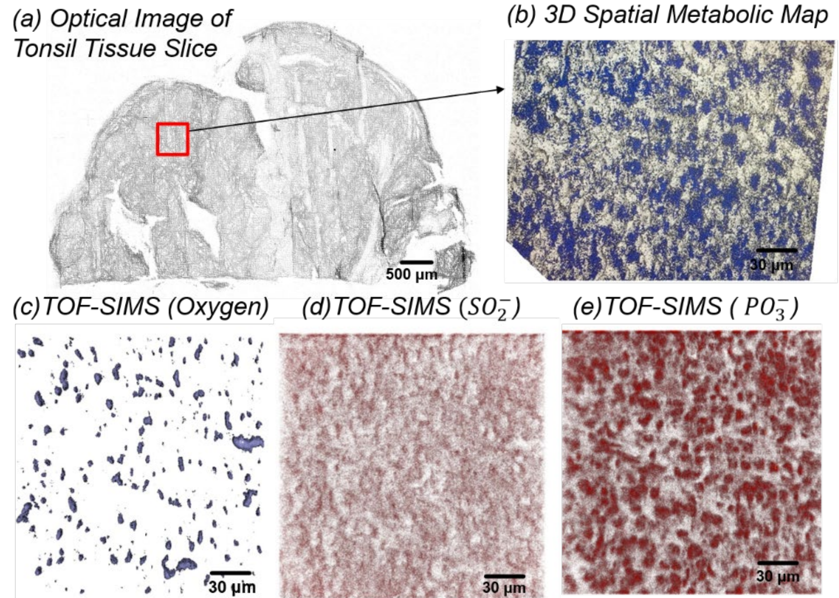
Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Research and Education Highlights

Year 4 (October 2018 – September 2019)

Spatially resolved 3D metabolomic profiling of immune cells by subcellular volumetric analysis

This project profiles human tonsil tissues by analyzing the spatial distribution of antibodies and immune cells such as T cells and B-cells, using three dimensional (3D) molecular analysis framework. Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS) instrument was used to obtain 3D metabolic profiles of chemical fingerprints such as phosphorous, sulphur, and lipid signatures from the immune cells in the tonsil tissue. To analyze these 3D metabolic channels in the immune cells, metabolic data dimensionality reduction techniques such as Principal Component Analysis (PCA) was initially carried out. To quantify 3D spatial metabolic distribution, unsupervised clustering algorithms such as K-means clustering was implemented based on the metrics such as density, means, and correlations. Thus, the presented 3D metabolic analysis pipeline will be useful for quantifying engineered immune cells in health and disease.



(a) Optical image of a tonsil tissue slice. Red highlighted region was profiled by 3D metabolomics imaging. Scale bar 500µm. (b) 3D render of twenty TOF SIMS images of metabolites. Metabolic signatures of (c) Oxygen, (d) SO_2^- and (e) PO_3^- in the red highlighted region. Scale bar 30µm.

Shambavi Ganesh, Eric Woods, Mayar Allam, Shuangyi Cai, Walter E. Henderson, and Ahmet F. Coskun, Biomedical Engineering, Electrical and Computer Engineering, Biological Sciences, Institute for Electronics and Nanotechnology, Georgia Tech and Emory University. Work performed at Georgia Tech Materials Characterization Facility.

This work was supported by BWF-CASI # 1015739.02, NIH # K25AI140783, and Georgia Tech & Emory start-up funds.

National Research Priority: NSF-Understanding the Rules of Life

National Nanotechnology Coordinated Infrastructure

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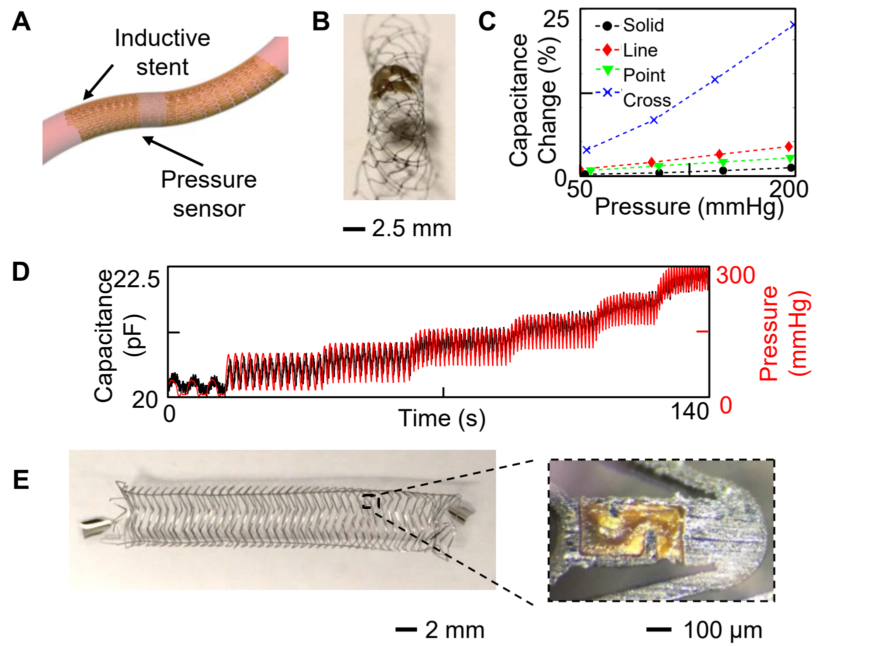
Fully Wireless, Nanostructured, Hemodynamic Sensor System for Continuous Monitoring of Blood Pressure and Flow Rate

