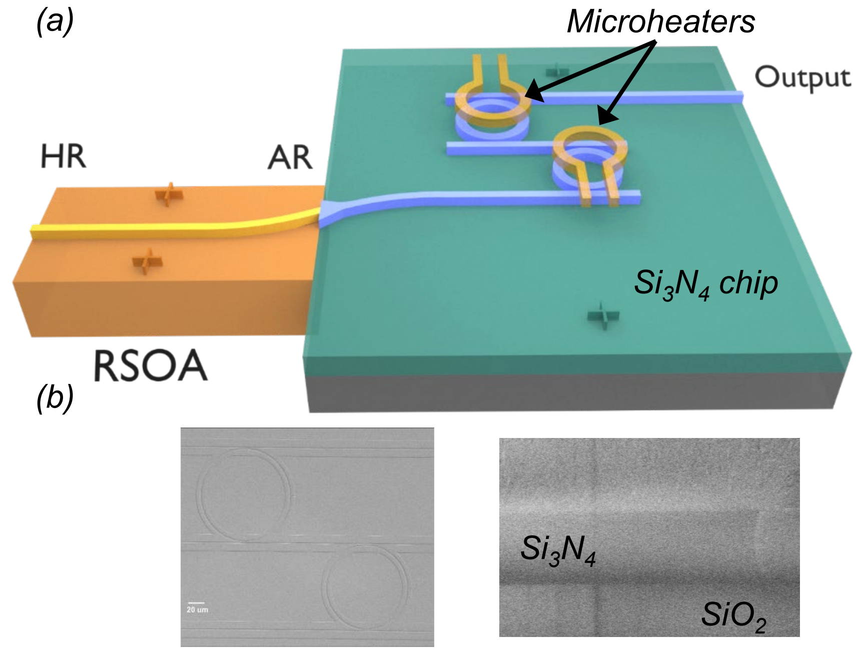
SEM images depicting the macro-scale topography of injection molded PEEK (A), machined PEEK (B), Ti-coated PEEK (C), and porous PEEK (D).

David Safranski, MedShape, Inc.; Todd Sulchek, Robert Guldberg, School of Mechanical Engineering, Georgia Institute of Technology. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by Vertera Spine.
Torstrick, FB, Lin, ASP, Potter, D, Safranski, DL, Sulchek, TA, Gall, K, Guldberg, RE., *Biomaterials*. 2018. Vol 185. p. 106-116.

Narrow-linewidth, Tunable External Cavity Diode Lasers through InP-Si3N4 Hybrid Integration

Narrow linewidth, tunable diode lasers are important for a wide range of applications, such as coherent optical communications, optical sensing, light detection and ranging (LIDAR) and spectroscopy [1]. In this work, we have demonstrated the hybrid integration of a low-loss, passive Si3N4 external cavity with a RSOA on silicon photonics platform to greatly reduce the laser linewidth and obtain the tunability. In addition to the quantum-well RSOA working around 1.55 um, a GaAs RSOA at 1 um with wider tunability can also be integrated in the hybrid platform due to the broad transparency window of the silicon nitride.



(a) Schematic plot of the hybridly integrated diode lasers; (b) The SEM images of the fabricated double-ring filter and cleaved waveguide facet.

Yeyu Zhu, Siwei Zeng, Xiaolei Zhao, Yunsong Zhao, and Lin Zhu, Department of Electrical and Computer Engineering, Clemson University. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by Army Research Office (W911NF-14-1-0640) and Office of Naval Research (N00014-17-1-2556).
Zhu, Yeyu, et al., CLEO: Science and Innovations, Optical Society of America, 2018.

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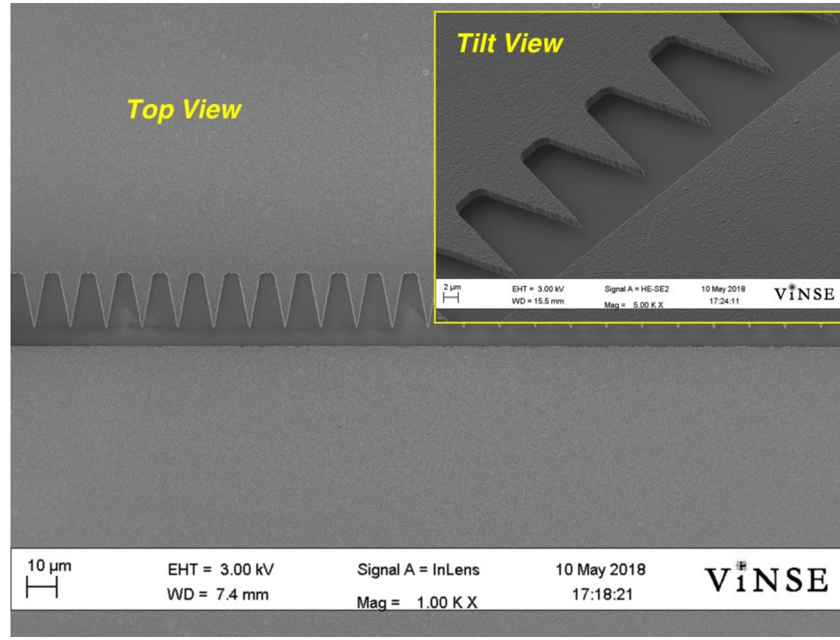
Radiation Hardened Electronics using Diamond Vacuum Field Emission Devices

