National Nanotechnology Coordinated Infrastructure (NNCI)

Research and Education Highlights

Year 2 (October 2016 – September 2017)

National Nanotechnology Coordinated Infrastructure

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Center for Nanoscale Systems (CNS)

CMOS Nanoelectrode Array for all-electrical intracellular electrophysiological imaging

Developing a new tool capable of high-precision electrophysiological recording of a large network of electrogenic cells has long been an outstanding challenge in neuro-biology and cardiology. Here, we combine nanoscale intracellular electrodes with complementary metal-oxide-semiconductor (CMOS) integrated circuits to realize a high-fidelity all-electrical electrophysiological imager for parallel intracellular recording at the network level.

Our CMOS NanoElectrode Array (CNEA) platform contains 1024 recording/stimulation pixels and intra-cellular recording from over 300 rat neonatal cardiomyocyte have been demonstrated. CNEA is also able to record delicate changes in membrane potential on a network level during drug perturbation.

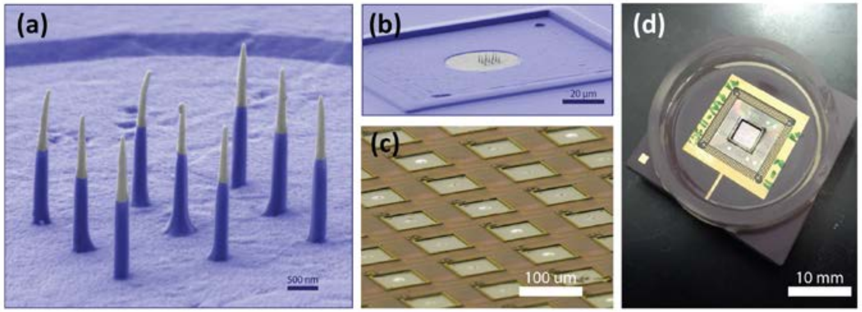

Figure 1: (a-c) False color SEM images of post-fabricated nanoelectrode array on top of the CMOS. (d) packaged device

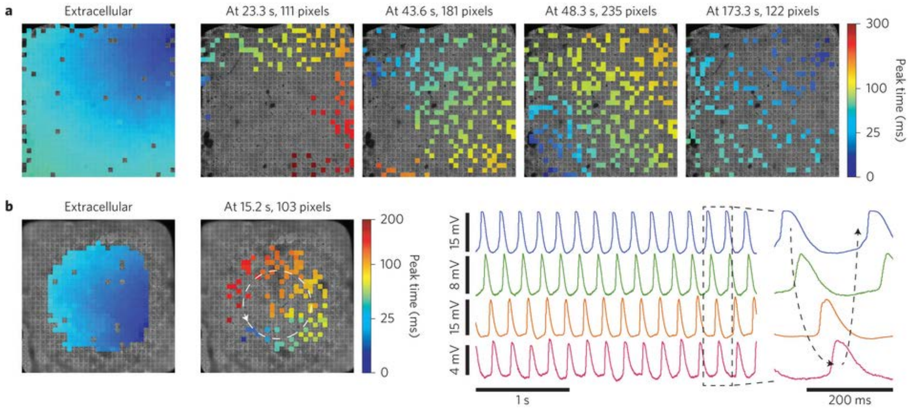

Figure 2: (a) Extra and intracellular recording from over 300 cardiomyocytes. (b) Induce re-entry behavior in cardiomyocyte culture via stimulation.

Abbott, J., Ye, T., Qin, L., Jorgolli, M., Gertner, R. S., Ham, D., Park, H.; Department of Chemistry, Harvard University (2017). CMOS nanoelectrode array for all-electrical intracellular electrophysiological imaging. *Nature Nanotechnology*.
Work partially performed at Center for Nanoscale Systems Harvard University.

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Center for Nanoscale Systems
Harvard University

Biomimetic Microsystems for investigating Cardiovascular Diseases

The cardiovascular tissue engineering laboratory (CTEL) at Mississippi State University investigates cardiovascular related diseases.

The CETL team uses biomimetic microdevices to investigate the role of various biomolecules to determine the roles of specific chemical cues in disease onset and progression.

Specifically we are using microfluidic devices (Figure 1) to examine vasculopathies such as sickle cell disease. We also use biomimetic systems to understand the microenvironmental cues that influence cardiac performance.

The ultimate goal for the CTEL team is to improve patient outcomes by improving our understanding mechanisms that contribute to these disease.

Kristen Hubbard, Allison Healey, Renita E. Horton, ; Department of Agricultural and Biological Engineering, College of Agricultural and Life Sciences, Bagley College of Engineering, MISSISSIPPI STATE UNIVERSITY
Work partially performed at Center for Nanoscale Systems, Harvard University

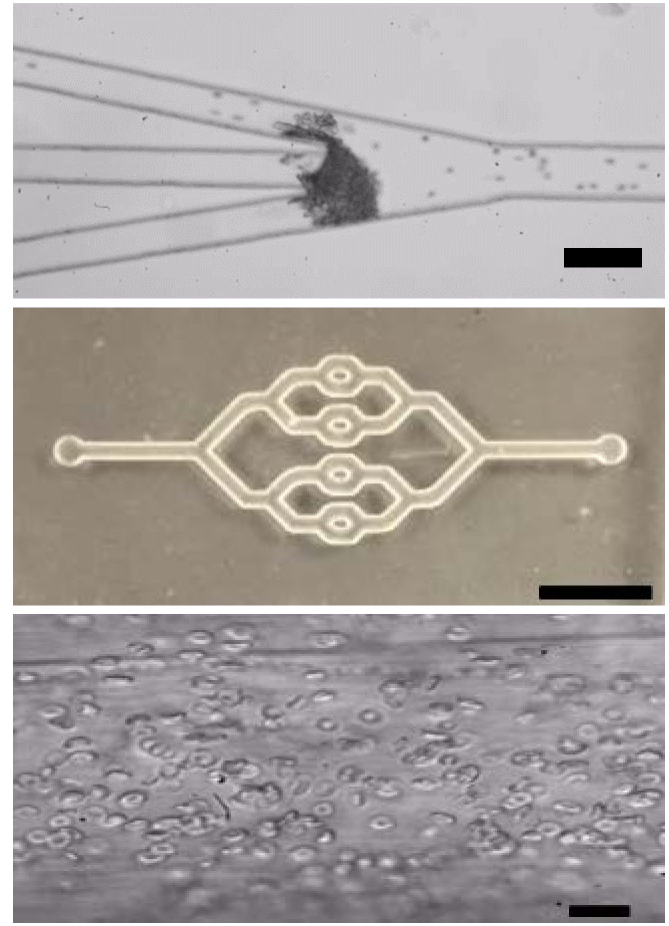

Figure 1: Example of the microdevice platforms used by CTEL.. Scale bar: 50 µm

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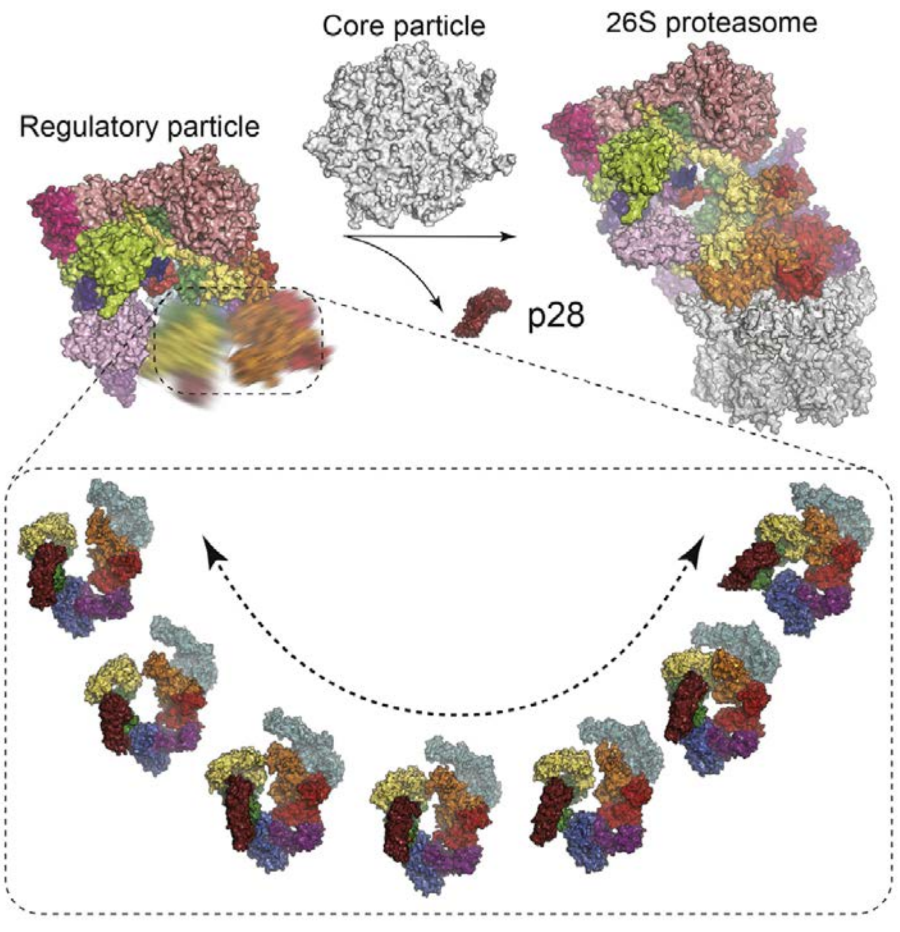
Harvard University

Conformational landscape of human 19S regulatory complex

At least four chaperones guide the assembly of the proteasome regulatory particle. Lu, Wu, et al. present the cryo- EM structures and dynamics of the p28 chaperone bound to the human proteasome regulatory particle and reveal how it guides conformational selection upon association of the regulatory and core particles.

- The AAA ring in the p28-bound RPs samples seven conformations
- d The assembly chaperone p28 guides the core particle to select a specific RP conformation
- d p28 is released in a shoehorn-like fashion during proteasome assembly



Y. Lu, J. Wu, …, M. Kirschner, Y. Mao; Dana-Farber Cancer Institute, Department of Microbiology and Immunobiology, Department of Systems Biology, HARVARD MEDICAL SCHOOL
Work partially performed at Center for Nanoscale Systems, Harvard University

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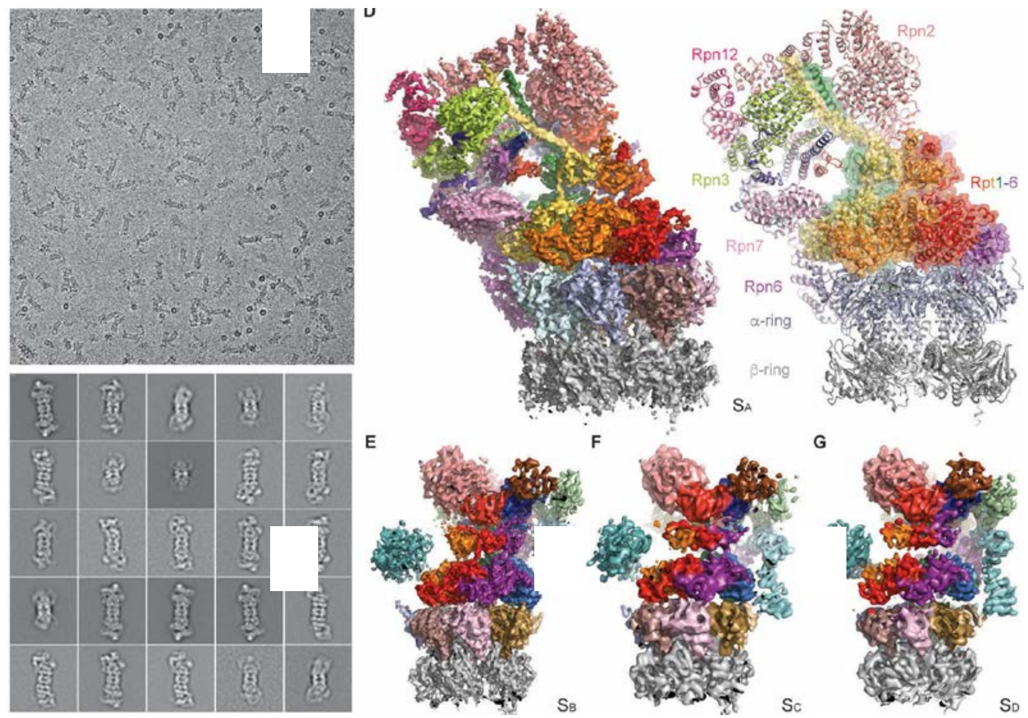
Harvard University

Dynamic regulation of human 26S proteasome

Cryo-EM was used to analyze four conformations of the human 26S proteasome holoenzyme, which provides significant insights into the dynamic regulation of the human 26S functions.

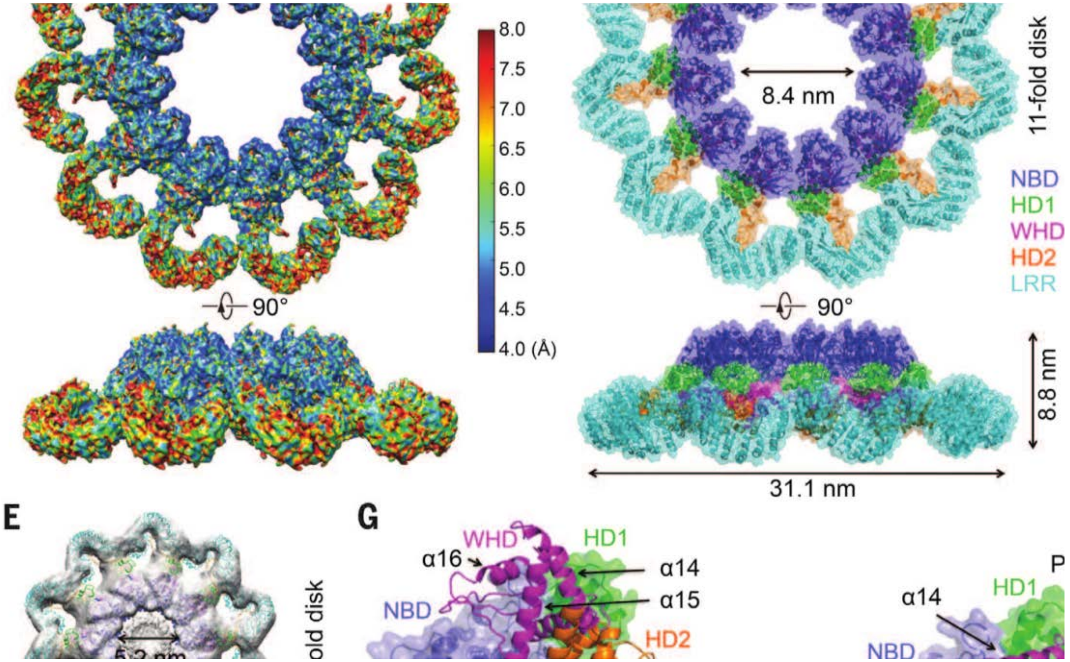
Using FEI Tecnai Arctica equipped with Gatan K2 Summit camera, the 26S structure in the resting state was determined at near-atomic resolution, with three alternative conformations at subnanometre resolutions, for the first time.



S. Chen, J. Wu, Y. Lu, …, M. Kirschner, Y. Mao; Dana-Farber Cancer Institute, Department of Microbiology and Immunobiology, Department of Systems Biology, HARVARD MEDICAL SCHOOL
Work partially performed at Center for Nanoscale Systems, Harvard University

Cryo-EM structure of the activated inflammasome

The NLR family apoptosis inhibitory proteins (NAIPs) bind conserved bacterial ligands, such as the bacterial rod protein PrgJ, and recruit NLR family CARD-containing protein 4 (NLRC4) as the inflammasome adapter to activate innate immunity. Using high-resolution cryo-EM, we found that the PrgJ-NAIP2-NLRC4 inflammasome is assembled into multisubunit disk-like structures through a unidirectional adenosine triphosphatase polymerization, primed with a single PrgJ-activated NAIP2 per disk.



L. Zhang, S. Chen, …, Y. Mao, H. Wu; Boston Children's Hospital, Dana-Farber Cancer Institute, Department of Microbiology and Immunobiology, Department of Systems Biology, HARVARD MEDICAL SCHOOL
Work partially performed at Center for Nanoscale Systems, Harvard University

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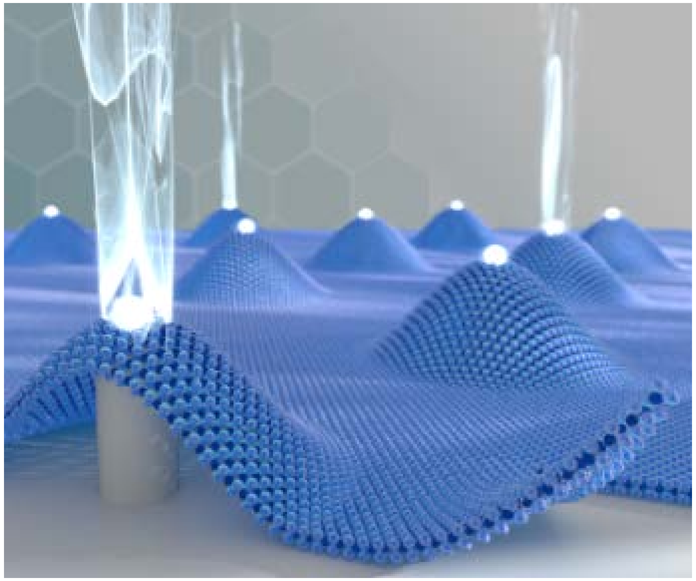
Harvard University

Quantum emitter arrays in 2d materials



A 2D, atomically-thin material rests on top of nanofabricated pillars. The localized strain turns the peaks into quantum emitters, illustrated here.

Going forward, new device architectures and 2D material heterostructures are being explored

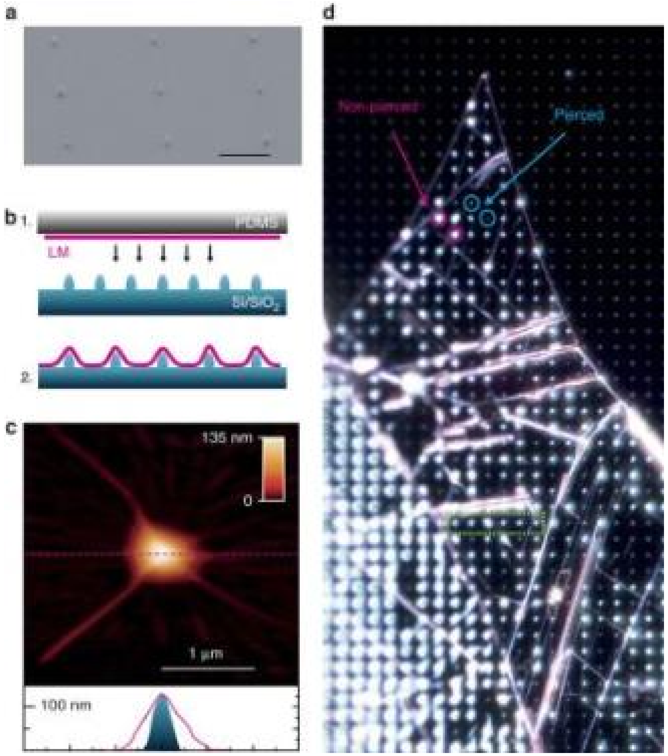


Figure 1: (a) SEM of nanopillar substrate (b) Fabrication flow schematic (c) AFM of 2d material on pillar (d) Optical micrograph of pillar array with 2d material on top, forming quantum emitters

Carmen Palacios-Berraquero, Dhiren M Kara, Alejandro R-P Montblanch, Matteo Barbone*, *Pawel Latawiec***, Duhee Yoon*, Anna K Ott*, *Marko Loncar***, Andrea C Ferrari*, Mete Atatüre; Cavendish Laboratory, UNIVERSITY OF CAMBRIDGE, *Cambridge Graphene Centre, University of Cambridge; **SEAS, HARVARD UNIVERSITY

Work partially performed at Center for Nanoscale Systems, Harvard University

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Harvard University

Investigating Perovskite Nanocrystal Formation, Purification, and Exchange Reactions

Lead halide perovskite nanocrystals have recently emerged as promising materials in both solar energy and optoelectronic devices due to their low-cost facile processing as well as their superior optical properties.[1]

My work focuses on understanding growth processes, exchange reaction mechanisms, and purification techniques within perovskite nanocrystals.