- Hemodynamic conditions are used as indications for cardiovascular diseases, which account for over 30% of deaths worldwide
- Focused on developing an implantable smart stent with two nanostructured, soft pressure sensors for wireless monitoring of blood pressure and flow rate
- Stent is balloon expandable and employs a solenoid-like shape with polymer support links to maintain mechanical integrity and a high inductance (1.4 μH)
- Fully printed, low-profile capacitive pressure sensors use a microstructured PDMS dielectric layer to achieve high sensitivity (3.8 fF/mmHg).
- Future work will include wireless testing and in vivo demonstration



A) Illustration of implantable smart stent and sensor. B) Low-profile pressure sensor integrated on stent. C) Pressure sensitivity comparison of PDMS microstructures. D) Pressure sensor response to pulsatile flow in model blood vessel. E) Smart stent after balloon expansion with enlarged view of polyimide support link.

Robert Herbert and Woon-Hong Yeo, Mechanical and Biomedical Engineering, Georgia Tech. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by an IEN Facility Seed Grant (funded by NSF ECCS-1542174).

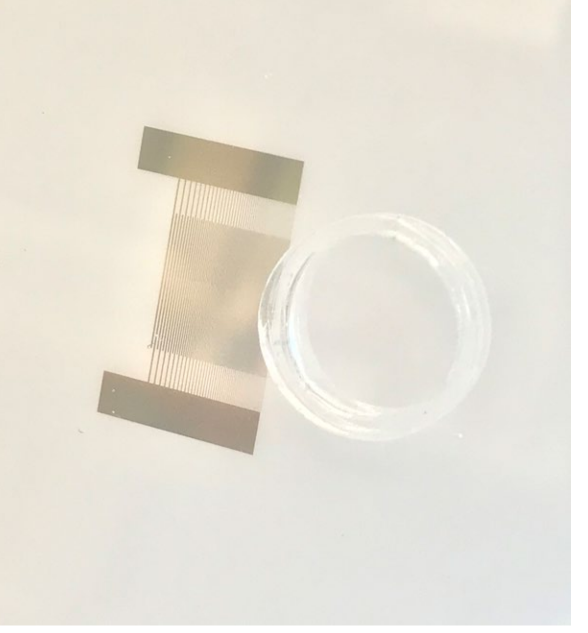
National Research Priority: NSF-Growing Convergence Research

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

Physics of Aacoustic-Neuro Interaction

The goal of this project is to study how ultrasonic waves of different frequencies alter the electrophysiology of neurons in vitro. A chromium and gold interdigitated transducer is deposited on a piezoelectric lithium niobate substrate. The spacing between digits on the transducer is varied to accommodate frequencies ranging from 10 to 60 MHz. A PDMS ring is positioned adjacent to the transducer and serves as a neural cell culture dish directly on the substrate. Directly growing the cells on the piezoelectric substrate allows for the ultrasonic waves to interact with the neurons with minimal attenuation. This device is suited to fit under a patching rig for patch clamping measurements or an optical interferometry stage to observe cell movement.



PDMS ring is plasma bonded to the lithium niobate wafer directly adjacent to the interdigitated transducer (IDT)

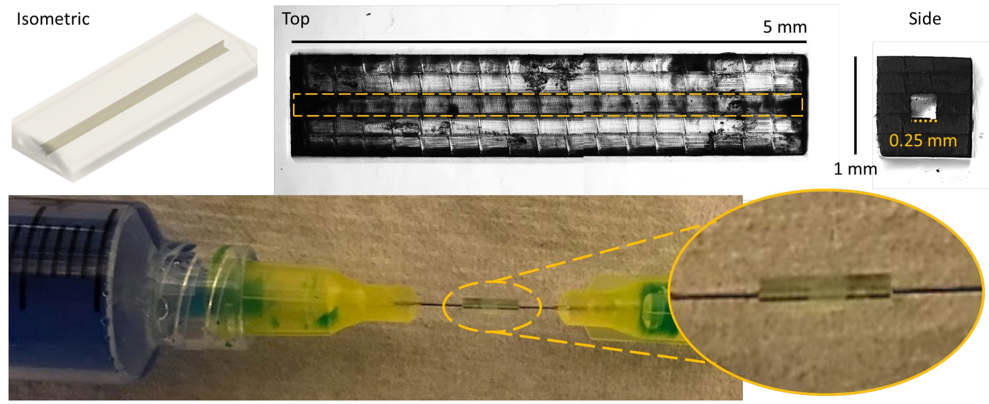
Phoebe J. Welch and Chengzhi Shi, Mechanical Engineering, Georgia Tech. Work performed at Georgia Tech’s Institute for Electronics and Nanotechnology.

This work was supported by an IEN Facility Seed Grant (funded by NSF ECCS-1542174).

National Research Priority: NSF-Growing Convergence Research

3D Bioprinted Endothelialized Vascular Tissues for Investigating Cardiovascular Diseases

This work targets a 3D printed platform for tissue engineering human microvasculatures. This work simultaneously investigates the endothelialization process and structural patterning of vasculatures to fabricate biomimetic channel systems in our tissue engineered constructs. A single channel construct with dimensions of 1x1x5 mm externally and 0.25x0.25x5 mm internally was developed and able to be perfused. From this construct, we successfully fabricated an arteriolar conduit model based on diameter (100-300 μm). With the channel suspended on all sides by cured photoresist, this avoids the need for a glass sample slide to enclose the channel. This is significant because printing with future biocompatible resists can be fully seeded and remodeled by cells for longer, more complex tissue cultures.