Vacuum micro/nanoelectronics (cold cathode) is an emerging technology that will lead to the development of “extreme” electronic devices with greater performance and higher radiation operational limits than those found in solid-state devices. Despite the popularity and wide deployment of solid-state semiconductor technology, its performance is primarily dominated by electron scattering transport in which the electron transport is impeded by the crystal lattice. The operational characteristics of vacuum field emission devices, where electrons transport through vacuum environment, are essentially independent of the ambient temperature and are insensitive to radiation damage. The “junction-free” vacuum electronic devices possess a wide bandwidth, high-speed throughput, and long operational lifetime.



SEM micrograph of diamond based vacuum field emission diode in a lateral configuration for radiation hardened electronics.

Supil Raina, Mesut Yilmaz, Mick Howell, Weng P Kang, Department of Electrical Engineering and Computer Science, Vanderbilt University.
Work performed at Georgia Tech’s Institute for Electronics and Nanotechnology.

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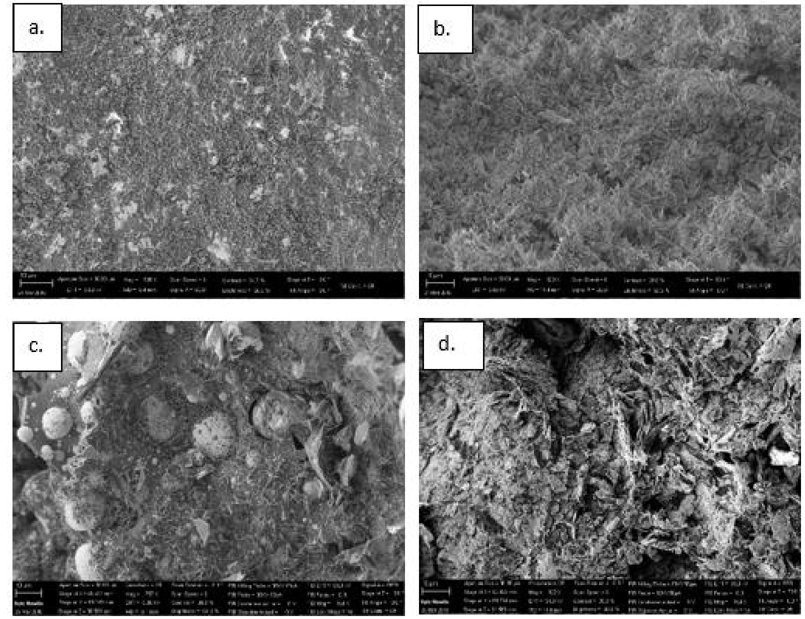
Investigating Sintering Mechanisms for Additive Manufacturing of Conductive Traces

This research explores a hybrid additive manufacturing technology. A variety of conductive materials were deposited on both rigid (glass) and flexible (Kapton) substrates. The deposited traces were cured using two sintering mechanisms which include furnace heating and in situ laser irradiation. The effect of curing mechanism on the conductance of deposited traces was evaluated. An increase in the laser power resulted in lower resistivity of the traces. The lowest resistivity was achieved at 40W laser power with a single laser pass. Scanning electron microscopy and energy dispersive spectroscopy were used to characterize the trace morphology and elemental compositions. Higher power laser curing resulted in better bonding of the particles. Laser cured samples had minimal oxidation to the cross-section region of the traces as compared to furnace cured samples.



Cross-sectional SEM images of silver traces (a) furnace top view (b) furnace cross-sectional view (c) 40W laser top view (d) 40W cross-sectional view

Salil Desai, Department of Industrial & Systems Engineering, North Carolina A&T State University. Work performed at Joint School of Nanoscience and Nanoengineering.