Currently, I am utilizing transmission electron microscopy at CNS to try to understand the effects of particle purification and aging on the resultant cubic particles following ion exchange reactions used for compositional tuning post synthesis.

Going forward, I am aiming to learn how to utilize the Hummingbird Flow Cell sample holder to get a unique *in situ* look at the particle formation, the particle purification process, and possible exchange reactions aimed at compositional tuning post particle synthesis.

Katie Hills-Kimball, Yasutaka Nagaoka, Ou Chen ; Department of Chemistry, Brown University
Work partially performed at Center for Nanoscale Systems, Harvard University

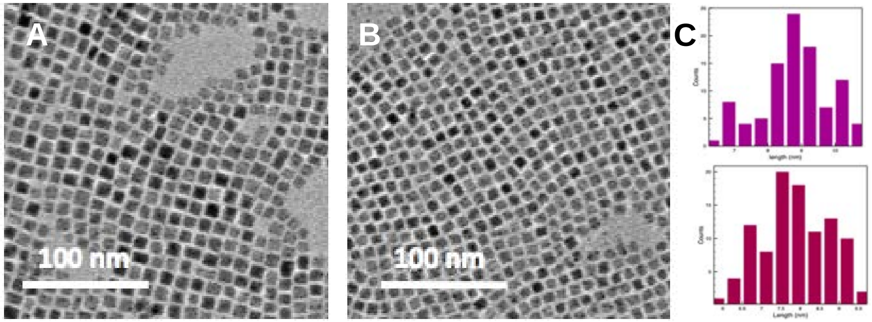

Figure 1: TEM images of $CsPbCl_3$ nanocrystals before (A) and after (B) a cation exchange reaction. Particle size distributions (C; initial, top and final, bottom) demonstrated that particle size and morphology was maintained.

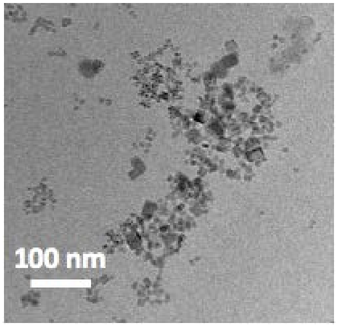

Figure 2: TEM image of the $CsPbCl_3$ nanocrystals following purification and 3 days of aging.

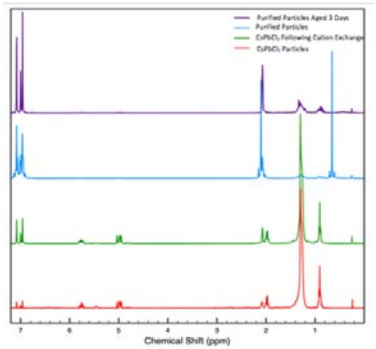

Figure 3: I am using NMR analysis in conjunction with the TEM analysis to understand what is occurring at the surface of the particles following cation exchange, purification and aging.

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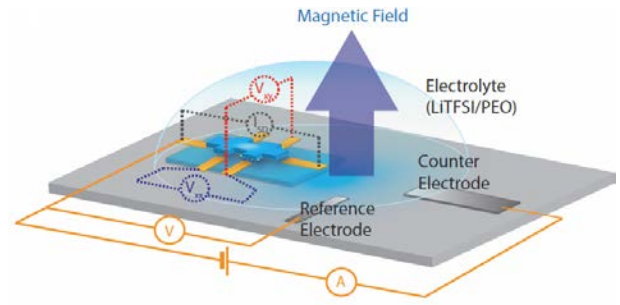
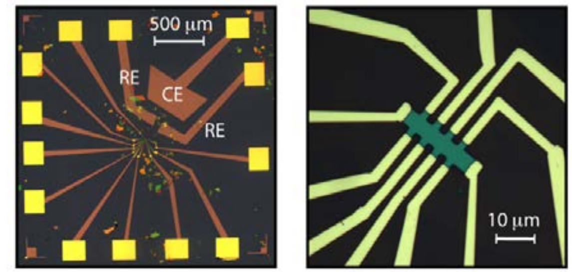
Electrochemical intercalation of discrete van der Waals heterostructures

Introduction: Two-dimensional (2D) materials can be assembled into hetero structure, creating artificial interface that can host intercalated species such alkali ions. This property makes them promising building blocks for innovative energy conversion/storage and electronic technologies. We have been studying graphene / Molybdenum disulfide(MoS2) hetero structure to explore mechanism of charge transfer and intercalation process in 2D hereto layers.

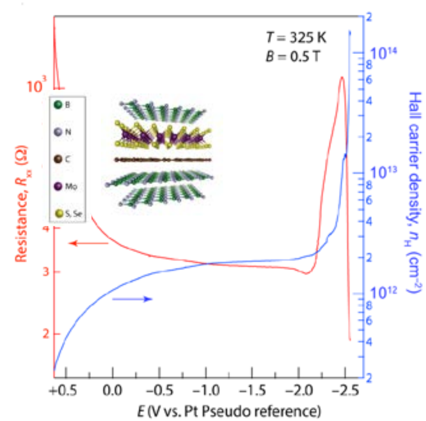
Goal: Maximize charge storage in interface of layered materials, Developing a technique for exploring of intercalation process in 2D van der Waals hereto structures



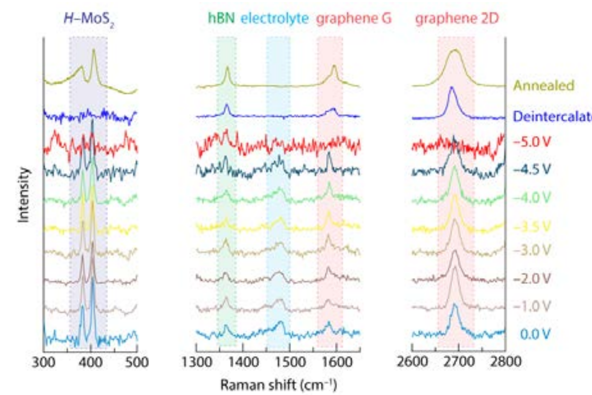
a) Schematic electrochemical cell for Hall voltammetry



b) on-chip electrochemical cell for charge transport and optical measurements



c) Transport measurement recorded at 325 K for a graphene–MoSe$_2$ device



d) Raman spectra of an hBN–graphene–MoS$_2$ over the course of electrochemical intercalation

D. Kwabena Bediako[1], Mehdi Rezaee[2], Tina L. Brower-Thomas[3] and Philip Kim[1]

1 Department of Physics, Harvard University; 2 Department of Electrical Engineering, Howard University; 3 Department of Chemical Engineering, Howard University

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Cornell Nanoscale Science and Engineering Facility (CNF)

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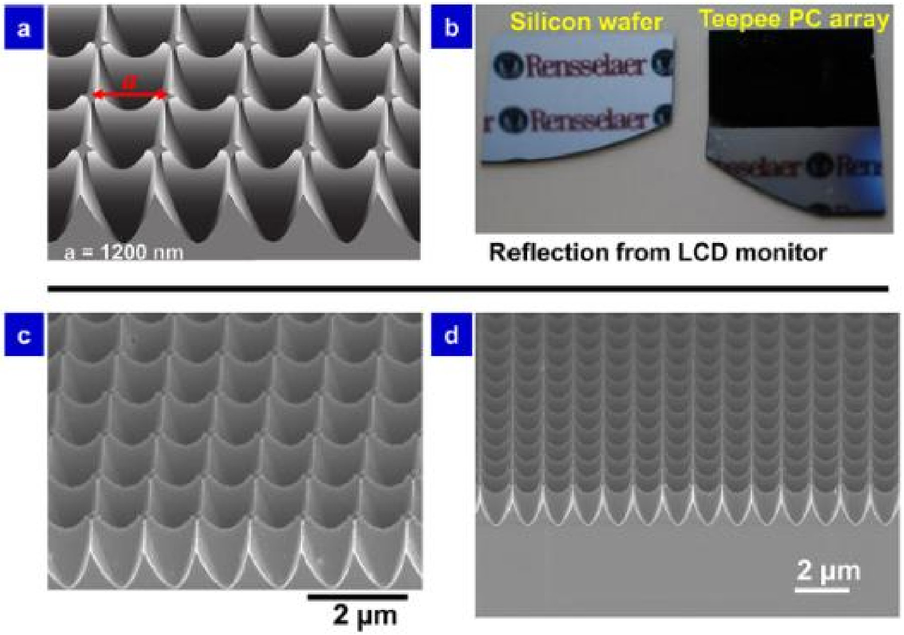
Nanostructures Enable More Efficient Light Harvesting

In ACS Nano, the Lin group at Rensselaer Polytechnic Institute in collaboration with researchers at the University of Toronto and National Chiao-Tung University used the Cornell Nanoscale Facility to create a teepee-like photonic crystal (PC) structure on crystalline silicon (c-Si) designed to fulfills two critical criteria in solar energy harvesting through a (i) its Gaussian-type gradient-index profile for excellent antireflection and (ii) near-orthogonal energy flow and vortex-like field concentration via the parallel-to-interface refraction effect inside the structure for enhanced light trapping. Depending on PC thickness, the capture of weakly absorbing wavelengths in significantly increased and angular dependence measurements show that the high absorption is sustained over a wide angle range (θ_{inc} = 0−60°) for teepee-like PC structures.



Photonic crystal structures

The Lin group at Rensselaer Polytechnic Institute
Work performed at the Cornell Nanoscale Facility

ACS Nano 2016, 10, 6116−6124

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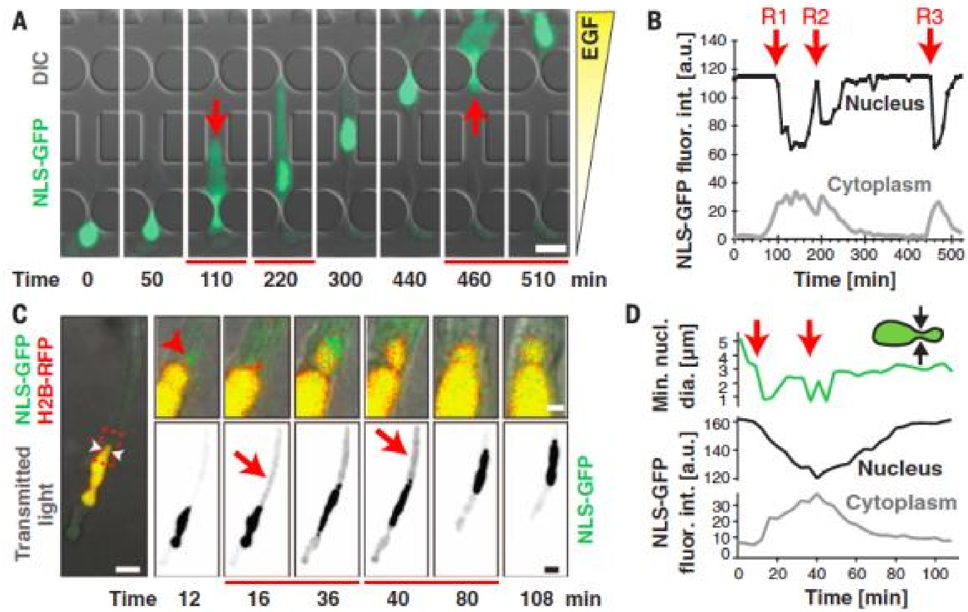
CNF Cornell NanoScale Science and Technology Facility

Interstitial Spaces between Cells

In **Science**, the Lammerding group at Cornell University in collaboration with researchers at Radboud University Medical Center, Nijmegen, Netherlands and The University of Texas MD Anderson Cancer Center, Houston, TX, used the Cornell Nanoscale Facility to construct microfluidic devices to model cancer cell invasion with precise control over cell confinement. During cancer metastasis, tumor cells penetrate tissues through tight interstitial spaces, which requires extensive deformation of the cell and its nucleus. Their findings indicate that cell migration incurs substantial physical stress on the nuclear envelope (NE) and its contents and requires efficient NE and DNA damage repair for cell survival.

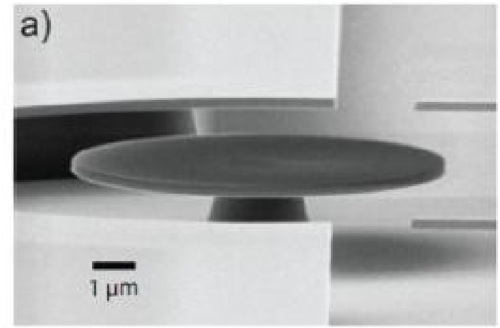


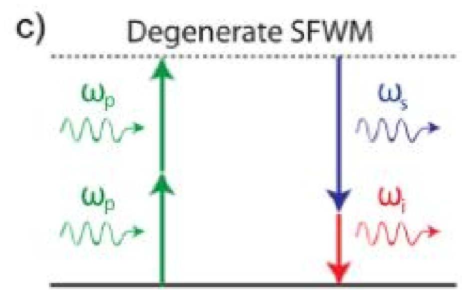
The Lammerding group at Cornell University
Work performed at the Cornell Nanoscale Facility

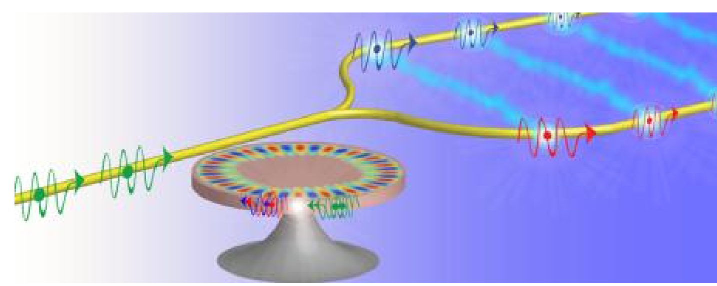
Science, 352(6283), 353 (2016).

Time-energy Entangled Photon Pairs

In **ACS Photonics**, the Lin group of the University of Rochester used the Cornell Nanoscale Facility to demonstrate a silicon nanophotonic chip containing a high-Q silicon microdisk that yields quantum interference visibility for time-energy entangled photons from a micro/nanoscale source used to generate time-energy entangled photon pairs. These researchers have demonstrated a silicon nanophotonic chip capable of emitting telecommunication band photon pairs that exhibit the highest raw degree of time-energy entanglement from a micro/nanoscale source, to date. Biphotons are generated through cavity-enhanced spontaneous four-wave mixing (SFWM) in a high-Q silicon microdisk resonator, wherein the nature of the triply resonant generation process leads to a dramatic Purcell enhancement, resulting in highly efficient pair creation rates as well as extreme suppression of the photon noise background.





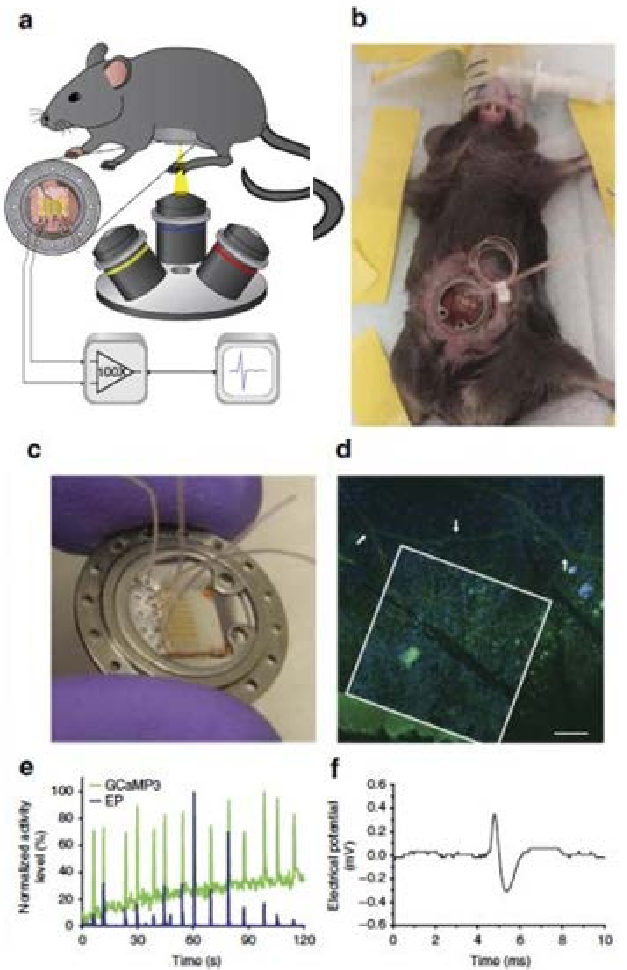


The Lin group at the University of Rochester
Work performed at the Cornell Nanoscale Facility

ACS Photonics 2016, 3, 1754−1761

Enteric Nervous System

In **Nature Communications**, the Shen group and colleagues at Cornell University in a highly collaborative project with researchers from Duke University, the Johns Hopkins University and the Howard Hughes Medical Institute used the Cornell Nanoscale Facility to create a graphene sensor on an abdominal window made from borosilicate glass for surgical implantation. The enteric nervous system (ENS) is a major division of the nervous system and vital to the gastrointestinal (GI) tract and its communication with the rest of the body. Unlike the brain and spinal cord, relatively little is known about the ENS in part because of the inability to directly monitor its activity in live animals. In this study researchers integrated a transparent graphene sensor with a customized abdominal window for simultaneous optical and electrical recording of the ENS in vivo. The implanted device captured ENS responses to neurotransmitters, drugs and optogenetic manipulation in real time.