An isometric view and brightfield images (top and side views, 4x) of the 3D printed construct are shown highlighting the channel in yellow. The physical construct was perfused via 32 gauge needles with no leakage when sealed.

Alexander Cetnar and Vahid Serpooshan, Biomedical Engineering, Georgia Tech and Emory University.
Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by an IEN Facility Seed Grant (funded by NSF ECCS-1542174).

National Research Priority: NSF-Growing Convergence Research

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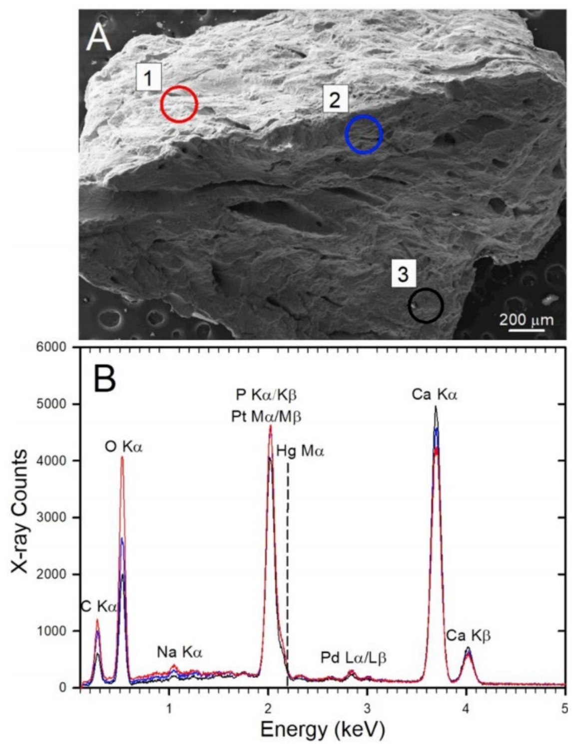
Mercury in archaeological human bone: biogenic or diagenetic?

In this work, mercury (Hg) levels in human bone from archaeological sites in the Iberian Peninsula were investigated. Previous analyses have shown high levels of total mercury (THg) in human bone at numerous Neolithic and Chalcolithic sites in this region, but the question remains if this mercury entered the bones via diagenetic processes in the soil, especially where cinnabar powder and paint was found associated with the burials, or if it entered the bone via biogenic pathways from exposure to mercury from using cinnabar in life. The pattern of Hg deposition in skeletal material from different sites and ages strongly suggests a biogenic origin for the mercury



EDS spectroscopy of human bone sample UE-112 from Montelirio tholos known to have high THg concentrations (> 273 ppm).

Steven D. Emslie, Alison R. Taylor et al., Department of Biology and Marine Biology, University of North Carolina Wilmington. Work performed at Joint School of Nanoscience and Nanoengineering.

Journal of Archaeological Science, 108 (2019) 104969.

National Research Priority: NSF-Understanding the Rules of Life

National Nanotechnology Coordinated Infrastructure

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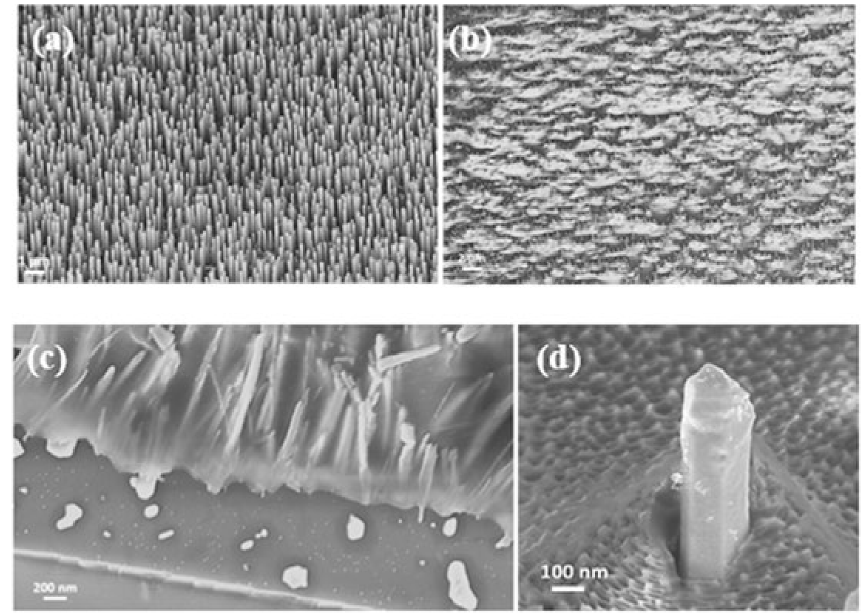
Space charge limited conduction mechanism in GaAsSb nanowires

In this work, the first observation of the space charge limited conduction mechanism (SCLC) in GaAsSb nanowires (NWs) grown by Ga-assisted molecular beam epitaxial technique, and the effect of ultra-high vacuum in situ annealing have been investigated. The low onset voltage of the SCLC in the NW configuration has been advantageously exploited to extract trap density and trap distribution in the bandgap of this material system, using simple temperature dependent current–voltage measurements in both the ensemble and single nanowires. In situ annealing in ultra-high vacuum revealed significant reduction in the trap density from 1016 cm−3 in as-grown NWs to a low level of 7 × 1014 cm−3 and confining wider trap distribution to a single trap depth at 0.12 eV.