This work was supported by NSF CMMI: Award 1435649.
McKenzie, J., & Desai, S. (2018). *American J. of Engineering and Applied Sciences*, 11(2).

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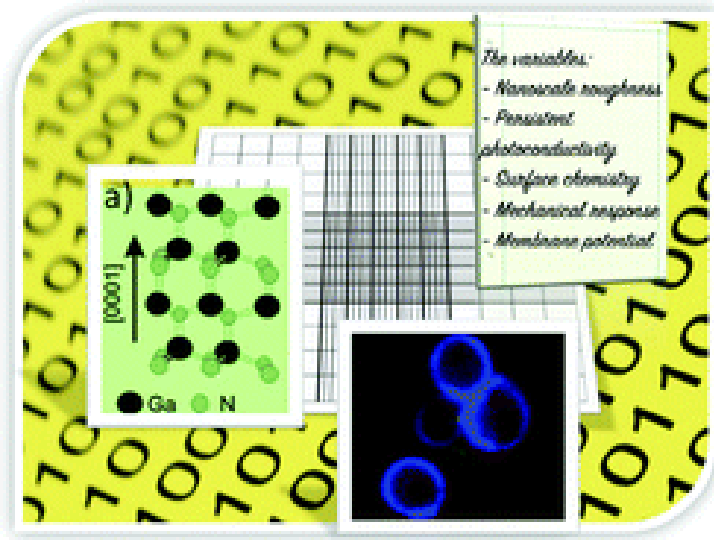
Bioelectronics Communication: Encoding Yeast Regulatory Responses using Nano GaN

Baker's yeast, S. cerevisiae, is a model organism that is used in synthetic biology. The work demonstrates how GaN nanostructured thin films can encode physiological responses in S. cerevisiae yeast. The Ga-polar, n-type, GaN thin films are characterized via Photocurrent Measurements, Atomic Force Microscopy and Kelvin Probe Force Microscopy. UV light is used to induce persistent photoconductivity that results in charge accumulation on the surface. The morphological, chemical and electronic properties of the nanostructured films are utilized to activate the cell wall integrity pathway and alter the amount of chitin produced by the yeast. The encoded cell responses are induced by the semiconductor interfacial properties associated with nanoscale topography and the accumulation of charge on the surface that promotes the build-up of oxygen species and in turn cause a hyperoxia related change in the yeast. The results thus define a strategy for bioelectronics communication.



Yeast cell interaction with GaN semicopnductor materials m elicit special behavioral and physiological changes

Snyder, LaJeunesse, Reddy, Kirste, Collazo, Ivanisevic, Materials Science and Engineering, NC State University, Nanoscience, UNC Greensboro and Adroit Materials. Part of this work was performed at Joint School of Nanoscience and Nanoengineering.

Partial financial support from NSF DMR-1312582, ECCS-1542174, ECCS-1653383 and NIH 1R15EB024921-01.
Snyder et al., *Nanoscale*, 2018,10, 11506.

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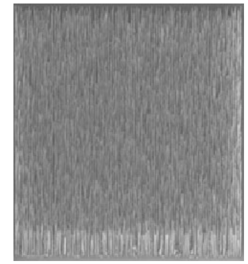
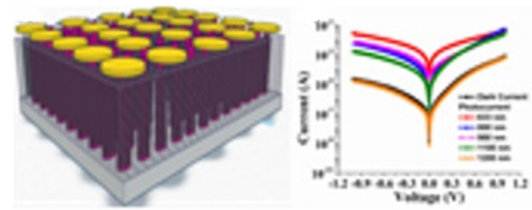
GaAsSb Nanowires for IR Photodetectors

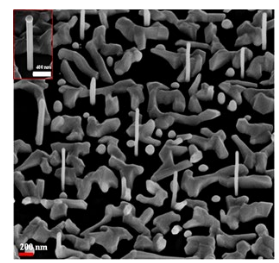
The focus of this work is on the Ga assisted molecular beam epitaxial growth of GaAsSb nanowires (NWs), characterization and demonstration of NW based photodetector in the near infrared region. High quality nanowires were grown as seen by the narrow full width half maxima of low temperature photoluminescence line-shape and lack of any defects in the transmission electron microscope images. In addition, site-specific growth of GaAsSb NWs with >90% hole occupancy and pitch induced band gap tuning were successfully shown. Next, GaAsSb NW photodetector device exhibited good spectral response up to 1.1 µm. Lastly, growth of GaAsSb NWs of high quality on monolayer graphene have also been demonstrated for the first time for flexible applications



SEM micrograph of GaAsSb patterned NW arrays by electron beam lithography.