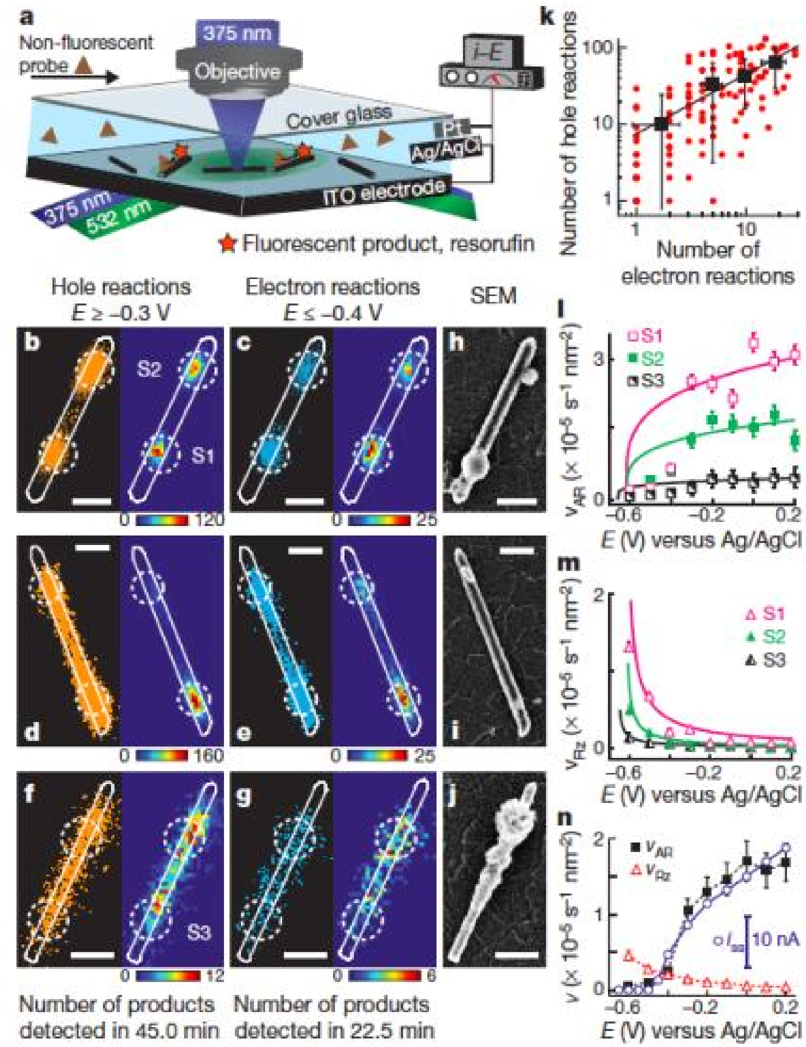
The Shen group at Cornell University
Work performed at the Cornell Nanoscale Facility

Nature Communications, | 7:11800 | DOI: 10.1038/ncomms11800

Photoelectrocatalysis: Water to Hydrogen

In **Nature**, the Peng group of Cornell University working with researchers from Colorado Mesa University, and the University of Michigan used the Cornell Nanoscale Facility to produce a device for both wide-field single-molecule fluorescence imaging of photoelectrocatalysis by semiconductor nanorods via two-laser total internal reflection excitation, and for sub-nanorod photocurrent measurements via focused laser excitation, in a three-electrode microfluidic photoelectrochemical cell. The splitting of water photoelectrochemically into hydrogen and oxygen represents a promising technology for converting solar energy to fuel. This work enabled mapping of both the electron- and hole-driven photoelectrocatalytic activities on single titanium oxide nanorods. These findings suggest an activity-based strategy for rationally engineering catalyst-improved photoelectrodes

The Peng group at Cornell University
Work performed at the Cornell Nanoscale Facility



Nature, 530, 77, 2016

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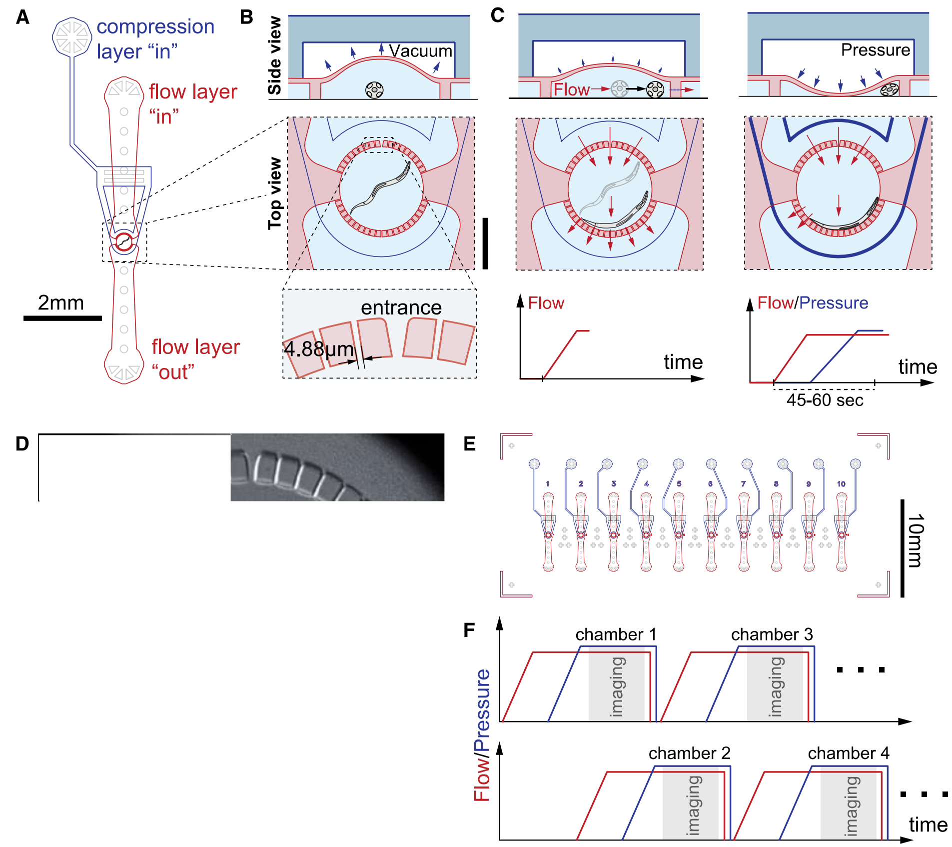
Imaging of C. elegans Larvae with Microfluidics

In **Developmental Cell**, Keil et al. present a microfluidics setup, enabling long-term, high-resolution, timelapse microscopy of up to ten *C. Elegans* larvae simultaneously. They collect vulval cell-cycle timing statistics, measure intensities of fluorescent transcriptional reporters during cell-fate specification, transdifferentiation, and cell death, and visualize complex neurite outgrowth in automatically registered z stacks.

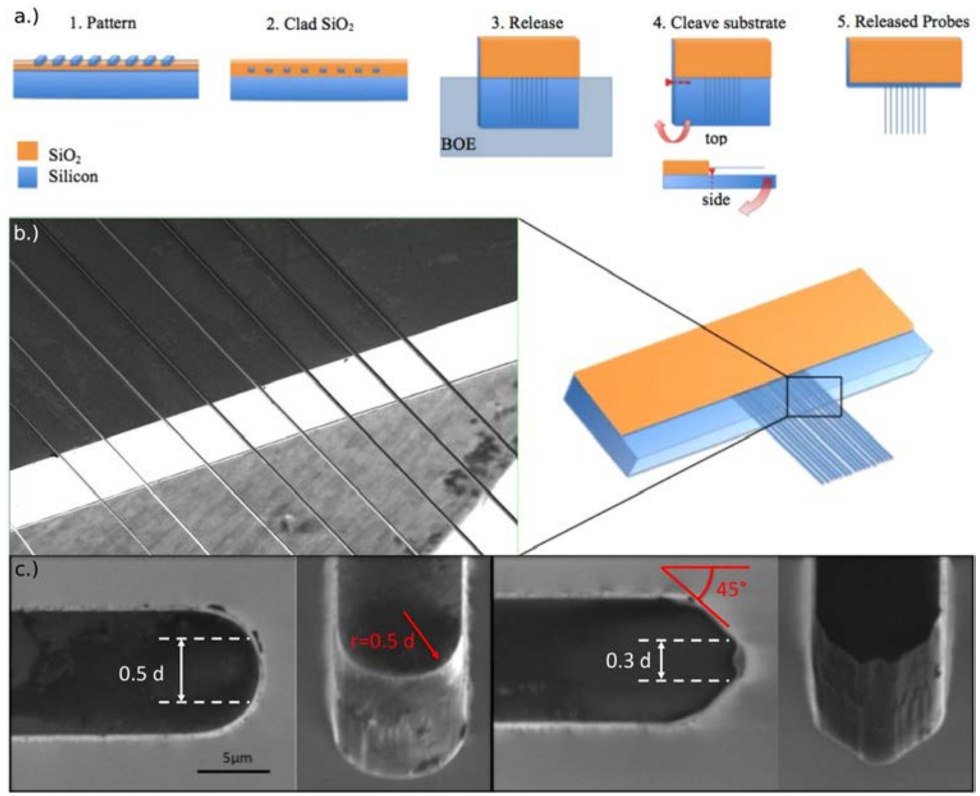


WolfgangKeil, Lena M.Kutscher, Shai Shaham, Eric D.Siggia, Rockefeller University
Work performed at the Cornell Nanoscale Facility

*2017, **Developmental Cell** 40, 202–214*

Photonic Needles for Light Delivery in Tissue

In **Nature – Scientific Reports**, Lipson et al. demonstrate a new platform for minimally invasive, light delivery probes leveraging the maturing field of silicon photonics, enabling massively parallel fabrication of photonic structures. These Photonic Needle probes have sub-10 µm cross-sectional dimensions, lengths greater than 3 mm–surpassing 1000 to 1 aspect ratio, and are released completely into air without a substrate below. They show the Photonic Needles to be mechanically robust when inserted into 2% agarose. The propagation loss of these waveguides is low–on the order of 4 dB/cm.

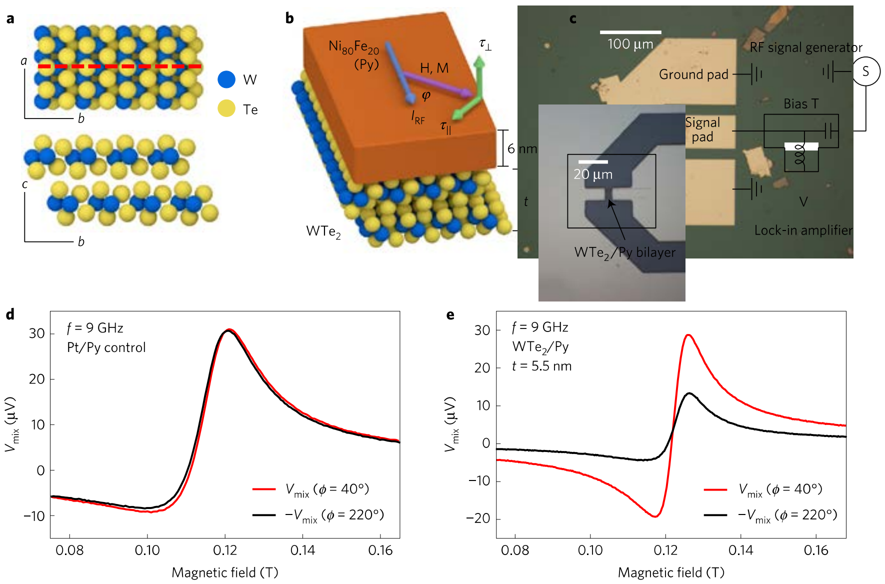


The Lipson group Columbia University
Work performed at the Cornell Nanoscale Facility

Scientific Reports **|** *7: 5627* **|** *DOI:10.1038/s41598-017-05746-7*

Control of Spin–orbit Torques in WTe_2/Ferromagnet Bilayers

Recent discoveries regarding current-induced spin–orbit torques produced by heavy-metal/ferromagnet and topological insulator/ ferromagnet bilayers provide the potential for dramatically improved efficiency in the manipulation of magnetic devices. However, in experiments performed to date, spin–orbit torques have an important limitation—the component of torque that can compensate magnetic damping is required by symmetry to lie within the device plane. This means that spin–orbit torques can drive the most current-efficient type of magnetic reversal (antidamping switching) only for magnetic devices with in-plane anisotropy, not the devices with perpendicular magnetic anisotropy that are needed for high-density applications. In this work by the Park (U Chicago) and Ralph (Cornell) groups show experimentally that this state of affairs is not fundamental, but rather one can change the allowed symmetries of spin–orbit torques in spin-source/ferromagnet bilayer devices by using a spin-source material with low crystalline symmetry.



Park (U. Chicago), Ralph(Cornell)
Work performed at the Cornell Nanoscale Facility

Nature Physics, 2017, 13, 301

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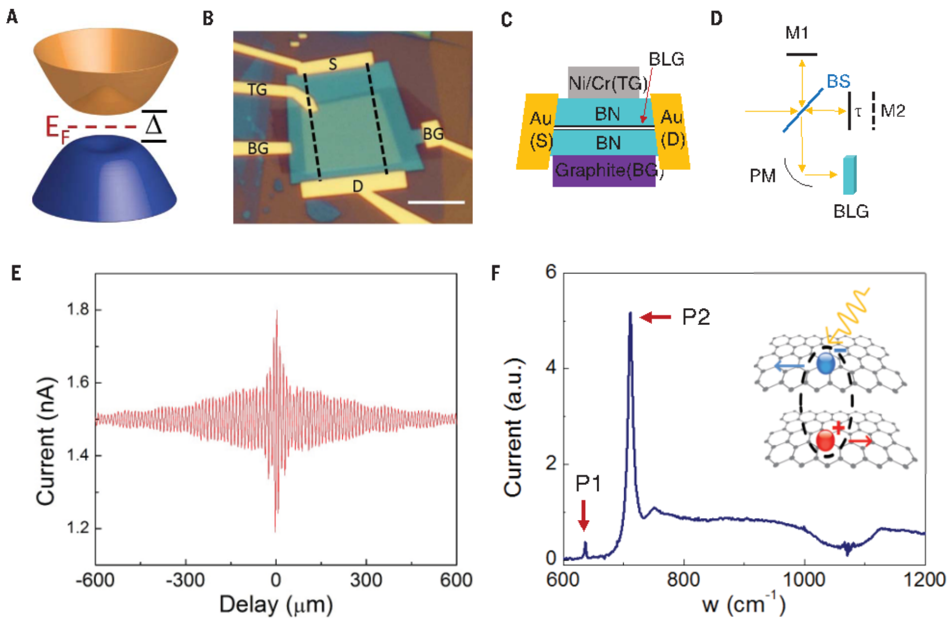
CNF Cornell NanoScale Science and Technology Facility

Tunable Excitons in Bilayer Graphene

In **Science**, McEuen et al. show that excitons, the bound states of an electron and a hole in a solid material, play a key role in the optical properties of insulators and semiconductors. They report the observation of excitons in bilayer graphene (BLG) using photocurrent spectroscopy of high-quality BLG encapsulated in hexagonal boron nitride. They observed two prominent excitonic resonances with narrow line widths that are tunable from the mid-infrared to the terahertz range. These excitons obey optical selection rules distinct from those in conventional semiconductors and feature an electron pseudospin winding number of 2. An external magnetic field induces a large splitting of the valley excitons, corresponding to a g-factor of about 20. These findings open up opportunities to explore exciton physics with pseudospin texture in electrically tunable graphene systems.



The McEuen group at Cornell University
Work performed at the Cornell Nanoscale Facility

Ju et al., Science 358, 907–910 (2017)

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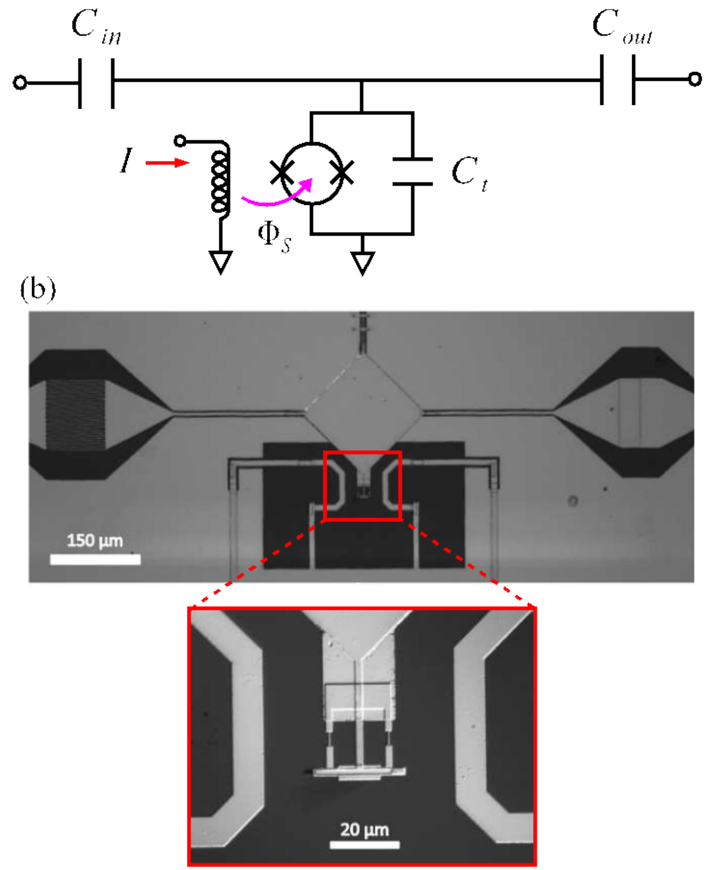
Transient Dynamics of a Superconducting Nonlinear Oscillator

Plourde et al. in **Phys. Rev. Applied**, investigate the transient dynamics of a lumped-element oscillator based on a dc superconducting quantum interference device (SQUID). The SQUID is shunted with a capacitor forming a nonlinear oscillator with resonance frequency in the range of several GHz. The resonance frequency is varied by tuning the Josephson inductance of the SQUID with on-chip flux lines. They report measurements of decaying oscillations in the time domain following a brief excitation with a microwave pulse. The nonlinearity of the SQUID oscillator is probed by observing the ringdown response for different excitation amplitudes while the SQUID potential is varied by adjusting the flux bias. Simulations are performed on a model circuit by numerically solving the corresponding Langevin equations incorporating the SQUID potential at the experimental temperature and using parameters obtained from separate measurements characterizing the SQUID oscillator. Simulations are in good agreement with the experimental observations of the ringdowns as a function of applied magnetic flux and pulse amplitude. They observe a crossover between the occurrence of ringdowns close to resonance and adiabatic following at larger detuning from the resonance. They also discuss the occurrence of phase jumps at large amplitude drive. The paper briefly outlines prospects for a readout scheme for superconducting flux qubits based on the discrimination between ringdown signals for different levels of magnetic flux coupled to the SQUID.