(a) GaAsSb NWs on Si (111), (b) top view of GaAsSb NW ensemble coated with PMMA, (c) tilted view of NW ensemble and (d) NW tip exposed above PMMA.

Mehul Parakh and Shanthi Iyer, Dept. of Nanoengineering, North Carolina A&T State University. Work performed at Joint School of Nanoscience and Nanoengineering.

This work was supported by NSF# ECCS-1832117. *Nanotechnology* 31, no. 2 (2019): 025205.

National Research Priority: NSF-Quantum Leap

National Nanotechnology Coordinated Infrastructure

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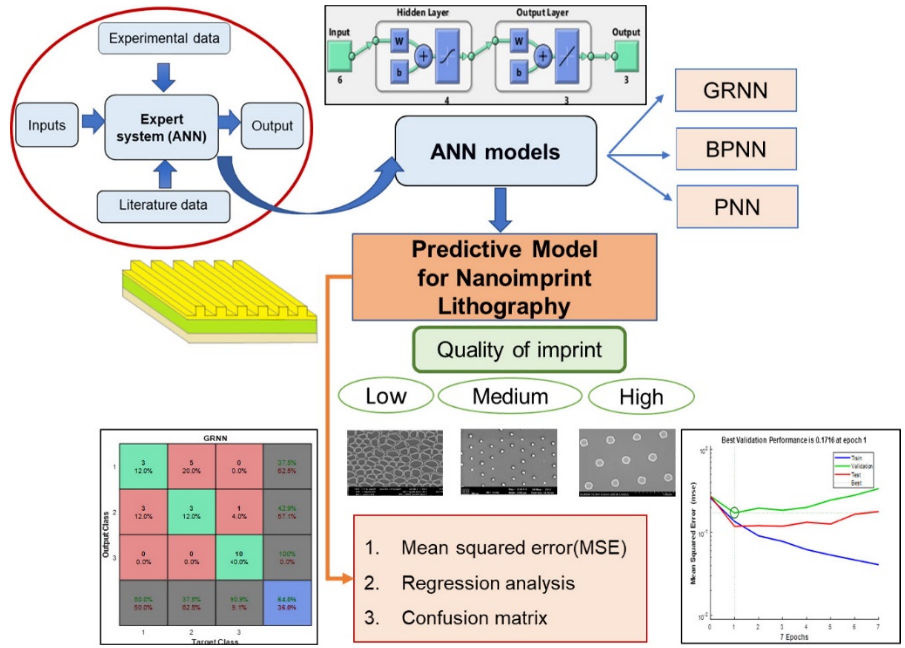
Developing a predictive model for nanoimprint lithography using artificial neural networks

Nanoimprint lithography (NIL) is a high-throughput and cost-effective technique for fabricating nanoscale features. However, the fine tuning of NIL process parameters is critical in achieving defect-free imprints. Currently, there exists no unified material and process design guidelines to deal with the complex set of process parameters. In this research, an artificial neural network (ANN) algorithm was developed to predict the imprint quality based on a set of input factors collected from experiments and literature. The prediction of the model was validated with experimental results confirming the accurate classification of all the outputs. This research lays the foundation for the development of an expert system for nanoimprint lithography.



Tahmina Akter and Salil Desai, Dept. 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-1663128. *Materials & Design* 160 (2018): 836-848.

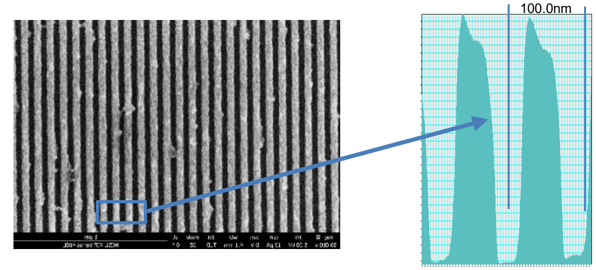
National Research Priority: NSF-Growing Convergence Research

National Nanotechnology Coordinated Infrastructure

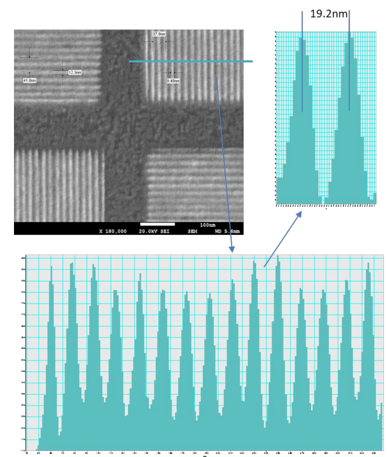
SENIC Southeastern Nanotechnology Infrastructure Corridor

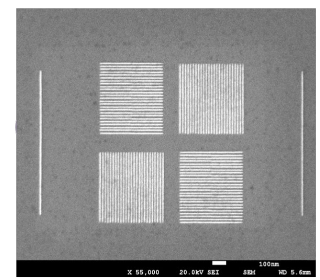
Development of a Sub-20nm Pitch Critical Dimension Standard Using Electron Beam Lithography

The objective of this project is to produce a critical dimension standard applicable to the calibration needs of the ultra-high-resolution field emission scanning electron microscopy community as well as electron microscope suppliers. The intent is to develop electron beam lithography (EBL) techniques to enable fabrication of a critical dimension standard with a pitch of 20 nm or less. The main goal is to obtain fiducial lines with a high Z contrast material relative to silicon such as gold, rather than the low Z contrast lines obtained from previous work using Hydrogen Silsesquioxane (HSQ) as the EBL resist. Following successful completion of this project, measurements of this novel metrology standard will be undertaken in collaboration with the NIST Semiconductor and Dimensional Metrology Division.