Axial p-I GaAsSb/GaAlAs core-shell NW ensemble photodetector



GaAsSb NWs on graphene

Shanthi Iyer, Nanoengineering/Electrical and Computer Engineering, North Carolina A&T State University.
Work performed at Joint School of Nanoscience and Nanoengineering.

This work has been supported by ARO W911NF-15-1-0379, NSF HRD-1649517, ONR N00014-16-1-2720.

P. Deshmukh et al. *Sem. Sci. Tech.* 33, 125007(2018), Estiak Ahmad et al. *Scientific Rep.* 7, 10111 (2017), M. Sharma et al. *Crystal Growth & Design*, 17, 307 (2017).

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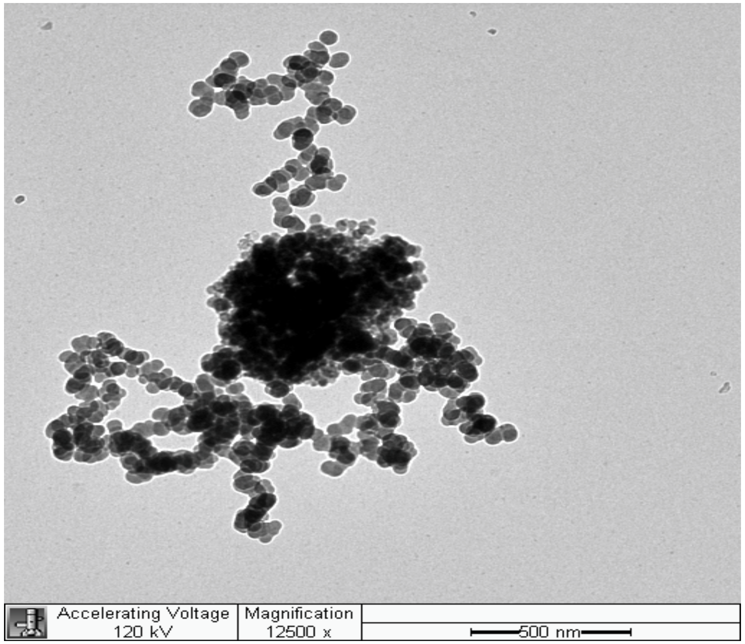
Modeling Refractive Indices of Biomass Burning Aerosols

Biomass burning emissions are a major source of fractal aggregates which are clusters of spherules forming aerosols of non-spherical shape. Both the developed and developing world are subject to biomass burning events through agricultural burning, wildfires, and domestic burning applications. Accurate quantification of their optical properties is important both for their measurement and for predicting their radiative effect. Raleigh-Debye -Gans (RDG) assumes that each monomer in the aggregate interacts independently with radiation, by neglecting multiple scattering and shadowing. Absorption is an incoherent process and as a result the absorption of the aggregate is equal to the number of monomers, N, times the absorption of a single monomer. TEM images are used to determine the size parameters of the fractal aggregates. We use T-Matrix and RDG theory to fit experimentally measured optical properties to extract the refractive indices of biomass burning aerosols.



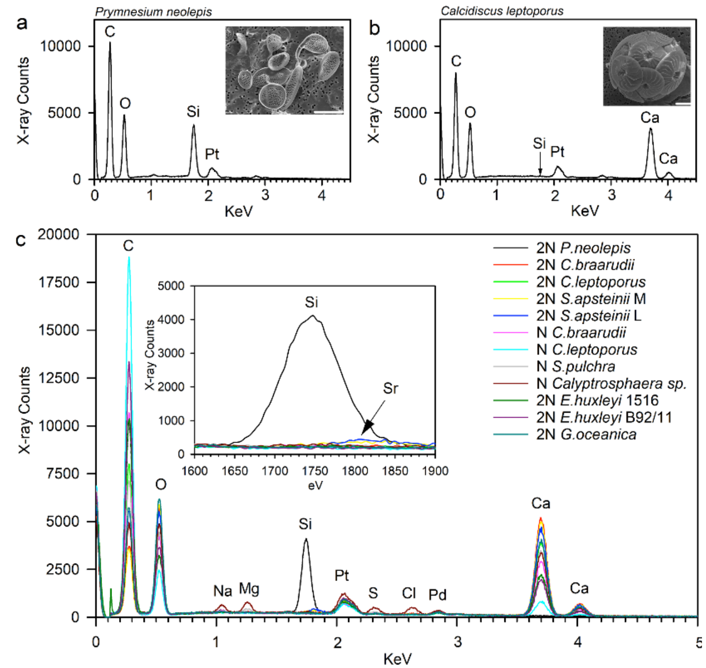
TEM images of biomass burning aerosols collected on filters

Solomon Bililign and Marc Fiddler, Department of Physics, North Carolina A&T State University.
Work performed at Joint School of Nanoscience and Nanoengineering.