The Plourde group at Syracuse University
Work performed at the Cornell Nanoscale Facility

*Phys. Rev. Applied, 2016, **5**, 024002*

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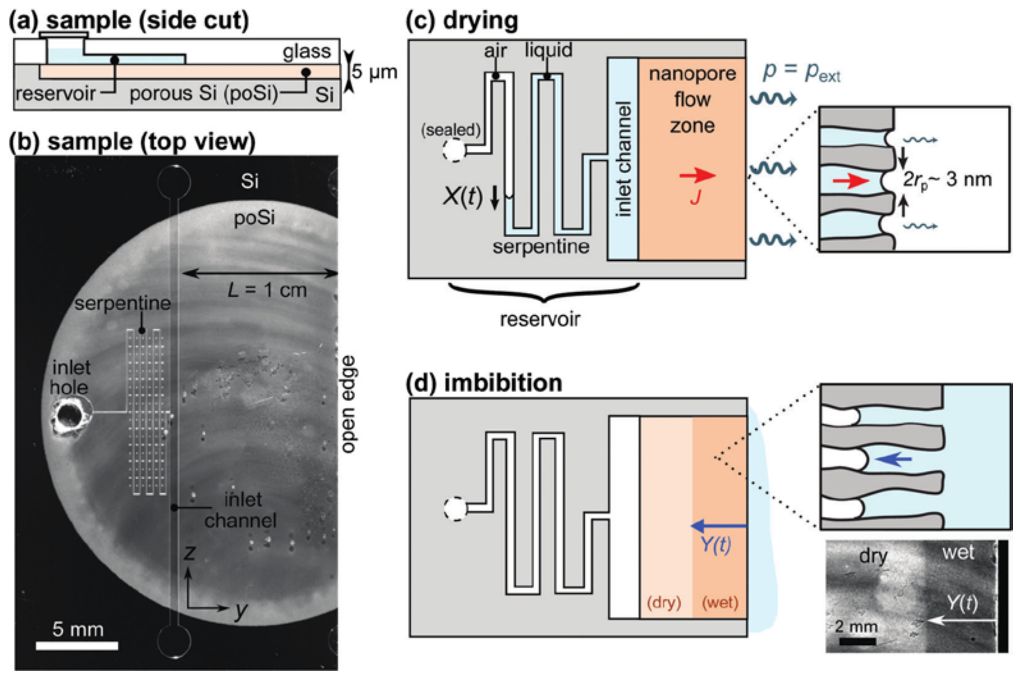
Capillarity-driven Flows at the Continuum Limit

In **Soft Matter**, Stroock et al. investigate the dynamics of capillary-driven flows at the nanoscale, using an original platform that combines nanoscale pores (~3 nm in diameter) and microfluidic features. In particular, they show that drying involves a fine coupling between thermodynamics and fluid mechanics that can be used to generate precisely controlled nanoflows driven by extreme stresses – up to 100 MPa of tension. They exploit these tunable flows to provide quantitative tests of continuum theories (e.g. Kelvin–Laplace equation and Poiseuille flow) across an unprecedented range and they isolate the breakdown of continuum as a negative slip length of molecular dimension. The results show a coherent picture across multiple experiments including drying-induced permeation flows, imbibition and poroelastic transients



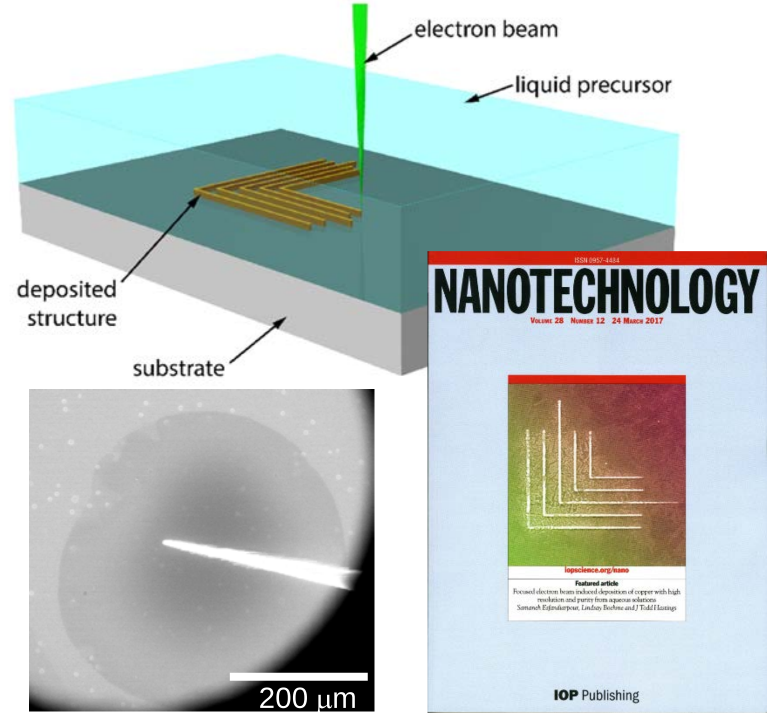
The Stroock group at Cornell University
Work performed at the Cornell Nanoscale Facility

Soft Matter, *2016, 12, 6656*

Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY MMNIN)

Focused Electron Beam Induced Processing in Liquids for Nanoscale Rapid Prototyping

Focused electron-beam induced processing (FEBIP) provides both additive and subtractive processes that address the need for nanoscale rapid prototyping, editing, and repair. However, standard gas phase reactants limit the materials available, the purity of deposits, and overall throughput. Liquid-phase reactants offer potential solutions, but understanding of the chemical and physical processes involved remains limited. We have found that copper can be locally deposited or etched by electron irradiation of substrates wetted with appropriate aqueous solutions. Purities exceed 90 at.%, conductivities improve by orders of magnitude compared to gas-phase processes, and highly selective etching is possible.

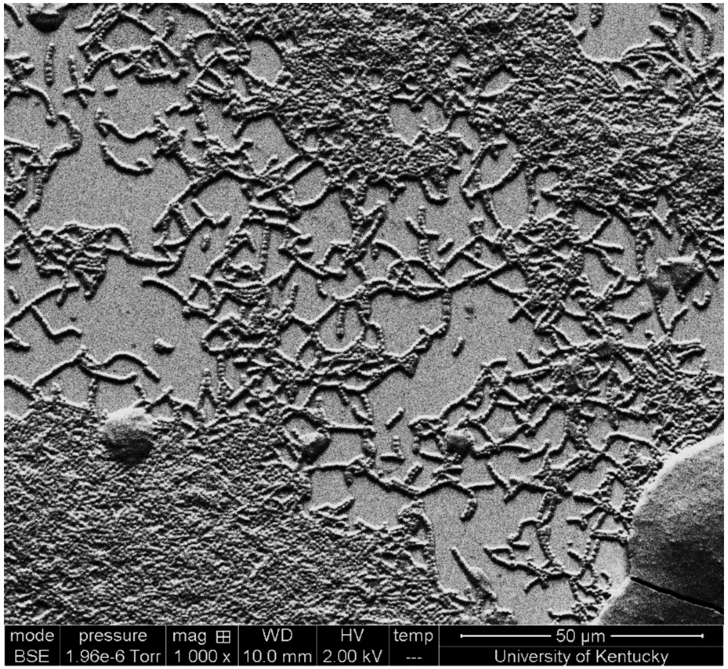


Electron-beam induced deposition of copper from bulk-liquid reactants. Schematic (top), liquid injection in an environmental SEM (bottom left), copper nested-L pattern deposited from an aqueous solution of sulfuric acid, copper sulfate, and polyethylene glycol (bottom right).

S. Esfandiarpour, L. Boehme, S. Lami, A. Syam, G. Smith, and J. T. Hastings, University of Kentucky (UK); J. Ranney and A. Botman, ThermoFisher Scientific. Work performed at the UK Center for Nanoscale Science and Engineering, the UK Electron Microscopy Center, and the University of Louisville Micro/Nano Technology Center.

Characterization of Biofilm Surface Adhesion, Developed via Laser-Induced Stress Waves

A biofilm is a thin biological film composed of colonized bacteria, coating surfaces such as teeth or surgical implants. Quantifying the adhesion strengths of biofilms is important in optimizing surfaces which prevent bacteria from adhering. To measure the adhesion strengths of biofilms accurately, an appropriate measurement technique must be established. Current techniques are less quantitative, and use surface-disrupting contact forces. The use of the laser spallation technique is optimal as it results in quantified adhesion strength, while using a non-contact high strain rate force. In this initial study, *Streptococcus Sanguinis* will be studied for its implications in the development of peri-implantitis.



Back-scatter SEM image of the biofilm on Ti substrate

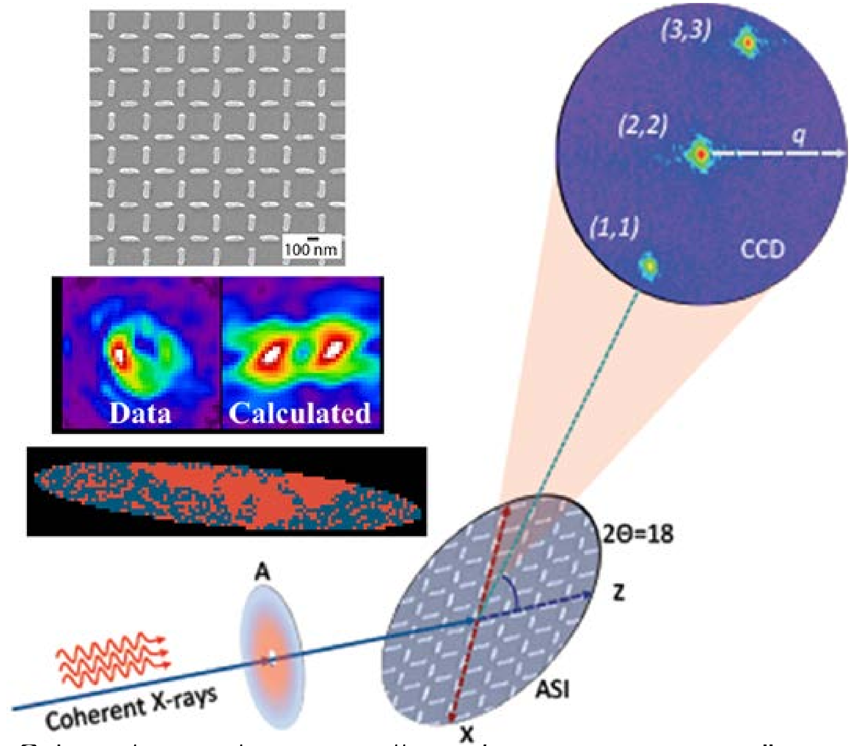
James D. Boyd, Stuart Ross, M.E. Grady, University of Kentucky.
Work performed at University of Kentucky Electron Microscopy Center.

National Nanotechnology Coordinated Infrastructure

KY MULTISCALE
The NSF NNCI Multi-Scale Manufacturing & Nano Intergration Node

Mapping magnetic heterogeneity in artificial spin ice using coherent x-ray magnetic scattering

Artificial spin ices (ASI) are periodic arrays of ferromagnetic thin-film islands whose shape anisotropy aligns their magnetizations to their long axes (Ising-like). The island size creates barriers to switching and limits equilibration to finite super-domains interspersed among disordered areas. Magnetic fields can fully order the island moments with net polarization along an easy [11] direction for square ASI. Excitations (flips) of magnetically ordered ASI produce pairs of opposite magnetic point charges connected by a chain of flipped islands ("Dirac strings"). Magnetic x-ray scattering data from square ASI show internal structure of Bragg peaks and diffuse intensity that are highly sensitive to emergent magnetic heterogeneity in ASI, which retains the zig-zag motif of the mesoscale strings in macroscale magnetic textures, as well as a memory effect under successive field cycles.

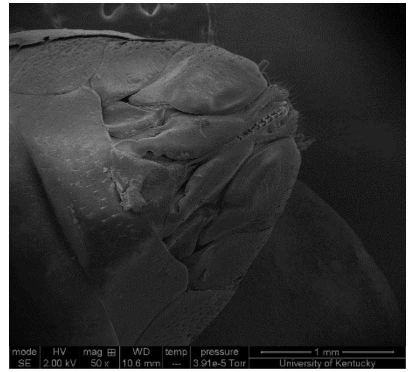


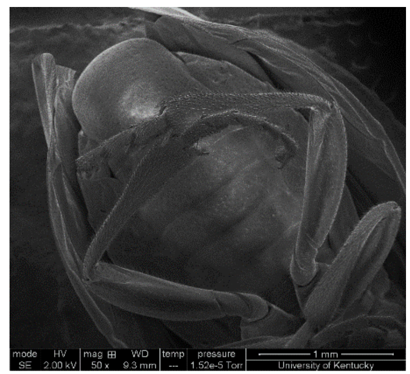
Coherent magnetic x-ray scattering from a square, permalloy, artificial spin ice (top left micrograph). Splitting of the Bragg peaks under applied magnetic fields (middle left, data vs. calculated) suggests formation of superdomains (red and blue regions) in the elliptical area illuminated by the x-ray beam.

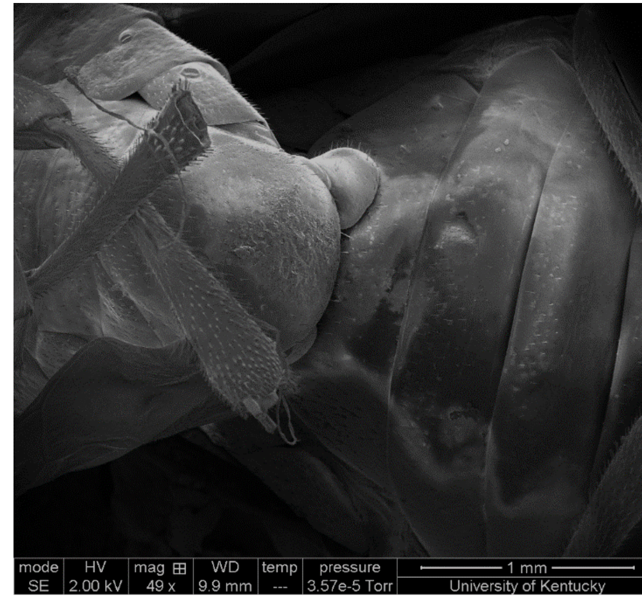
J. C. T Lee, S. K. Mishra, V. S. Bhat, R. Streubel, B. Farmer, X. Shi, I. McNulty, P. Fischer, S. D. Kevan, S. Roy, and L. E. De Long. U. of Kentucky, Berkeley Lab, U. of Oregon, Argonne National Lab., and U.C. Santa Cruz. NNCI related work performed at the UK Center for Nanoscale Science and Engineering and Center for Advanced Materials.

Study on Genital Morphology on Pine Sawflies

This study investigates the role genital morphology plays in speciation. This research group studies pine sawflies as a model organism for speciation and evolution, and they have determined that the females of the two sister species we study (*Neodiprion leconeti* and *pinetum*) have drastically divergent egg-lay behavior and ovipositor (the device she uses to lay her eggs), and that this change is correlated with a pine host-shift. Their hypothesis is that if the male genitalia have changed in response to this host shift event to “keep up” with female changes. They are using SEM images to quantify variation in male genitalia.





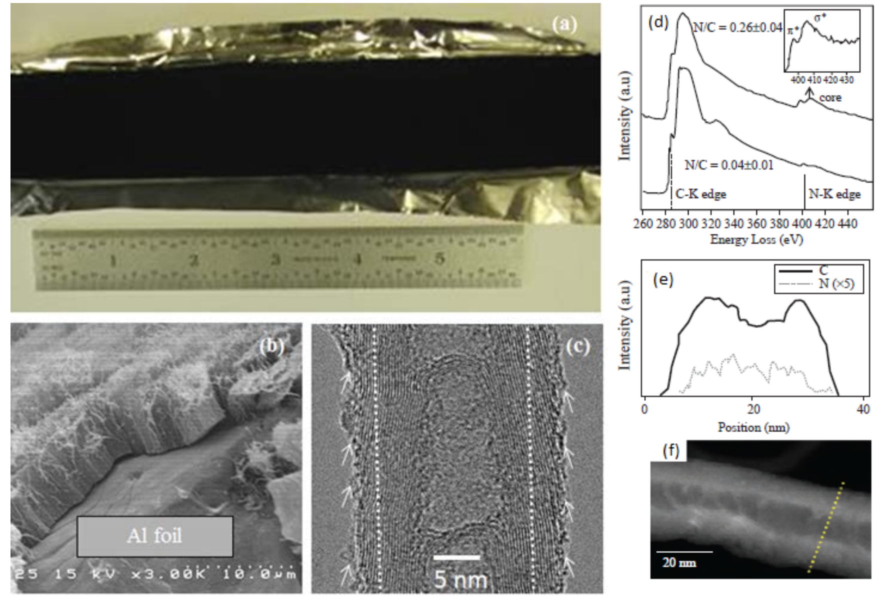


Secondary electron SEM image of the (A) female, (B) male genitalia. (C) Both male and female while mating.

M. Thomas, University of Kentucky
Work performed at University of Kentucky Electron Microscopy Center

Characterizations of N-doped Carbon Nanotube Arrays on Metal Substrates

N-doped multiwall nanotube (MWNT) arrays have been produced by pyrolysis of ferrocene-acetonitrile mixtures at 600 ◦C, which is lower than the melting point of display glass, and therefore ideal for applications in electronics. Electron energy-loss spectroscopy (EELS) analysis reveals that the doped-N-C bonds are pyridine-like with the N-K edge at 398 eV having a higher N concentration in tube core region. Such N-doped MWNT arrays directly grown on Al (or/and Cu, Ti, et al) foil with large areas can form Li-ion or metal-air battery cathodes with advantages including: (i) herring-bone fringes on nanotube walls providing nano-channels for small ion intercalations, (ii) highly reactive pyridine-like sites on the nanotube surfaces to reduce over-potentials and retain capacity, (iii) large number of nanotubes as nano-cathodes on metal current collector.

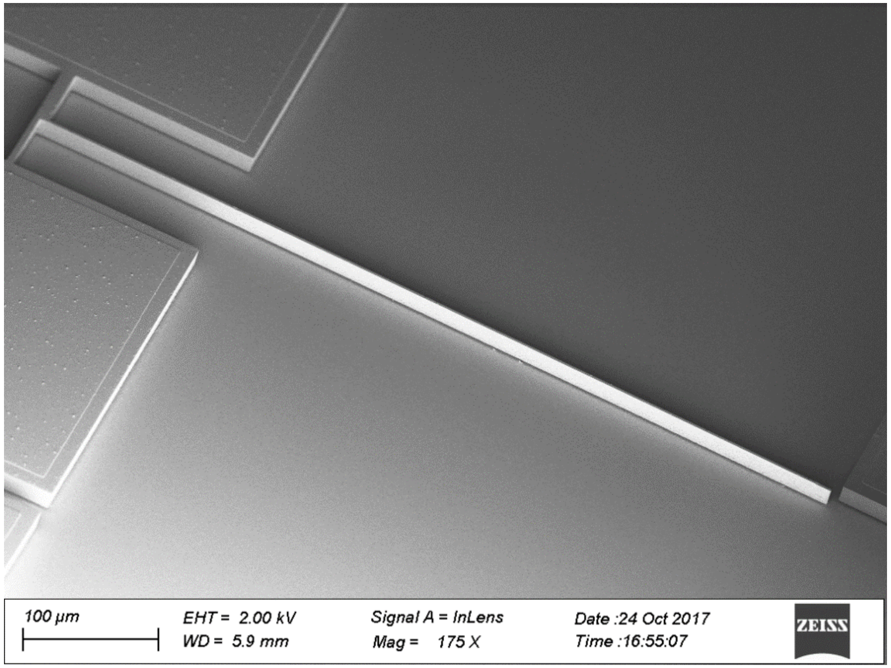


Well-aligned N-doped carbon nanotube arrays grown on aluminum foil by pyrolysis of acetonitrile-ferrocene precursor at 600◦C for 2 hours. (a) Nanotubes grown on Al foil surface directly, (b) SEM image showing aligned MWNT array, (c) HRTEM revealing herringbone-like graphene fringes on nanotube wall, EELS revealing higher doped-N in nanotube core than wall (d), as shown EELS line-scanning along radial direction (e, f).

Dali Qian, Matthew Weisenberger, Rodney Andrews, and Mark Meier at University of Kentucky.
Work performed at the UK Electron Microscopy Center and Center for Applied Energy Research.

Exploration of Radiation Damage Mechanism using MEMS resonators

Ultrasensitive MEMS resonators are used to investigate radiation induced ionization damage and displacement damage mechanism. In-plane oscillation was obtained by driving the resonator electrostatically. Asymmetric piezoresistive base enables detection of resonance with ppm level accuracy. The resonator provides a very high Q-factor of 36000 at high vacuum (> 5e-4 mbar). Resonance frequency change was observed with X-ray, UV and proton radiation. UV radiation induced change saturates at about 40ppm. X-ray causes a change of about 20 – 60ppm (for 1Mrad total dose) at different dose rate with no clear indication of saturation but it shows clear dose rate dependence. Lower dose rate caused higher shift in resonance frequency. Proton radiation showed both ionization damage and displacement damage. Different surface to volume ratio resonators are being fabricated and currently being tested for dimensional dependence of radiation effect.



SEM image of ultra-sensitive electrically driven MEMS resonator that detects ppm level change in resonance frequency caused by radiation.

Bruce Alphenaar, Shamus McNamara, Kevin Walsh, University of Louisville.
Work performed at the University of Louisville Micro/Nano Technology Center (MNTC).