SEM micrograph of recent ~50nm half pitch Cr-Au metal lift-off lines obtained from a test sample produced at Georgia Tech IEN





Line width 9.6 +/- 0.5nm
Pitch 19nm +/- 1nm
Line edge roughness better than 2nm

SEM of previously obtained EBL patterns using HSQ EBL resist.

Dudley S. Finch, AISthesis Products, Inc. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

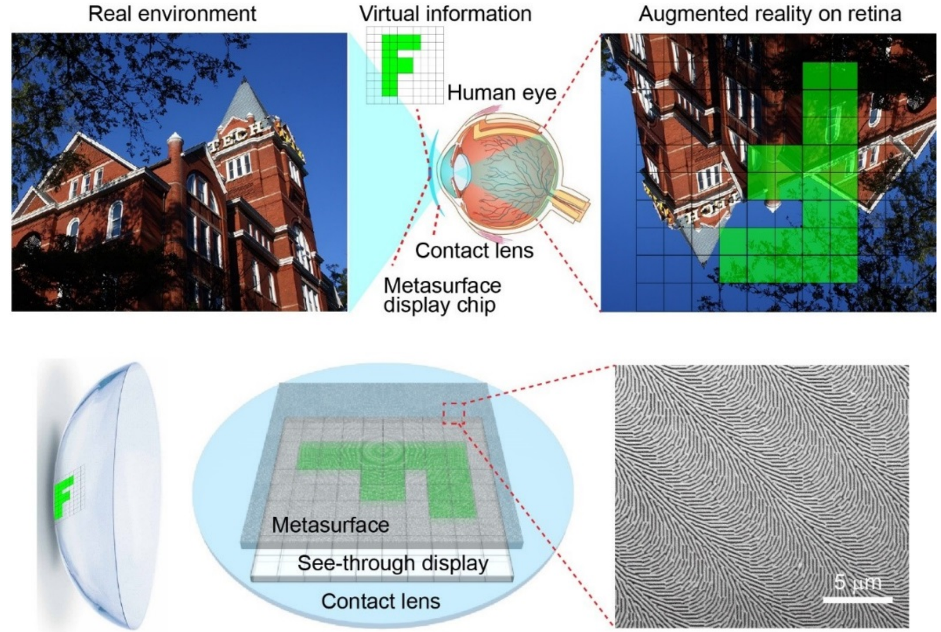
National Research Priority: NAE Grand Challenge-Engineer the Tools of Scientific Discovery

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

Metasurfaces for Near-Eye Augmented Reality

This work proposes and experimentally demonstrates a holographic display technology that casts virtual information directly to the retina so that the eye sees it while maintaining the visualization of the real-world intact. The key to our design is to introduce metasurfaces to create a phase distribution that projects virtual information in a pixel-by-pixel manner. Unlike conventional holographic techniques, our metasurface-based technique, based on Pancharatnam-Berry phase elements made of silicon, is able to display arbitrary patterns using a single passive hologram. With a small form-factor, the designed metasurface empowers near-eye AR, excluding the need for extra optical elements, such as a spatial light modulator, for dynamic image control.



Schematic of metasurface enable device. The lower-right image is the SEM micrograph of a small portion of the metasurface comprises the predesigned distribution of silicon nanobeams.

Shoufeng Lan, Xueyue Zhang, Mohammad Taghinejad, Sean Rodrigues, Kyu-Tae Lee, Zhaocheng Liu, and Wenshan Cai, Electrical and Computer Engineering, Georgia Tech. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by NSF Award # ECCS-1542174. *ACS Photonics* 2019, 6, 864−870

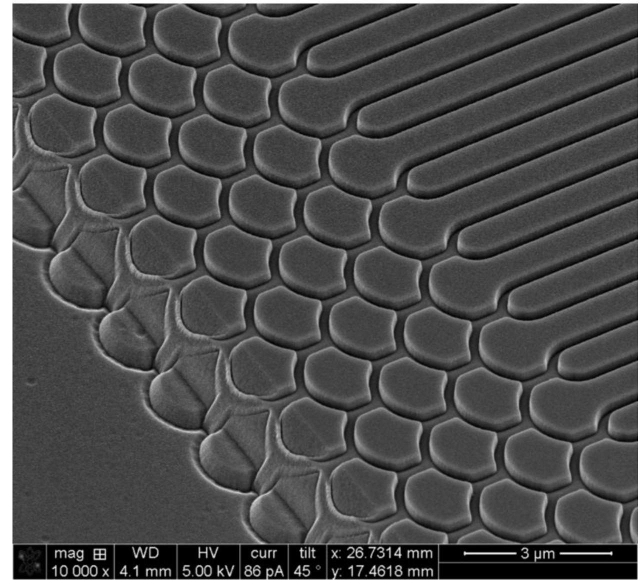
National Research Priority: NSF-Future of Work at the Human-Technology Frontier

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

Continuous Flow Nanofluidic Devices for Whole Genome Optical Mapping

This work focuses on the development of nanofluidic devices for the real-time restriction site mapping of whole genomes. Devices are fabricated with nanochannels through which single molecules of genomic DNA are electrokinetically driven. Molecules are digested during transit using restriction endonucleases to produce an ordered map sensitive to structural variation in the genome. Electron beam lithography with proximity error correction produces devices capable of generating high-resolution optical maps. In combination with sequencing data, such maps promise to illuminate the full spectrum of genomic variation impacting human health.