This work was supported by NSF Award AGS-1831013 and AGS-1555479.
Poudel et al., *Atmosphere* 2017, 8, 228.

Biomineralization Mechanisms in Marine Phytoplankton

Coccolithophores are calcifying marine algae which produce taxonomically distinct CaCO3 (calcite) coccoliths to form an outer covering of the cell. Certain species form large blooms, which can account for nearly half of global annual CaCO3 production. Despite their significant impact on biogeochemical cycles, the cellular mechanisms of calcification remain poorly understood. Coccoliths are produced in a highly regulated intracellular process that involves crystal nucleation on an organic baseplate, interactions with organic macromolecules, Ca2+, HCO3- and other cations. This work utilizes analytical SEM to understand the role of key elements such as Si and Sr in the precipitation and nanomorphology of the biomineral structures in order to better understand the mechanisms of coccolith production by these globally important marine microbial organisms.



Elemental analysis of (a) a silicifying haptophyte (Prymnesium neolepis) and (b) calcifying Calcidiscus leptoporus using EDS. Note Si and Ca peaks respectively. (c) EDS analysis across multiple species. A small Sr peak was observed for Scyphosphaera apsteinii (arrow).

Erin Meyer and Alison Taylor, Biology and Marine Biology, University of North Carolina Wilmington.
Work performed at Joint School of Nanoscience and Nanoengineering.

This work was supported by NSF Award # OCE-1638838.
Walker C., Taylor A.R. et al., *New Phytologist*, 2018

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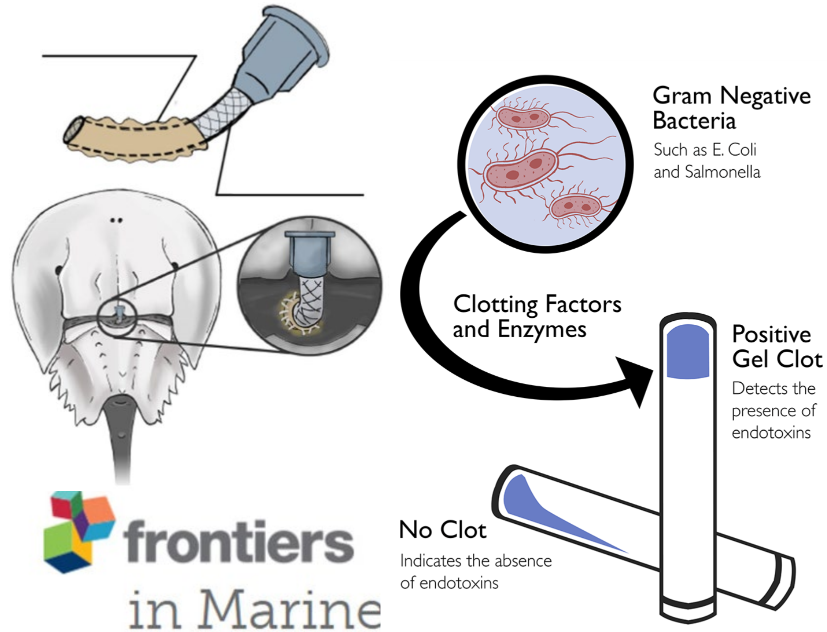
Innovation for Horseshoe Crab Bleeding and Management

Kepley BioSystems Inc (KBI), a JSNN NIC member was recently awarded NSF Phase 1 SBIR grant to develop a novel surgical implant and management strategy to improve the harvest of amebocytes from horseshoe crabs. Amebocytes play a critical role in safeguarding modern medicine and serve as the back bone of the FDA mandated QC method for drug developers, however currently used methods are deleterious to the species viability and have been estimated to cause a 26% mortality rate, annually.



Surgical Implant to Improve Bleeding Horseshoe Crabs

Kristen Dellinger, Chris Kepley, Anthony Dellinger, Kepley Biosystems, Greensboro, NC.
Work performed at Joint School of Nanoscience and Nanoengineering

This work was supported by NSF SBIR Phase II Award #1555752. Gannon et al., The Role of Horseshoe Crabs in the Biomedical Industry and Recent Trends Impacting Species Sustainability, *Front. Mar. Sci.*, 2018.