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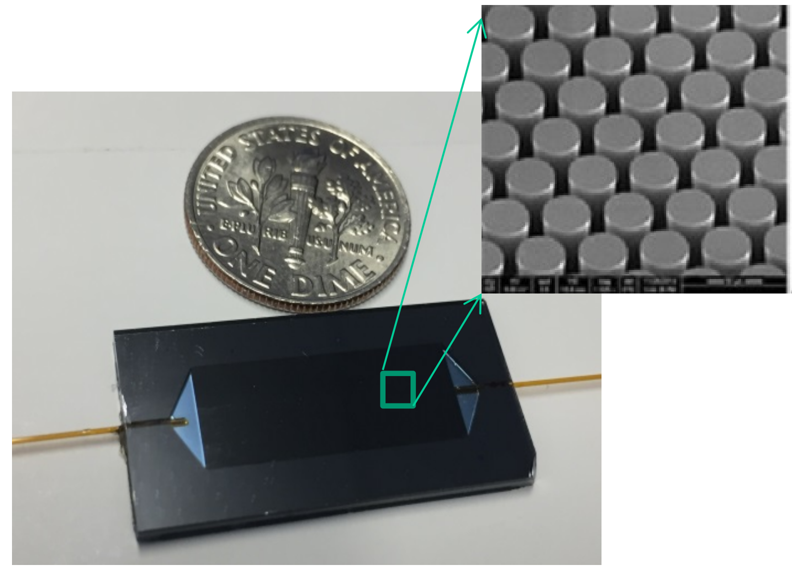
Capture of Trace Volatile Organic Compounds in Air and Exhaled Breath by Microreactors

The objective of this work is to develop a highly efficient microreactor platform for capture of trace target volatile organic compounds (VOCs) in air and exhaled breath. There are thousands of micropillars in the microreactor coated with reactive compounds on the surfaces of the micropillar for capture of VOCs via chemoselective reactions. The adducts of reacted VOCs can be easily eluted with solvents and analyzed by standard GC-MS and UHPLC-MS. The microreactors has been used for identification of lung cancer biomarkers in exhaled breath for early detection of lung cancer and for detection of toxic compounds in environmental air.



A picture of a microreactor with inserted SEM micrograph to show the micropillars inside of the microreactor for capture of trace VOCs.

Xiaoan Fu and Michael Nantz, Department of Chemical Engineering, Department of Chemistry, University of Louisville. Work performed at University of Louisville Micro/Nano Technology Center.

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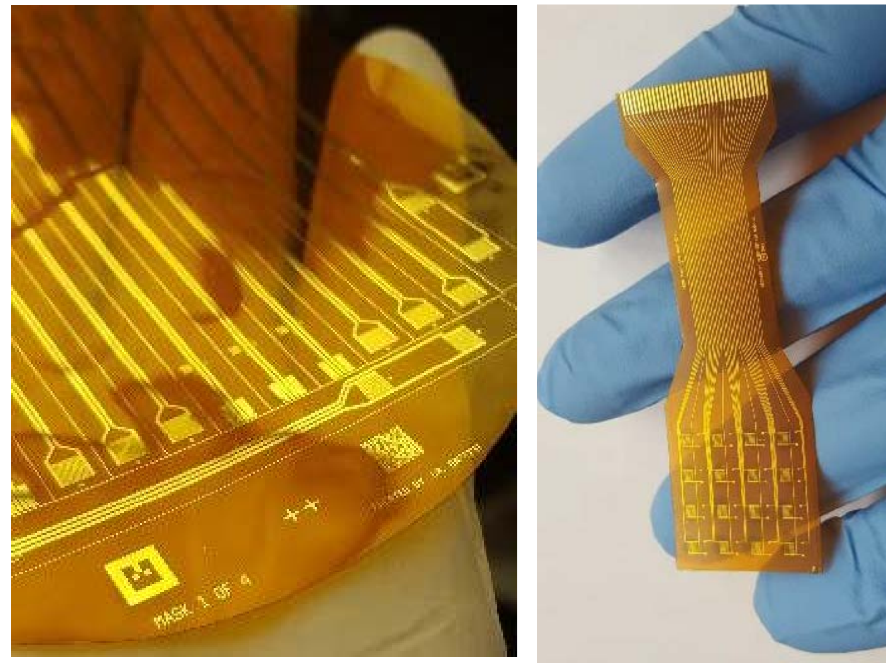
Pressure Sensitive Arrays for Next Generation Collaborative Robot Skins

This work involves fabricating embedded pressure sensors on laminated flexible Kapton substrates, for deployment on the body, arms and end-effectors of collaborative robots. A wet lithography process for PEDOT:PSS piezoresistive films has been developed to pattern sensors over interdigitated Au electrodes. The resulting sensor films are less than 100 nm thick and show good sensitivity. Electrodes are designed to have circular symmetry and spacing in order to avoid cross-talk between tactels. 4x4 double sided SkinCell arrays have been prototyped and tested for deployment on force sensitive robotic grippers, and on the outer surfaces of future robot nursing assistants.



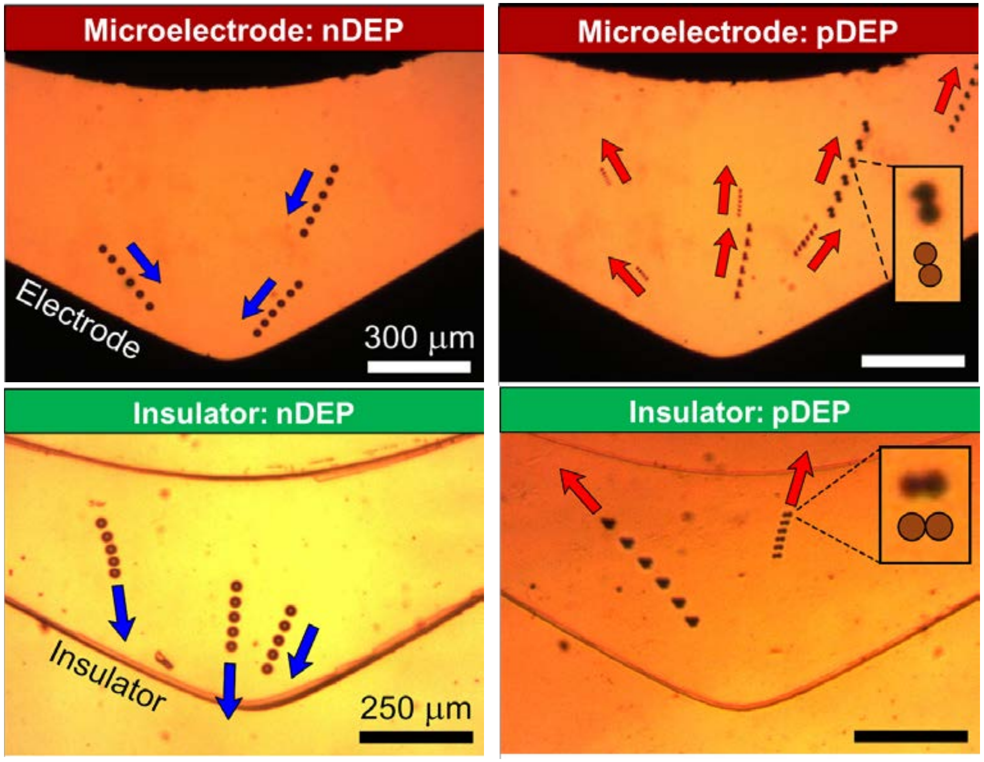
Single pressure gauges on a Kapton wafer and 4x4 pressure sensitive SkinCells with half mm pitch.

Dan Popa, University of Louisville NSF grants #IIP 1643989 and #IIP 1713741.
Work performed at University of Louisville Micro/Nano Technology Center.

Isomotive Dielectrophoresis (isoDEP) for Dielectric Characterization of Particles

This work focuses on the design of an isomotive dielectrophoresis (isoDEP) platform that provides a uniform DEP force throughout the microchannel. Particle translation is a function of the applied AC signal (voltage, frequency) and gives insight into the dielectric properties of the suspended particles.

Two platforms have been fabricated and tested. First, the field is applied across the microchannel sidewalls as the walls themselves serve as electrodes. The walls were patterned via DRIE of doped silicon. Second, an insulator version is created with PDMS via standard soft lithography; the field is applied through the length of the microchannel. Interestingly, both configurations yield an isomotive solution.



Two microfluidic isoDEP platforms (microelectrode, insulator) demonstrating both positive and negative dielectrophoresis. Figure modified from Electrophoresis **38**, 1441-1449 (2017).

Stuart J. Williams, University of Louisville.
Work performed at University of Louisville Micro/Nano Technology Center.

A Novel Photodiode Array for Characterizing Optical Fibers

Light attenuates as it travel along an optical fiber. Multiply traditional methods have been utilized to characterize it. But they all have their own inherent disadvantage. We proposed and demonstrated an innovative approach for measuring the attenuation of light in optical fibers. The technique fabricates a silicon device containing a v-groove that positions the fiber and a detector array along the v-groove. The detectors within the v-groove are designed to partially surround the fiber in order to maximize the coupling of scattered light from the fiber into each detector.

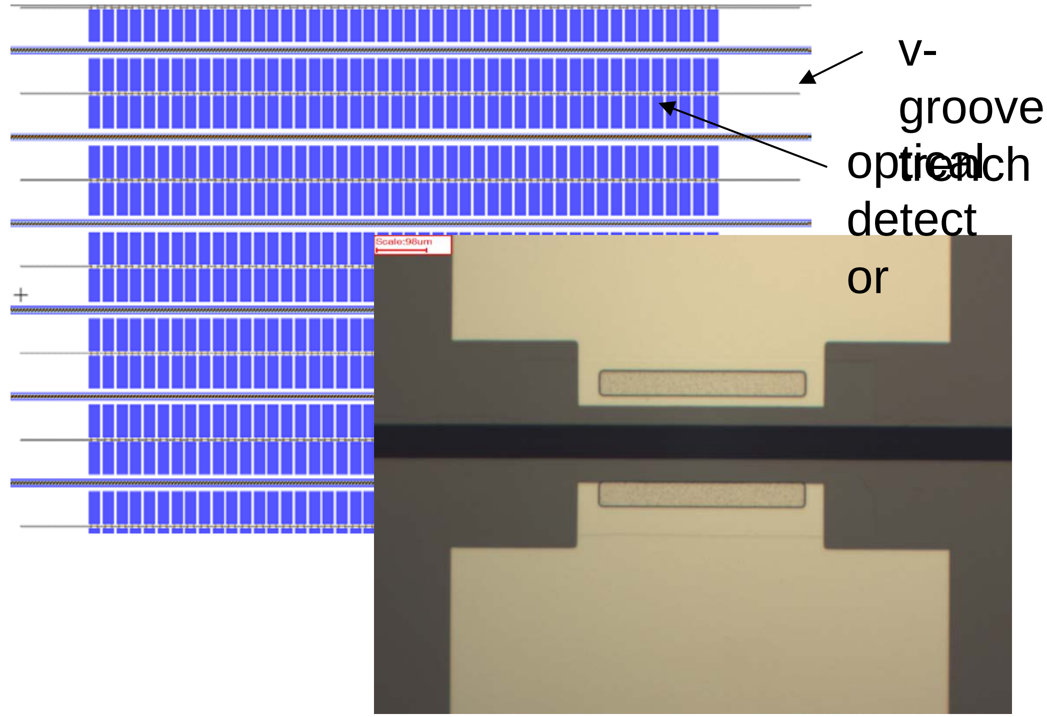


Image of one of the optical detectors in the linear photodiode array. There are a total of 46 photo-detectors around the v-groove trench in which the optical fiber under test is positioned.

Air Force Research Laboratory, Wright Patterson Air Force Base, Ohio.
Ken Hopkins (AFRL), Xiaojin Wang (UofL), Hiren Trada (UofL) and Kevin Walsh (UofL).
This work was performed at the University of Louisville Micro/Nano Technology Center

Mid-Atlantic Nanotechnology Hub (MANTH)

Nanomechanics of the Pericellular Matrix of Cartilage

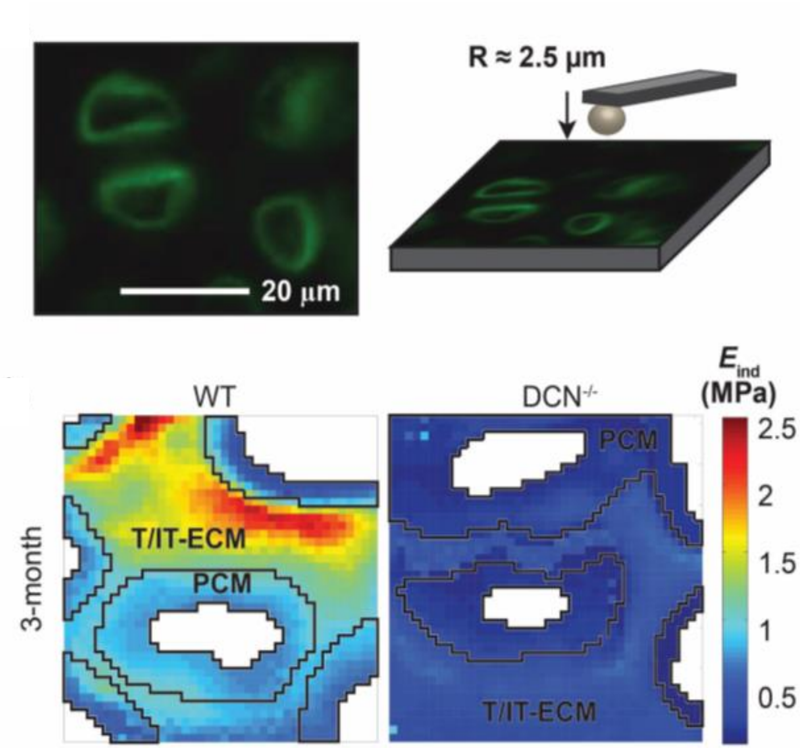
- Conducted at MANTH by Researchers from Drexel University
- Life Sciences Research

The pericellular matrix (PCM) of cartilage is a 3 to 5 μm-thick layer of tissue surrounding each chondrocyte (cell that produces and maintains collagen), regulating the biomechanical microenvironment of the chondrocytes and protecting the chondrocytes from overloading. The PCM is composed of localized collagen VI in the form of beaded filaments and perlecan.

Recent studies at MANTH discovered the indispensable roles of decorin, a class I small leucine-rich proteoglycan, in the properties of the articular extracellular matrix (ECM); however decorin's role in the PCM mechanics is unclear.

Using the MANTH Total Internal Reflection Fluorescence (TIRF)-AFM, researchers performed nano-indentation force mapping with the guidance of type VI collagen fluorescence imaging to distinguish the PCM versus ECM.

The PCM has significantly lower moduli than the ECM regardless of genotype and age, revealing an important role of decorin in cartilage PCM mechanical properties.



This work has been done by Daphney Chery in Prof. Lin Han's group at the School of Biomedical Engineering, Drexel University.

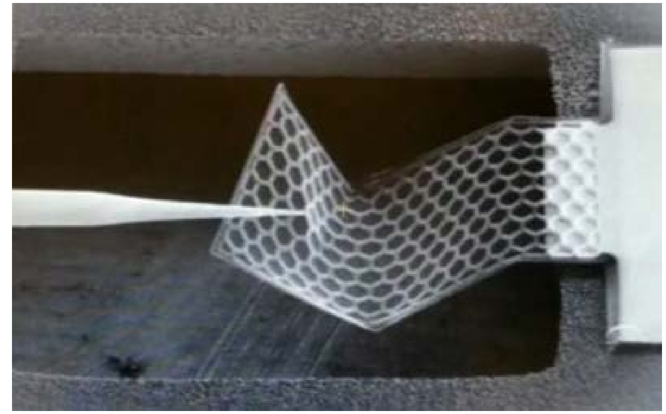
Nanoscale Flexible Membranes for Glaucoma Treatment

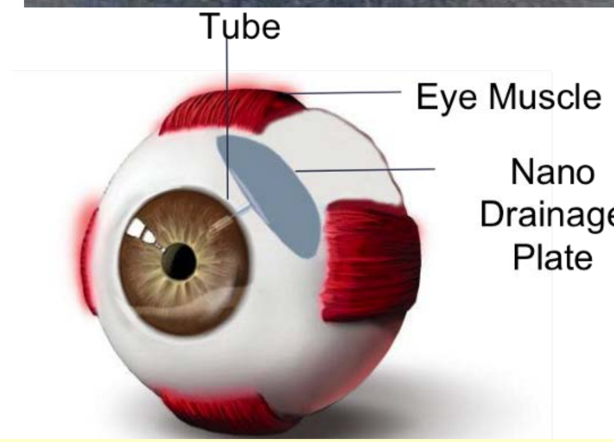
- Penn Researchers and Y Prize, Seed Grant Startup
- Materials and Medical Research

Each year, the Mack Institute for Innovation, Penn Engineering, Penn Wharton Entrepreneurship, and the Penn Center for Innovation come together to administer the invention competition known as the Y-Prize. This year's Grand Prize winner was VisiPlate, which seeks to use nanoscale plates (fabricated and characterized at MANTH) as part of a treatment for Glaucoma. These plates, developed in the lab of Igor Bargatin, Class of 1965 Term Assistant Professor of Mechanical Engineering and Applied Mechanics, are the thinnest that can be picked up and manipulated by hand. Despite being hundreds of times thinner than household cling wrap or aluminum foil, the corrugated plates of aluminum oxide can spring back to their original shape after being bent and twisted.

This unique combination of strength and thinness intrigued juniors Brandon Kao of Engineering, and Rui Jing Jiang and Adarsh Battu of Wharton. With assistance from Richard Stone and Eydie Miller, ophthalmologists at the Perelman School of Medicine, they envisioned a new way of fighting blindness.

In open angle glaucoma, aqueous fluid in the eye builds up, putting damaging pressure on the optic nerve. Non-invasive treatments, such as eyedrops, have low levels of compliance, and surgical interventions, such as shunts that drain the fluid into the muscles surrounding the eye, have high rates of failure. Because the Bargatin lab's plates are so thin, they can be implanted just under the surface in the front of the eye. Diffusing the shunted fluid over a wide area, they would allow that fluid to be reabsorbed at a manageable rate.



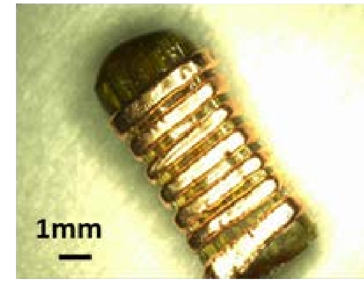


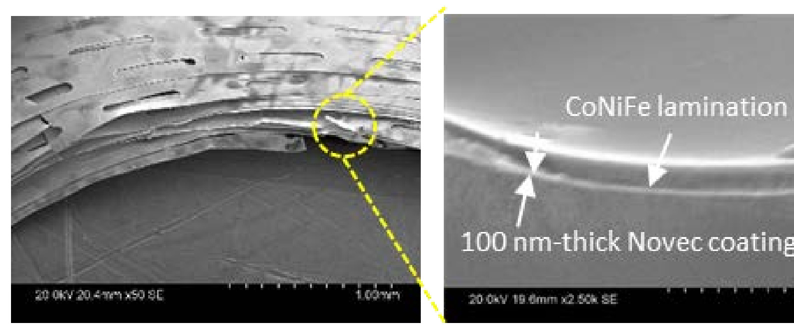
Prof. Igor Bargatin's group, Penn, with Brandon Kao, Penn, Adarsh Battu, Rui Jing Jiang, Wharton, Richard Stone and Eydie Miller, Perhman

Nano-Laminated Ferromagnetics

- Penn Researchers and Industrial Collaborator, EnaChip
- Materials Research for Biomedical Applications

One of the challenges of nanotechnology is to achieve macroscale devices and systems with materials/structures with desired nanoscale dimensions. The work combines electrodeposition and MEMS/micromachining to address such challenges. Based on this technology, nanolaminated cores comprising hundreds of submicron-thick ferromagnetic layers that are electrically-insulated from the neighboring layers by ~100 nm-thick fluoroacrylic polymer layers have been fabricated. Superior magnetic energy densities, surpassing that of conventional ferrite materials, are achieved even at high operating frequencies up to 10 MHz while the eddy current losses within the magnetic layers are suppressed. Micromachined inductors with millimeter-thick nanolaminations are developed to achieve inductive devices with reduced sizes. Such inductive devices based on thick laminations are promising solutions for the miniaturization of DC-DC power conversion systems in multifunctional portable systems such as cell phones, lab tops.