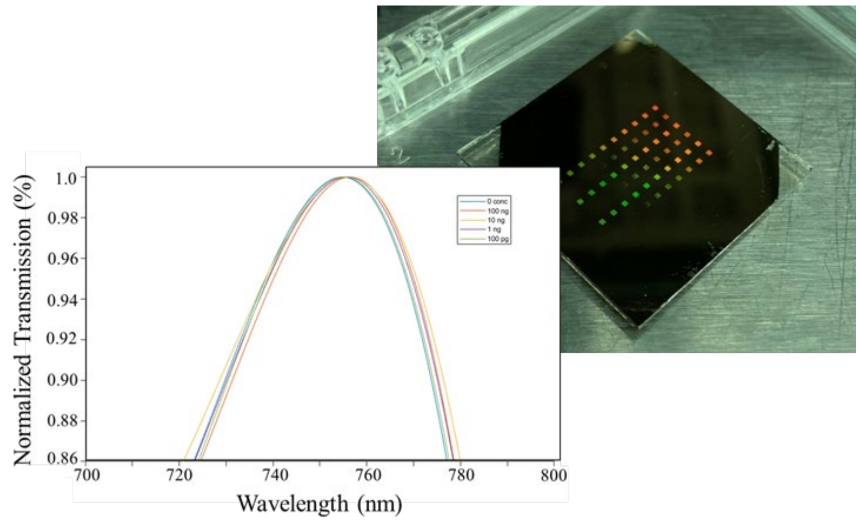
SEM micrograph of the entry of a nanochannel array used for generating high-resolution human genome maps.

Varshni Singh and Laurent D. Menard, Genturi Inc. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

National Research Priority: NSF-Growing Convergence Research and Understanding the Rules of Life

Nanoslit Arrays for Plasmonic Sensing of Cardiac Biomarker

This work targets large scale nanoslit arrays (0.5x0.5 mm) fabricated in gold film coated on a quartz substrate. A series of nanoslit arrays with different slit width (around 100 nm) were obtained and demonstrates optical characteristics (showing different color under nature white light) due to plasmonic resonance within the nanoslit array. The extraordinary optical transmission (EOT) of the array has peak shift to red as a response to biological binding at the gold surface of the nanoslit area which is used for biomarker detection due to the refractive index changes before and after the binding reaction.



An image of the nanoslits arrays generated on gold film on a quartz substrate.

Jianjun Wei, Bhawna Bagra, Dept. of Nanoscience, Joint School of Nanoscience and Nanoengineering, UNC Greensboro.

This work was partially performed at Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by North Carolina Biotechnology Center (NCBC), NCBC Grant #2019-TEG-1501.

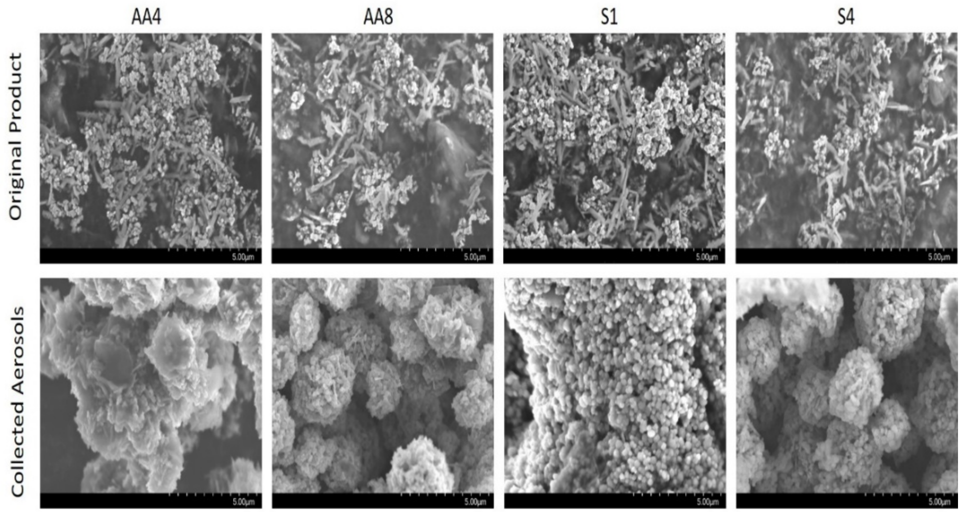
National Research Priority: NAE Grand Challenge-Engineer the Tools of Scientific Discovery

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

Characterization of particles emitted from aerosolized consumer products

This work focuses on understanding potential inhalation risks and hazards during the use of common aerosolized consumer products. Four de-identified consumer aerosolized cosmetic aerosols (AA4, AA8, S1, and S4) were assessed. Aerosols were generated, monitored and sampled using a novel aerosol generation system complete with aerosol monitoring instrumentation and animal exposure pods for in vivo toxicological evaluations. Aerosols were sampled onto aluminum substrates and evaluated using transmission electron microscopy coupled with energy dispersive X-ray spectroscopy (TEM-EDX)(Figure 1). Aerosols were multimodal consisting of micro-sized particles decorated with nanoparticles containing primarily titanium and iron.



TEM micrograph consumer product aerosols emitted from aerosolized nano-enabled cosmetics.

K.M. Pearce, W.T. Goldsmith, R. Greenwald, C. Yang, G. Mainelis, & C. Wright, Dept. of Population Health Sciences, School of Public Health, Georgia State University, IEStechno, Morgantown, WV, Institute for Electronics and Nanotechnology, Georgia Tech, Dept. of Environmental Sciences, Rutgers University. TEM-EDX work completed at Georgia Tech IEN.

Inhalation Toxicology, DOI: 10.1080/08958378.2019.1685613 (2019)

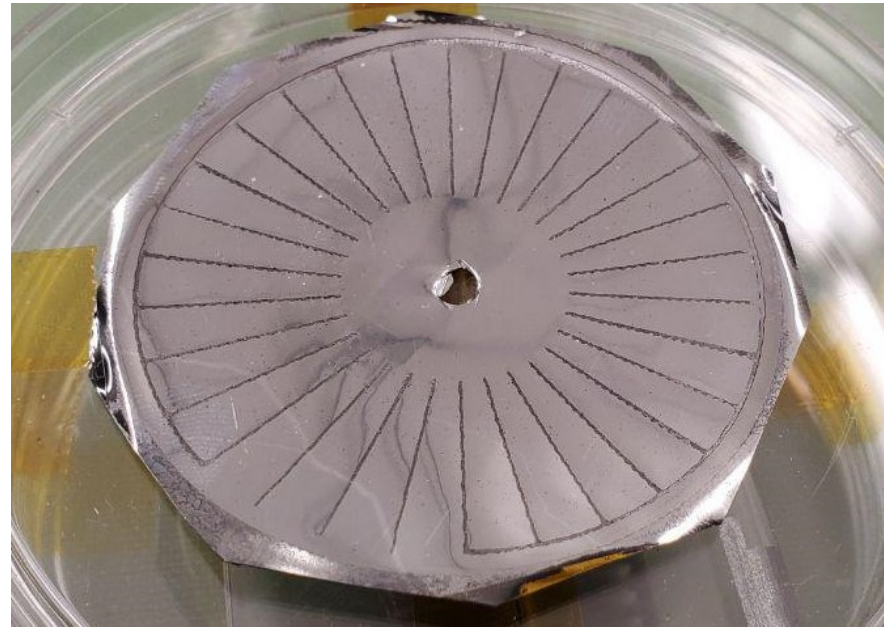
National Research Priority: NSF-Growing Convergence Research

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

Subsurface pressure profiling: computing colony pressures on substrate during fungal infections

Colony expansion is an essential feature of fungal infections. Although mechanisms that regulate hyphal forces on the substrate during expansion have been reported previously, there is a critical need of a methodology that can compute the pressure profiles exerted by fungi on substrates during expansion. This will facilitate the validation of therapeutic efficacy of novel antifungals. Here, we are trying to introduce an experimental method based on Biot's incremental stress model, which was used to map the pressure distribution from an expanding mycelium of a popular plant pathogen, Aspergillus parasiticus.



Using Denton Explorer - E-beam Evaporator to deposit the Chromium electrodes on both sides of PVDF membrane

Sourav Banerjee and Mohammadsadegh Saadatzi, Dept. of Mechanical Engineering, University of South Carolina. Work performed at Georgia Tech's Institute for Electronics and Nanotechnology.

National Research Priority: NAE Grand Challenge-Engineer the Tools of Scientific Discovery

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

On-chip energy harvesting using the movement of highly flexible suspended graphene

This work targets the extreme flexibility of suspended graphene as a source of vibrational energy. During this phase of the project we etched a pattern into silicon dioxide to form trench, well, and tip structures. Next, we re-patterned the surface and coated this with gold. Afterward, graphene was suspended over the well/tip structures to form a capacitor. Graphene can be seen in the photograph over the array of electrodes in section E to the right (under left probe). As the graphene moves up and down, the capacitance of the tip-graphene junction also fluctuates and this produces an alternating current. This technology is an on-chip power source.

Optical photograph of graphene suspended over a previously etched silicon tip, well, and trench structures.

Paul Thibado, Millicent Gikunda, et al. Department of Physics, University of Arkansas-Fayetteville. High-resolution lithography work was performed at the Georgia Tech's Institute for Electronics and Nanotechnology.

This work was supported by Walton Family Foundation Charitable Trusts.