Dr. Mark Allen's MicroSensor MicroActuators (MSMA) group, Penn

3-D Metal Nanostructures for Energy Storage Applications

- Materials and Energy Research

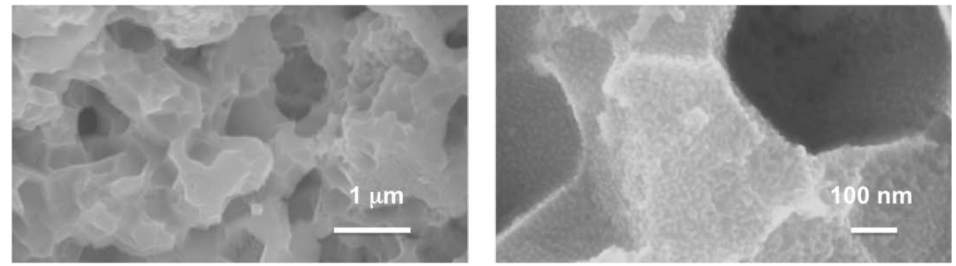
Prof. Detsi's research thrusts span these principal areas:

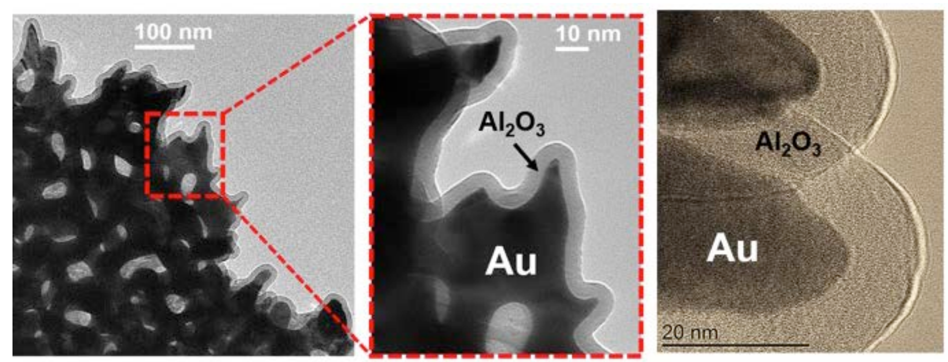
3D Nano Heterojunctions, making use of solid-solid interfaces in the bulk of 3D nanoporous metal scaffolds, as well as metal/dielectric based 3D nanocomposites.

3D Earth Abundant Metals for Energy Storage, for air-free non-aqueous synthesis routes to non-precious nanoporous metals as well as the integration into chemical and electrochemical energy storage systems.

3D Dual Microscopic Length Scale Structures for Energy Applications, developing nanoporous materials with bimodal porosity (macro pores and mesopores), with an emphasis on high-capacity alloy-type battery anodes for Li, Na or Mg.

Prof. Detsi's group constructs nanoporous scaffolds by co-depositing two metals, X and Y, followed by selective removal of Y (selective wet etching) and annealing, thus leaving behind a nanoporous framework of X. Nanoporous structures of Sn and Au are shown in the figures. Thin film deposition and dielectric capping of Au structures with Al_2O_3 were done in the MANTH cleanroom, and the materials were imaged at MANTH characterization facility.





Prof. Eric Detsi's group, Materials Science & Engineering, Penn

National Nanotechnology Coordinated Infrastructure

SINGH Center for Nanotechnology

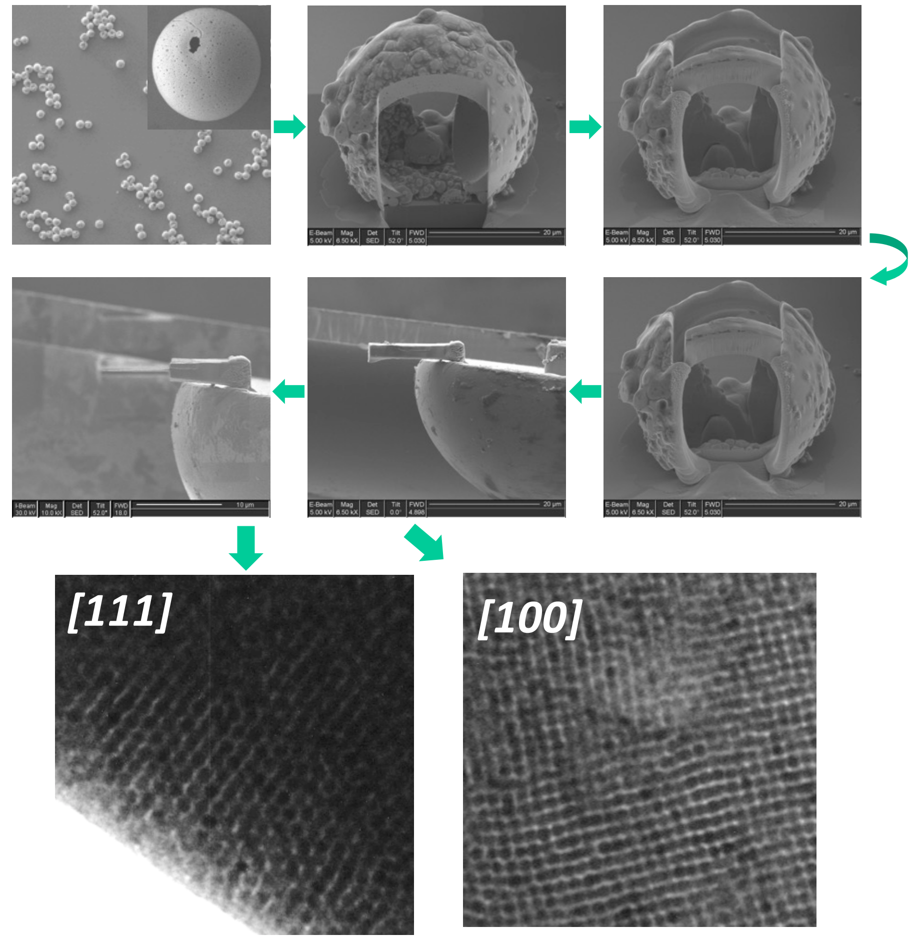
Penn Engineering

Self-assembled Supraballs of Nanoparticles

- Materials and Photonics Research

Supraballs are micron-sized spherical shells, formed by micelle-assisted colloidal self-assembly of nanoparticles. These supraballs combine multi-scale properties of the single nanoparticles such as quantum confinement, with collective effects resulting from being arranged on a 3D lattice. The combination of focused ion beam (FIB) and transmission electron microscopy (TEM) enables us to characterize the inner structure of a supraball.

The micrometer-scale supraballs are synthesized through the self-assembly of 6 nm PbSe nanocrystals in a droplet confinement configuration. We use FIB to lift out a part of the supraball, slice it into a thin film, and characterize the superlattice by TEM. The last two TEM images show a close-packed nanocrystal superlattice lifted out by FIB.



Prof. Christopher Murray's group, Penn

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SINGH Center for Nanotechnology

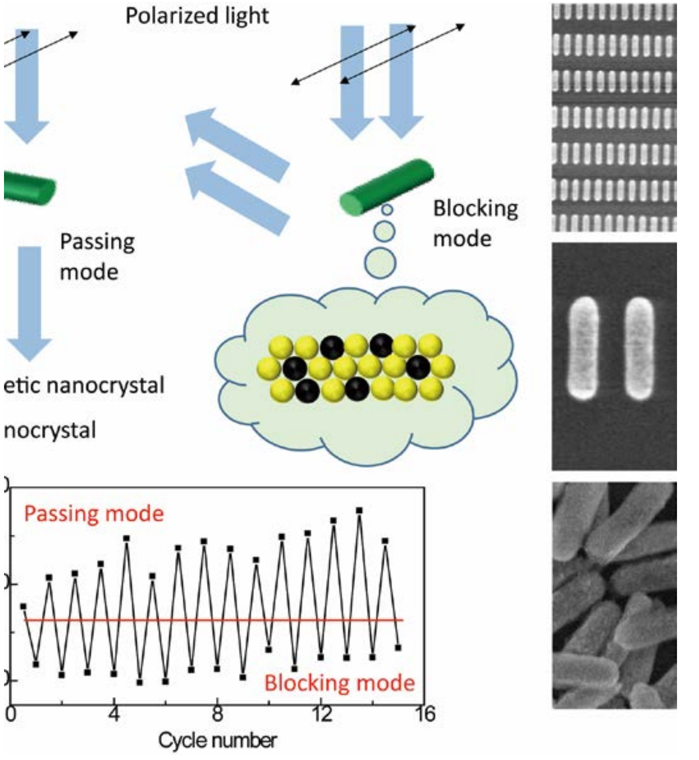
Penn Engineering

High Strength, Magnetically Switchable, Plasmonic Nanorods

- Photonic/Plasmonic Materials

Mingliang Zhang, a postdoctoral researcher in Cherie Kagan's group at Penn, reported the fabrication of multifunctional 'smart' nanoparticle systems by combining top-down fabrication and bottom-up self-assembly methods. The process of templating nanorods from a mixture of superparamagnetic $Zn_{0.2}Fe_{2.8}O_4$ and plasmonic Au nanocrystals. Nanocrystal-derived superparamagnetism prevents these nanorods from spontaneous magnetic-dipole-induced aggregation, while their magnetic anisotropy makes them responsive to an external field.

Ligand exchange drives Au nanocrystal fusion and forms a porous network, imparting the nanorods with high mechanical strength and polarization-dependent, infrared surface plasmon resonances. The combined superparamagnetic and plasmonic functions enable switching of the infrared transmission of a hybrid nanorod suspension using an external magnetic field.



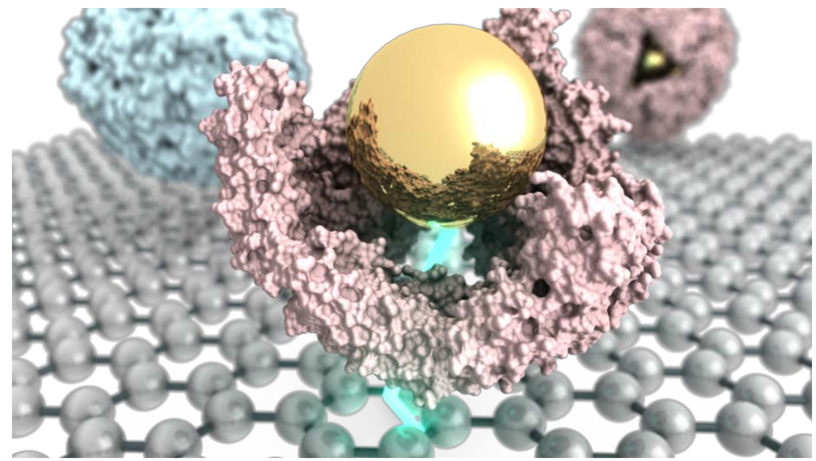
This work was reported in the 2016 November edition of Nature Nanotechnology. Groups contributing to the publication were Nader Engheta, Electrical and Systems Engineering, Dan Gianola, Materials Science, Jay Kikkawa, Physics, and Christopher Murray, Chemistry.

Structural-functional analysis of engineered protein-nanoparticle assemblies using graphene microelectrodes

- Electronics, Materials, and Life Sciences Research

The characterization of protein-nanoparticle assemblies in solution remains a challenge. We demonstrate a technique based on a graphene microelectrode for structural-functional analysis of model systems composed of nanoparticles enclosed in open-pore and closed-pore ferritin molecules. The method readily resolves the difference in accessibility of the enclosed nanoparticle for charge transfer and offers the prospect for quantitative analysis of pore-mediated transport, while shedding light on the spatial orientation of the protein subunits on the nanoparticle surface, faster and with higher sensitivity than conventional catalysis methods.

The interdisciplinary project involved Penn researchers in the groups of A.T. Charlie Johnson (Physics and Astronomy) and Ivan Dmochowski (Chemistry), who leveraged their expertise in two-dimensional materials and protein engineering along with the state-of-the-art facilities of the QNF. The lead author on the paper was Jinglei Ping, a postdoctoral fellow in Johnson's group.



Prof. A.T. Charlie Johnson's and Ivan Dmochowski's groups, Penn

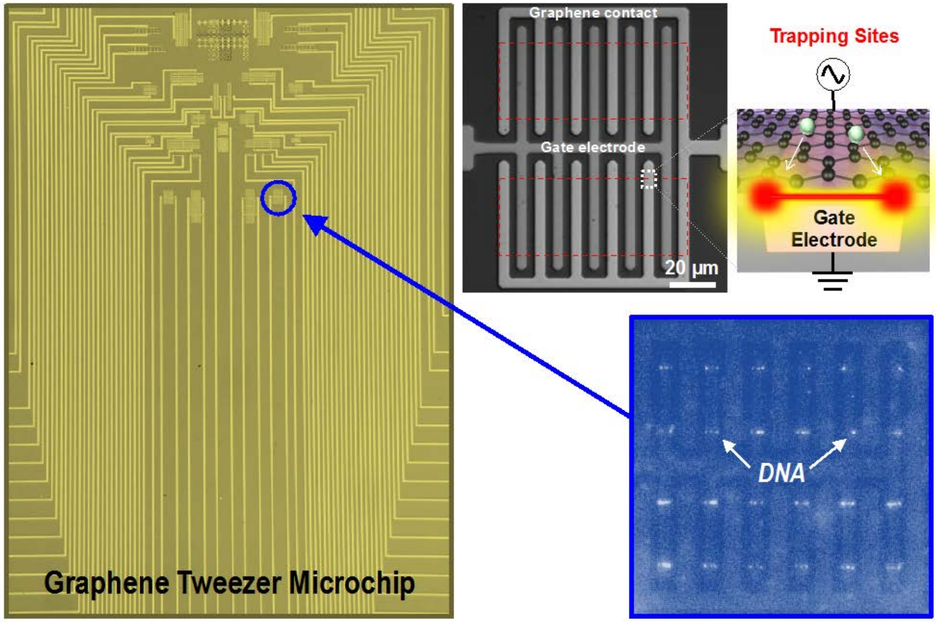
Midwest Nanotechnology Infrastructure Corridor (MINIC)

National Nanotechnology Coordinated Infrastructure

Graphene-Edge Electronic Nanotweezers

A research team led by Sang-Hyun Oh and Steve Koester has demonstrated that atomically sharp edges of graphene can act as the world's sharpest tweezers. The unique capabilities in the MINIC cleanroom facility allowed them to fabricate graphene-based electronic tweezers chip with high throughput and high yield.

This chip utilizes a mechanism known as 'dielectrophoresis' for electronic trapping of biomolecules and nanoparticles in solution. Patterned graphene ribbons possess atomically sharp edges, which act act as 'lightning rods' and create ultra-high electric field gradients. As a result, the team was able to show sub-1V trapping of DNA molecules on graphene edges.



A microchip fabricated in the MINIC cleanroom consists of a large-scale array of metal electrodes in contact with patterned graphene ribbons. Upon applying an AC bias, the edges of graphene ribbons create strong electric field gradients and can trap biomolecules (DNA) and nanoparticles in a solution. Adapted from A. Barik et al. *Nature Communications* (2017) dx.roi.org/10.1038/s41467-017-01635-9

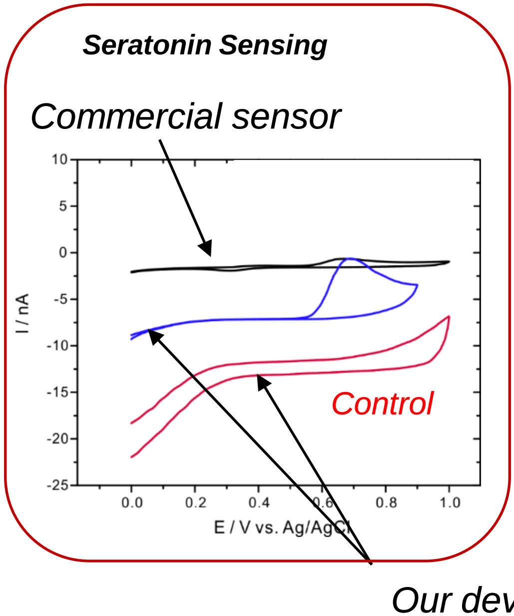
Profs. Sang-Hyun Oh and Steven Koester, University of Minnesota
Work performed at Minnesota's Midwest Nano Infrastructure Corridor (MINIC)

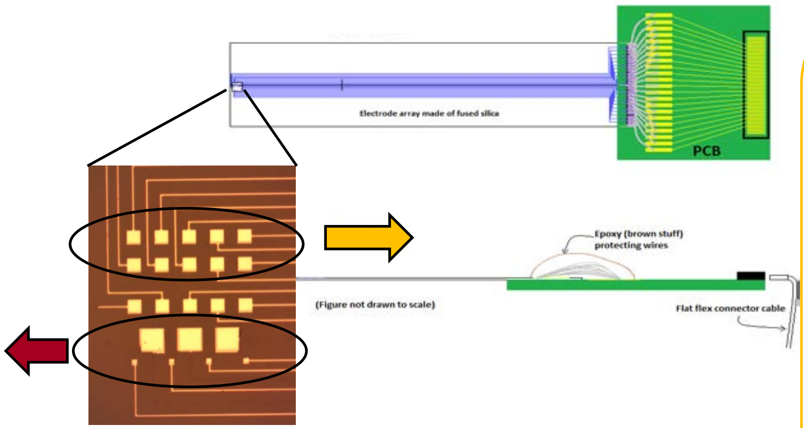
National Nanotechnology Coordinated Infrastructure

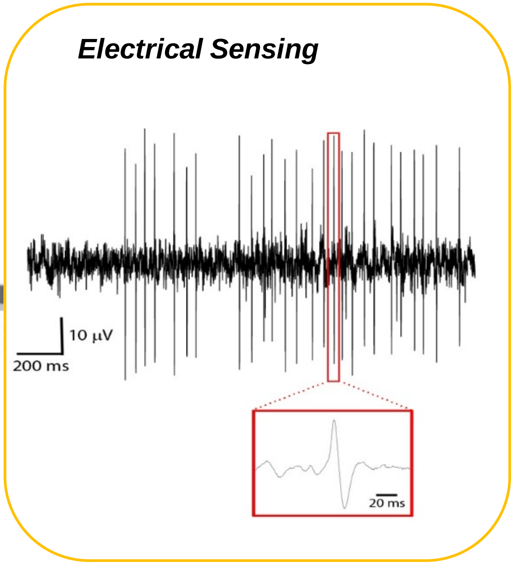
MiNiC

Multimode ECOG

Simultaneous detection of electrical and chemical signals is useful for a fuller understanding of brain function, but cyclic voltammetry measurements must be robust and reliable. We are constructing multifunction devices with novel materials to achieve these goals.