National Research Priority: DOE-Microelectronics

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

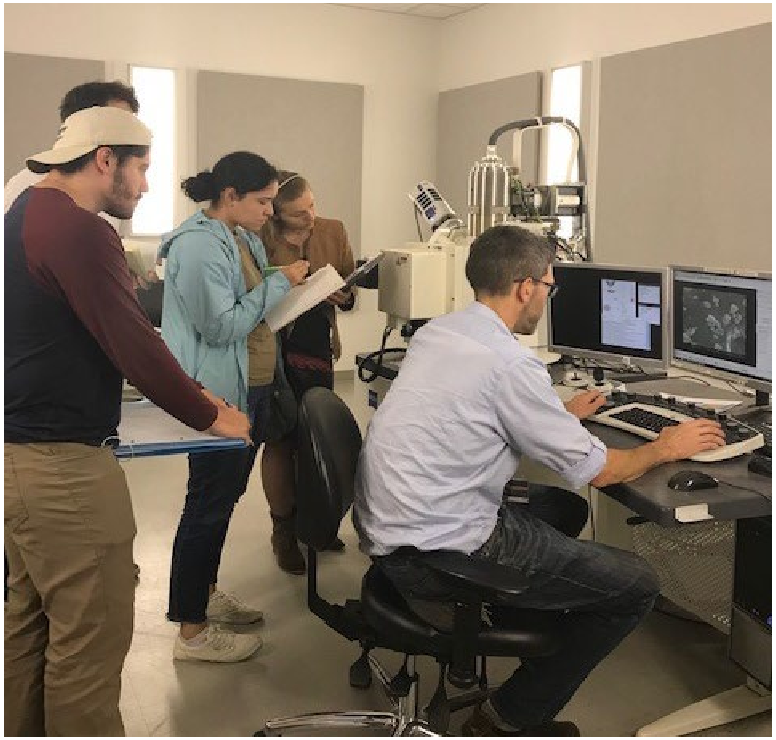
Demonstrations of Microscopic (SEM/TEM) and Surface Analysis Techniques

This work supported a site visit for ten students enrolled in GEOS 4042/6042, Environmental Analytical Instrumentations, at Georgia State University.

After learning the theory and operational procedures of each instrument, the students visited the Materials Characterization Facility (MCF) twice for demonstrations of SEM/TEM, AFM, XRD, XPS and TOF-MS.

The students, in groups of 3-4, rotated to each station and spent 30 minutes with each instrument specialist who went over basic terminology and results from a typical sample.

The demonstrations were very powerful for the students to visualize the concepts they learned in class. The graduate students in the class were pleased to learn of potential avenues to obtain characterization data they may need in their work.



Class demonstration for students enrolled in GEOS 6046, Environmental Analytical instrumentations, at Georgia State University.

Nadine Kabengi, Georgia State University. Work performed at Georgia Tech's Materials Characterization Facility.

This work was supported by a SENIC Catalyst Grant (funded by NSF ECCS-1542174).

National Research Priority: NSF-NSF INCLUDES

National Nanotechnology Coordinated Infrastructure

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Nanotechnology Summer Institute for Middle School Teachers

In June 2019, GT organized a Nanotechnology Summer Institute for Middle School Teachers (Nano SIMST). Based on nano@Stanford's curriculum, 15 teachers from across GA spent 4 days learning about nanotechnology through lectures, hands-on activities, tours, and guest speakers. They were also tasked to develop their own lesson plans to bring back to their classrooms. Adaptations of the original program were included, such as a session on the social and ethical implications of nanotechnology, an opportunity to work on scopes in the Materials Characterization Facility, a remote access session through RAIN, and a career panel featuring reps from different local companies. Both GT and JSNN plan to host Nano SIMST in summer 2020.

Feedback from the workshop at SENIC was very positive: "(T)his workshop was absolutely phenomenal."

"I learned so much about a topic I had no previous knowledge of and have easy ways to implement them in my classroom."

2019 Nano SIMST cohort (top); teachers working through a size sorting activity (bottom)

This work was supported by SENIC, NSF ECCS-1542174.

National Research Priority: NSF-NSF INCLUDES

National Nanotechnology Coordinated Infrastructure

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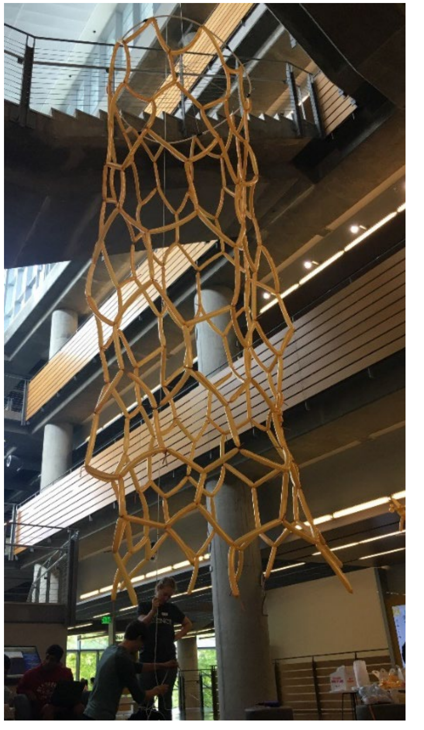
Graduates In Nanotechnology

In the fall 2018, Georgia Tech started the Graduates in Nanotechnology (GIN) student group to support undergraduates through post-docs who are interested or doing research related to nanotechnology. GIN has hosted lunch-time speakers, Researchers Open-Mic Presentations (ROMP), outreach training session, and has an invited seminar speaker series. Lunch guests have discussed preparing for jobs in academia, how to launch a start-up company, job opportunities at national labs, and the students' own nanotechnology research. When possible, JSNN students join GIN meetings via teleconference. JSNN recently started a Materials Research Society Chapter. These two student groups plan to stream or teleconference events when relevant.



GIN sponsored seminar (left); GIN students in the GT student center building a balloon model of a CNT in honor of National Nanotechnology Day (above)

This work was supported by SENIC, NSF ECCS-1542174.

National Research Priority: NSF-NSF INCLUDES