Collaborators:
Christy Haynes (Chem)
Karen Mesce (Entomology)

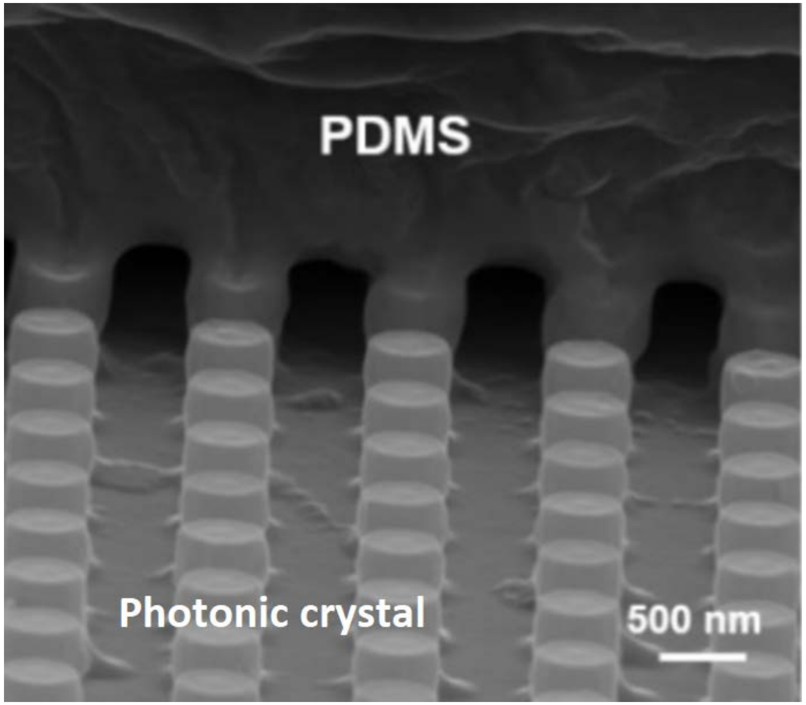
Liang Dong, Iowa State University
Work performed at Minnesota's Midwest Nano Infrastructure Corridor (MINIC)

National Nanotechnology Coordinated Infrastructure

MiNiC

Optofluidic Sensor for Cancer Biomarker Detection

- A lateral flow-through biosensor, combining silicon nanophotonics and nanofluidics, is developed for detection of cancer biomarker with a limit of detection of 0.7 ng mL^{-1} for epidermal growth factor receptor 2, a protein biomarker for early-stage breast cancer screening.
- The sensor is featured with a lateral flow-through feature and utilizes a high-Q resonance mode associated with optical bound states of metasurface.
- This project was supported by National Science Foundation. The e-beam lithography and deep reactive ion etching machines at MINIC were used to manufacture the device.



Wang et al., MicroTAS 2017, pp. 565-567

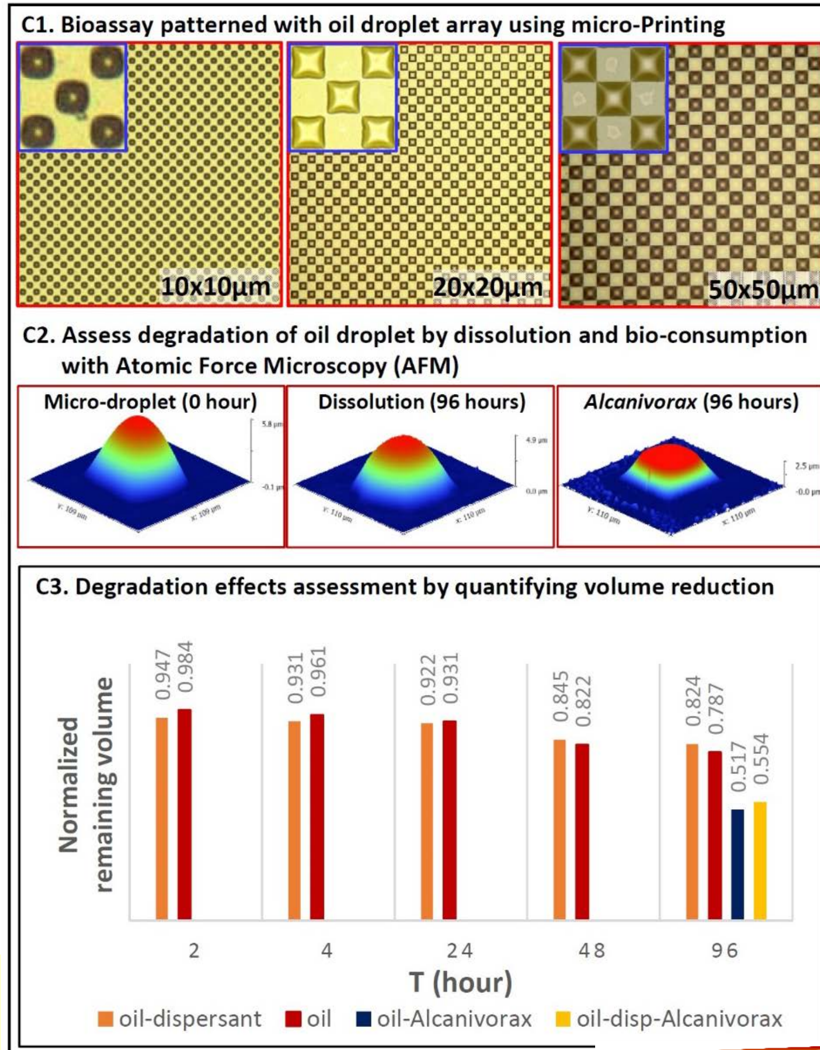
Infrared reconfigurable split-ring resonator

Liang Dong, Iowa State University
Work performed at Minnesota's Midwest Nano Infrastructure Corridor (MINIC)

Ecology-on-a-Chip

This project studies the behavior of oil-eating bacteria. Several types of bacteria found naturally in the marine environment play key roles in breaking down petroleum. The goal is to study the effects of bacterial action on the properties of the oil. Researcher Maryam Jalali-Mousavi patterns oil droplets on a substrate, then uses the Bio-Nano lab facilities to culture several types of marine bacteria on the oil. During the oil exposure, bacterial growth is monitored using the Bio-Nano Lab's inverted microscope.

During the course of this work the lab has established documented procedures for cell culture and handling, nanoparticle functionalization, and cell imaging for the Bio-Nano Lab. These capabilities are now available to researchers from any University department as well as external academic and industrial users.



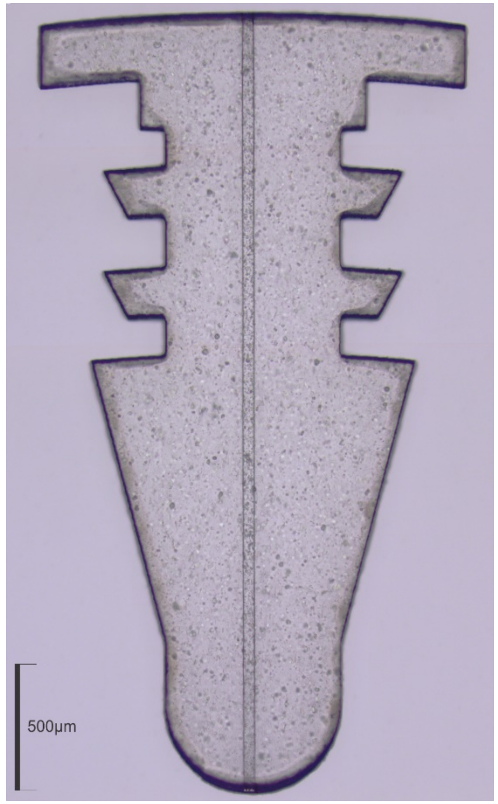
Jian Sheng and Maryam Jalali-Mousavi Texas A&M
Photolithography, AFM, cell culture microprinting, microscopy

National Nanotechnology Coordinated Infrastructure

MiNiC

Brown Glaucoma Implant

- Glaucoma is the world's leading cause of irreversible blindness.
- MicroOptx has developed a groundbreaking microfluidic device aimed at halting the progression of blindness associated with glaucoma.
- After 71 animal subjects, MicroOptx recently received approval from the FDA to begin our first-in-man clinical trials.
- Minnesota Nano Center produces the high-quality, low-tolerance silicon molds required to fabricate our device.
- Given the small-quantity production of iterative prototyping, Minnesota Nano Center is uniquely positioned to service companies in our stage of development.
- Minnesota Nano Center has been absolutely crucial in our quest, and we look forward to a continued partnership.



Brown Glaucoma Implant Model 2D

Aaron Cohen, MicroOptx, Inc.
Silicon Wafer Etching via Photolithography, DRIE

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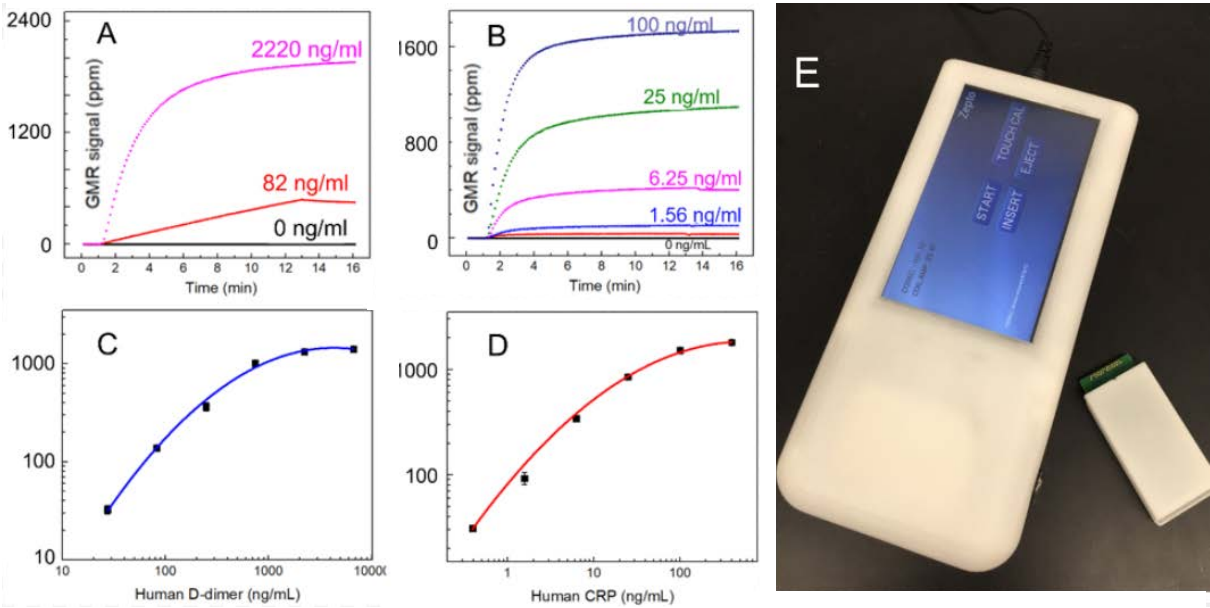
GMR Based Bio Sensing

Zepto Life Technology is building a handheld protein biomarker detection platform with integrated microfluidics. This has great potential for the development of simple, rapid, automatic and cost-effective point-of-care testing (POCT).

Biologically functionalized GMR sensors paired with biologically functionalized magnetic nanoparticles detect protein biomarkers. ***Goal****: multiplex detection of protein biomarkers at medically relevant sensitivities in a hand-held battery-powered format*



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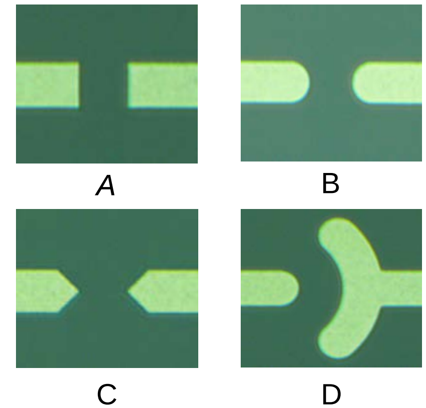
High Voltage Planar Devices

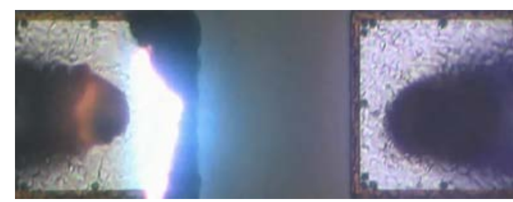
This research is to characterize the surface breakdown voltages of planar devices. Four different pad types were developed to see the impact of pad shape and the distance between the pads.

The four pad types shown to the right were characterized at six different gaps between the edges of the pads:100, 200, 300, 400, 600 and 800um. The pointed pad type “C” performs the worst and the rounded type “B” performs the best. The rounded pad type hard breakdown voltage at 100um gap is 1000V and 800um gap is 2500V. The pointed pad type hard breakdown voltage at 100um gap is 900V and 800um gap is 2250V.

Celadon Systems is a high performance probe card manufacturer located in Burnsville, MN. The facilities at the University of Minnesota enabled cost effective hands on research allowing me to learn the fundamentals of wafer processing and observe important mechanisms related to high voltage devices.



Four Pad Structures



Surface Breakdown Between Pads

Adam Schultz, Celadon Systems
Work performed at Minnesota’s Midwest Nano Infrastructure Corridor (MINIC)

National Nanotechnology Coordinated Infrastructure

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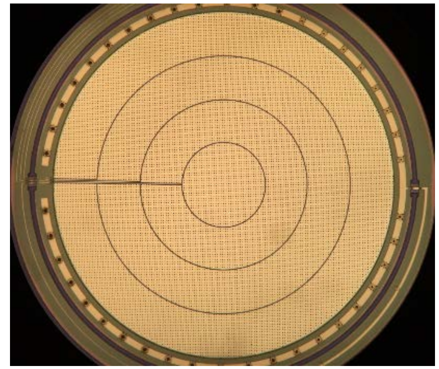
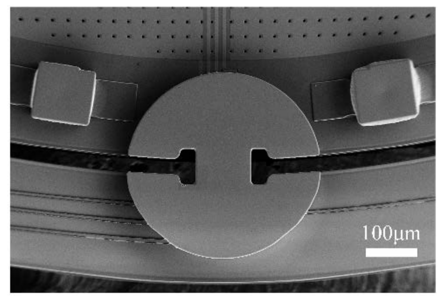
Montana Nanotechnology Facility (MONT)

Active Optics Devices for In Vivo Microscopy for Cancer Diagnosis

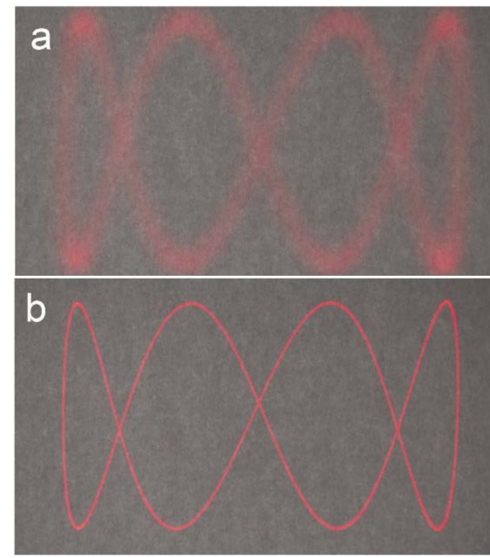
Ph.D. student Tianbo Liu is developing a 3D laser beam scanning mirror for medical imaging. Confocal laser scanning microscopy allows micron resolution imaging of cells throughout a 3D volume of intact tissue. This allows clinicians to evaluate individual cells to determine whether there is a suspicion of cancer. It is non-invasive compared to traditional biopsies and therefore can be prescribed to each site that appears suspicious, eliminating the chances of malignant growths going unnoticed. Confocal microscopy works by scanning a focused laser beam throughout a 3D volume of tissue; two galvanometric scanning mirrors and a motorized focus control mechanism, all leading to a bulky optical system. The 3D laser beam scanning mirror in this project tilts on two axes to scan the beam in *x* and *y*, and can also adjust its surface curvature to control the focus location in *z*, all in a millimeter sized package. These micromechanical devices are the key to pencil-sized confocal probes for clinical microscopy not only of skin, but inside the mouth, the GI tract and other endoscopically accessible sites.



A top view image of the mirror's surface. The aperture is 4mm. At the center are four concentric thin-film aluminum rings that serve two purposes – they are the highly reflective mirror surface and carry a voltage that creates an electrostatic force to deform the membrane, controlling the mirror curvature and therefore its focal length. This deformable mirror is situated as part of a 2-D gimbal that allows tilting in x and y, to fulfill the 3D beam scanning function.



Detail of a gimbal hinges. The hinge is made from a thicker portion of a similar SU-8 material, about 50 µm thick, and also supports electrical traces that connect to the focus control electrodes function. The array of vias on the surface of the mirror is to facilitate the release process during fabrication.



Biaxial scan patterns generated by using the 3D mirror to scan a laser. (a). Beam is not focused. (b). Mirror surface is deformed to focus beam.

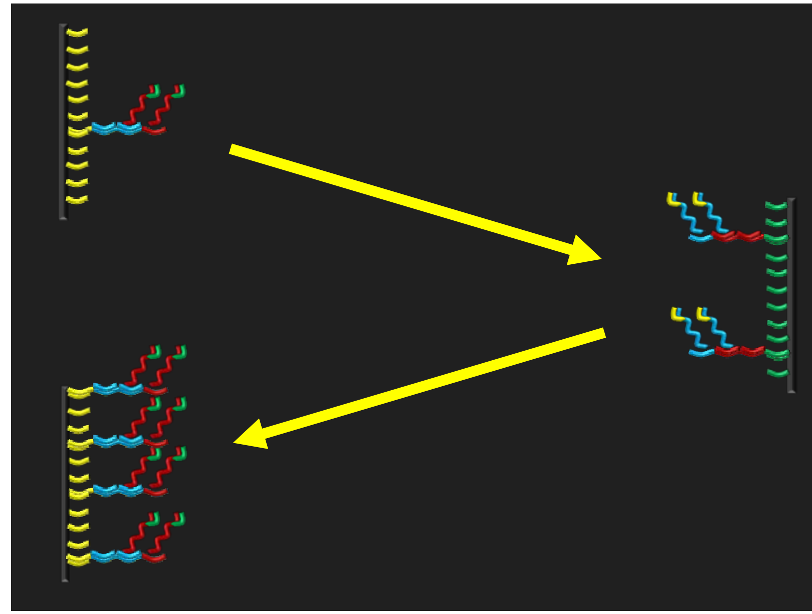
Tianbo Liu, David Dickensheets, Montana State University
Work performed at Montana State University, MONT facility MMF.

National Nanotechnology Coordinated Infrastructure

MONTANA STATE UNIVERSITY | Montana Nanotechnology Facility

Development of a Non-enzymatic, Exponential Signal Amplification System

Biomodum LLC is generating data in support of a submitted patent for a signal amplification system. The patent addresses shortcomings of existing enzyme based detection systems that are used in the developing world, including the requirement for cold-chain transportation and storage of reagents, stable electricity or large batteries, inhibition of enzyme activity by sample components, and constraints upon amplification rate. The current invention addresses all these issues and has implications for the development of point-of-care diagnostic instruments.

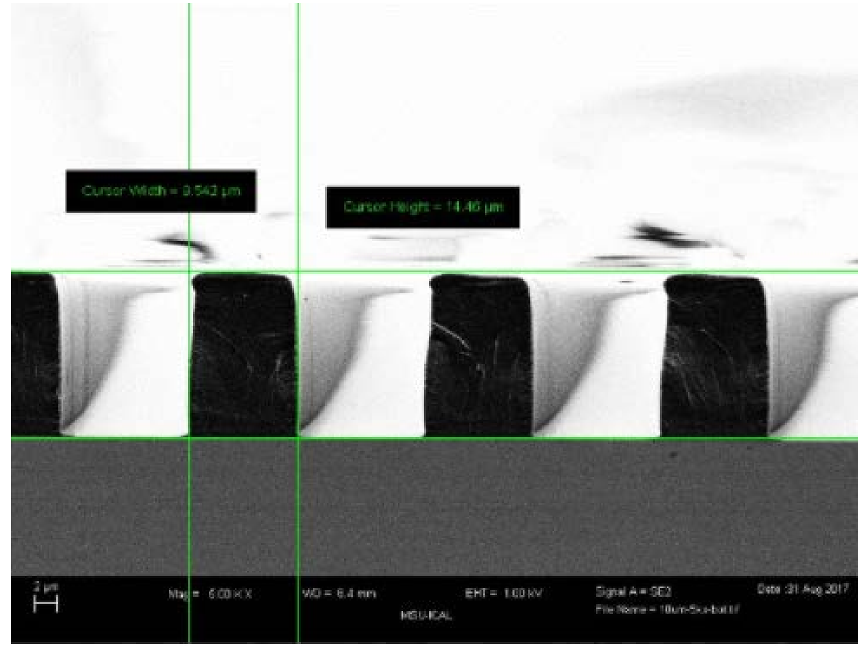


One amplification cycle

Robert Burris, Biomodum LLC, Big Sky, Montana
Work performed at Montana State University, MONT facility **Center for Biofilm Engineering**

Development of Photolithography Procedures

This goal of this work is to develop standard photolithography protocols for different photoresists. Facility users would be able to use these protocols to expedite photolithography steps in their own research. Procedures have been completed for KMPR 1010, a negative photoresist, at a height of approximately 15 microns on both glass and silicon substrates. Angles of approximately 90 degrees between the wafer and photoresist have been achieved. Procedures for SU-8 3025 on silicon are currently being developed.

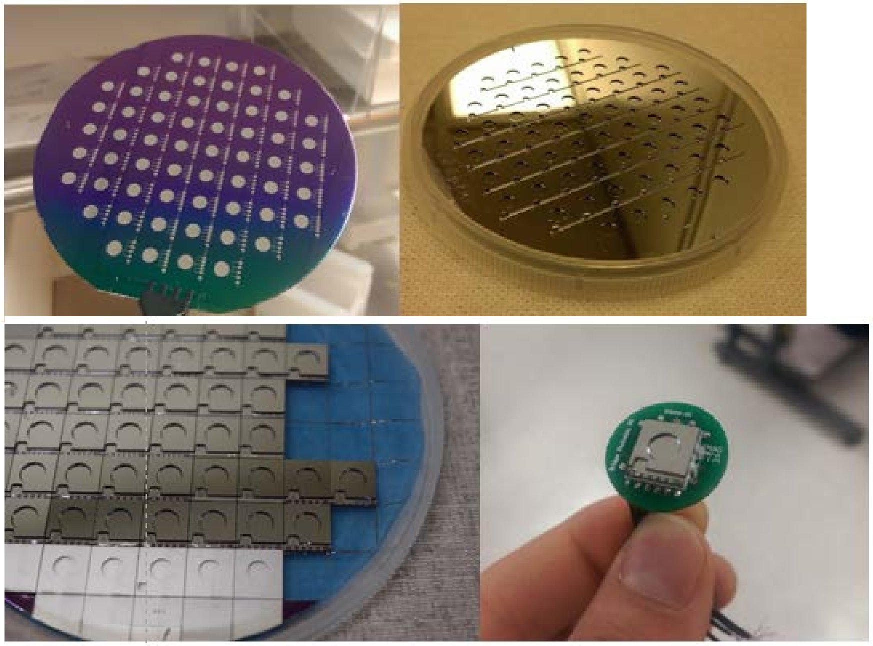


Side profile SEM image of KMPR 1010 on silicon sample.

Benjamin C.H. Huang, Erik Sobeck, and Tristan Cunderla, Montana State University
Work performed at Montana State University, MONT facility **Montana Microfabrication Facility**

MEMS Adjustable Focus Mirrors

Revibro Optics is working to commercialize the MEMS deformable mirror technology developed at MSU. Our current work is aimed at developing new optical coatings for our mirrors, and refining the design and fabrication process to increase mirror yield. Our mirrors consist of a metal coated flexible membrane situated above a series of electrodes. Electrostatic actuation produces a curvature change in the surface, and allows for very high-speed focus adjustments – more than 1000 adjustments per second. Our work is enabled by the existence of this MONT facility, and we make extensive use of the MMF as a commercial user.



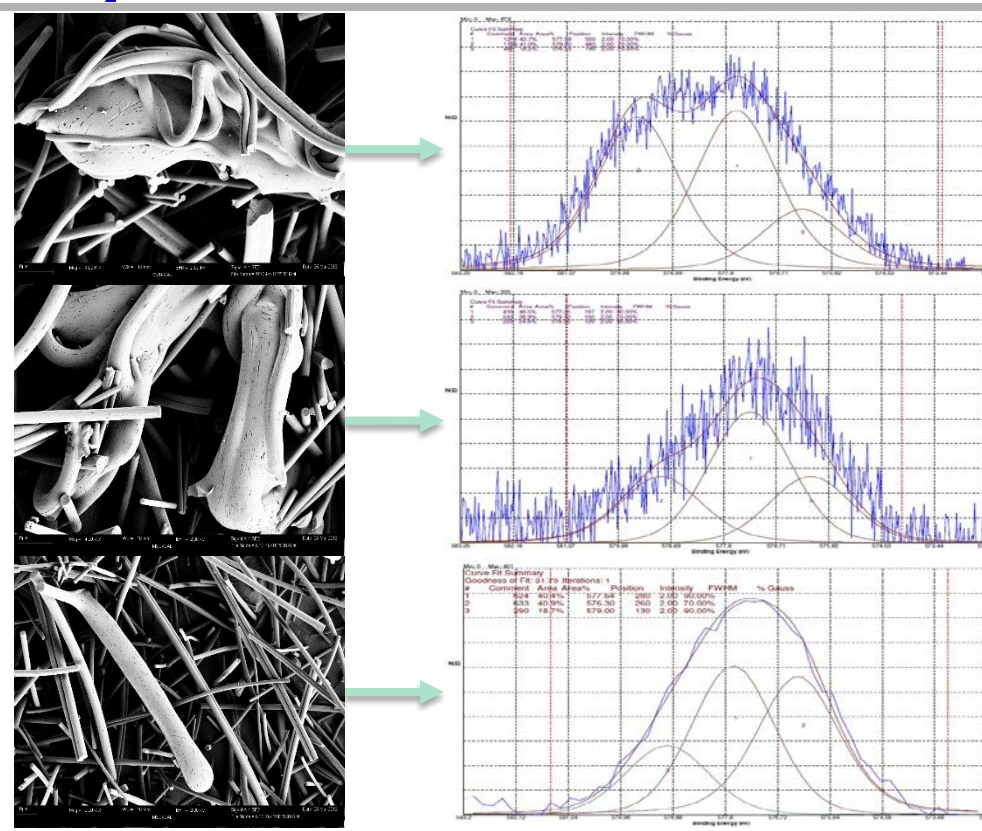
MEMS deformable mirrors manufactured at MMF.

REVIBRO OPTICS

Chris Arrasmith, Revibro Optics LLC
Work performed at Montana State University, MONT facility **MMF and ICAL**

Investigating Surface Interactions between Volatile Chromium Species and Ceramics

Volatile chromium species are formed when chromium containing materials are exposed to high temperature oxidizing environments. This work examines how these volatile species interact with aluminosilicate fiber surfaces. Interactions are characterized using x-ray photoelectron spectroscopy (XPS), x-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive x-ray spectroscopy (EDS). Examination of the Cr $2p_{3/2}$ region from XPS analysis yields information concerning the oxidation state(s) of condensed chromium species. Using XRD, one may identify the presence of phases such as chromate, chromia, and chromium trioxide. Morphological differences and corroborative data are sought using SEM and EDS.

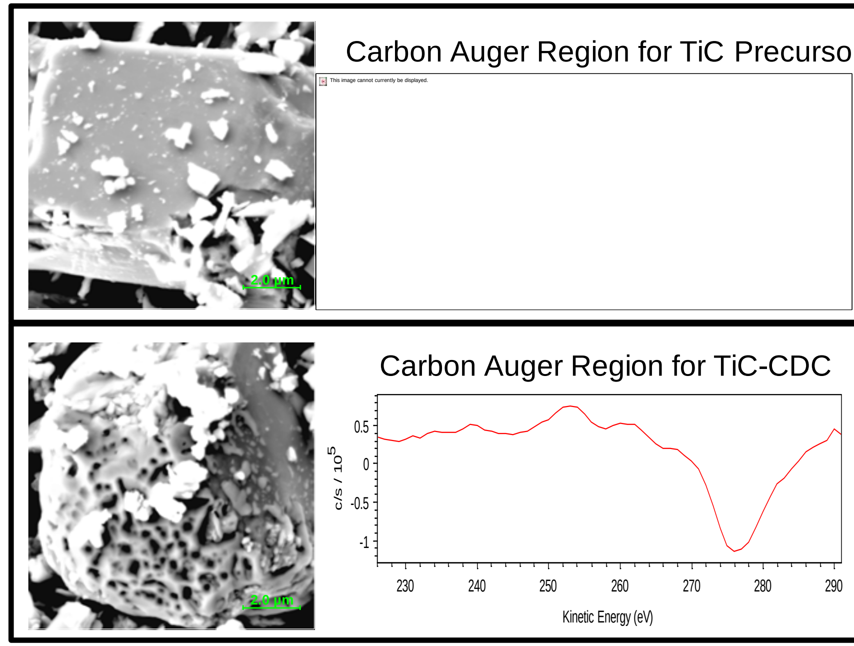


X-ray photoelectron spectra of Cr $2p_{3/2}$ regions used to analyze the speciation of chromium on aluminosilicate fibers.

Greg Tatar, Paul Gannon, Spencer Dansereau, and Emily Remington, Montana State University. Work performed at Montana State University, MONT facility **Imaging and Chemical Analysis Laboratory**

Identifying Structural Changes of Metal Carbides Transitioning to Carbide-Derived Carbons Using Auger Scanning Spectroscopy

Our research investigates an alternative carbide-derived carbon (CDC) synthesis route using an inexpensive halogen-containing etchant, ammonium chloride (NH_4Cl), to produce porous CDCs with tunable microstructures. To ensure tunable microstructures are achievable through our synthesis method, analytical techniques including scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and auger electron spectroscopy (AES) are used. SEM images are used to show a developing porous layer on the surface of the Me_xC. AES of the carbon KLL region is used to show a transition from a carbide to carbon structure and to determine the resulting allotrope of the Me_xC-CDC powders.



Microstructural changes of TiC precursor to processed TiC-CDC powders are observed via SEM surface images (left) and their corresponding carbon KLL spectra obtained via AES (right).

Emily Remington, Spencer Dansereau, Paul Gannon, Montana State University
Work performed at Montana State University, MONT facility **Imaging and Chemical Analysis Laboratory (iCal)**

National Nanotechnology Coordinated Infrastructure

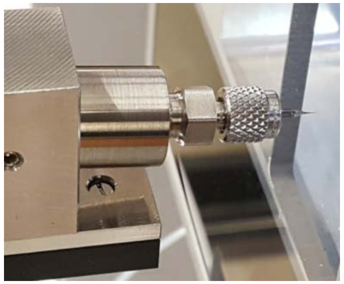
MONTANA STATE UNIVERSITY | Montana Nanotechnology Facility

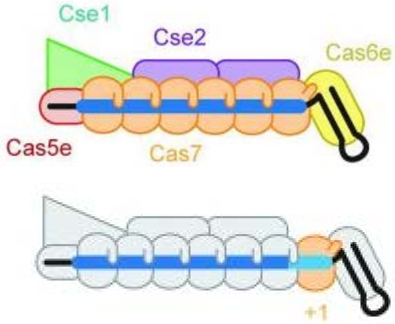
Investigation of multi-protein complex stoichiometry using gold-coated glass capillaries

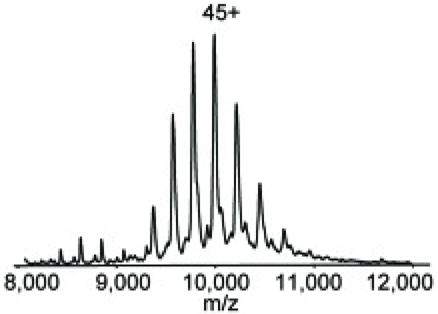
Analysis of non-covalent protein complexes is performed by means of nanoflow electrospray ionization, using glass or quartz capillaries which have been pulled to a fine tip (~1 μm inner diameter), and coated with conductive material (gold). Precision application of the coating improves the stability of the current and electrospray.

This technique allows protein complexes to be transferred from liquid to gas phase (and ionized) without disruption of non-covalent interactions.

We found that extending the spacer portion of the crRNA resulted in larger Cascade complexes with altered stoichiometry. Together with *in vivo* studies these findings demonstrate the flexibility of the Type I-E CRISPR machinery and suggest that spacer length can be modified to fine-tune Cascade activity.







Top: gold-coated borosilica glass capillaries; Bottom: nanoflow electrospray probe; Right: native mass spectrum of 446kDa Cascade complexes containing (extended) crRNA spacer with 38 nucleotides. As a result of extended spacer Cascade complex acquired additional (+1) Cas7 subunit. [Nucleic Acids Res. 2016 Dec 15;44(22)]

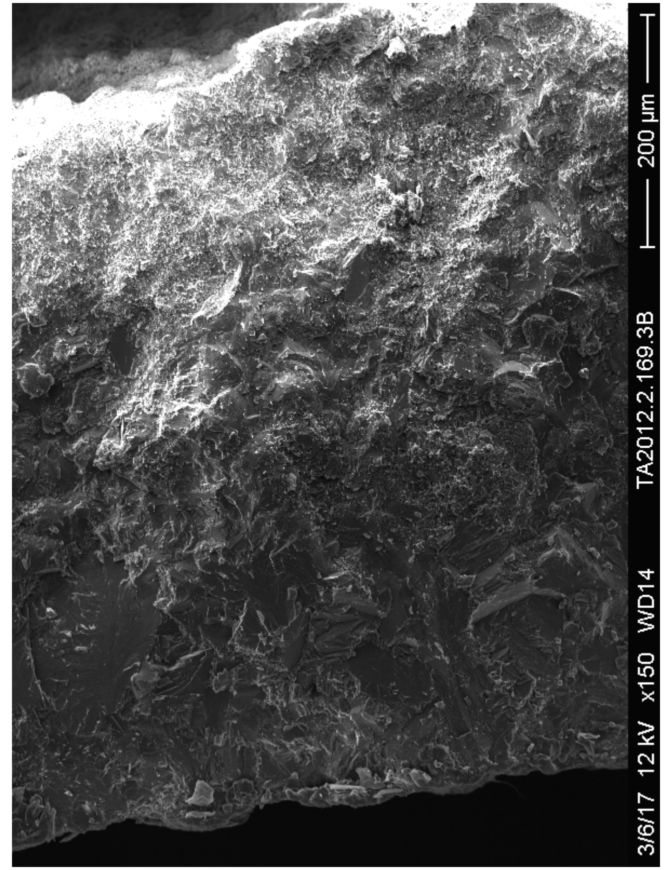
Monika Tokmina-Lukaszewska, Angela Patterson, Brian Bothner, Montana State University
Work performed at Montana State University, Montana Microfabrication Facility & Mass Spectrometry Facility

National Nanotechnology Coordinated Infrastructure

MONTANA STATE UNIVERSITY | Montana Nanotechnology Facility

Diversity of Fossil Eggshell from the Late Cretaceous of Montana

A team of students at Montana State University have been investigating a number of eggshell samples from the Upper Cretaceous Two Medicine Formation of Montana using SEM. They have revealed eggshell from theropod dinosaurs and birds as well as possible crocodilians and lizards. These specimens represent otherwise hidden vertebrate diversity, new egg forms, and highlight the variety of nesters at localities like Egg Mountain.

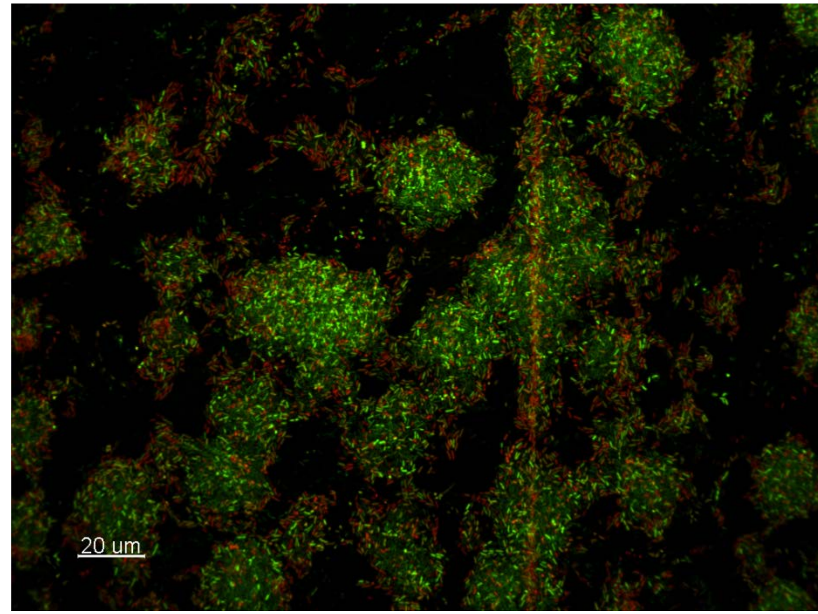


SEM micrograph of the cross-section of a new variety of dinosaur eggshell.

David Varricchio, Jacob Burgo, Eric Przybyszewski, and Paul Germano
Work performed at ICAL, Montana State University

IMMOBILIZED SILVER NANOPARTICLES:
An eco-friendly way of preventing biofilm-related health risks?

Developing and testing nanosilver-based coatings for controlling biofilm formation is an important global health challenge of our time. In this project we assessed the efficacy of nanosilver-coated surfaces against microbial colonization in order to evaluate its ranges of application and limitations. Assessment was made of the development and structure of biofilms grown on test samples in a drip flow biofilm reactor system. Fluorescence microscopy was used to visualize the biofilm and assess viability of microorganisms. Our data showed that the coatings were not efficient at preventing biofilm formation. Therefore, it is important that novel antimicrobial surface coatings undergo testing to confirm their efficacy and to provide scientific evidence to support any claims that the manufacturer wishes to make about them.



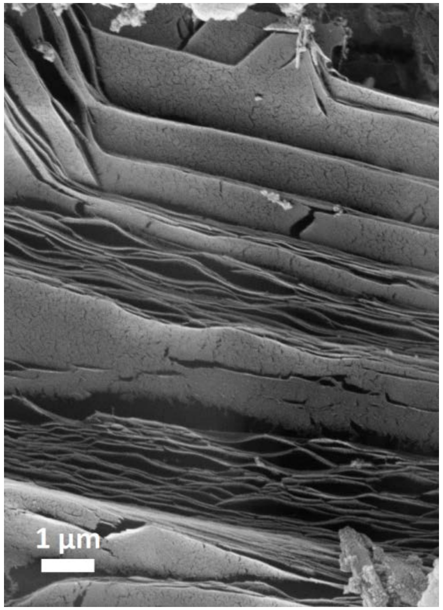
Pseudomonas aeruginosa biofilm formed on nanosilver coated polyethylene coupon stained with LIVE/DEAD BacLight viability kit and visualized using a confocal laser-scanning microscopy.

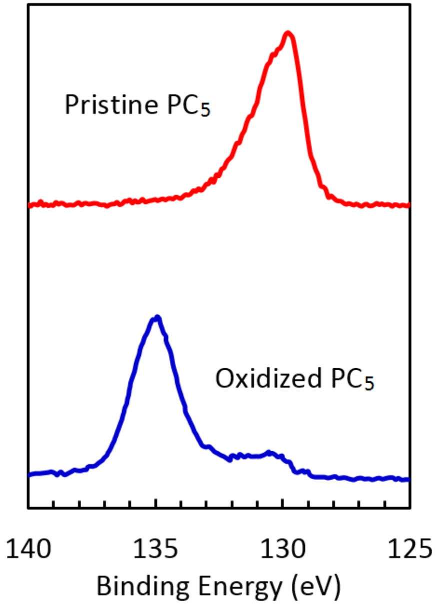
Marketa Hulkova, Masaryk Univerzity, Czech Republic
Work performed at Montana State University, **Center for Biofilm Engineering (CBE)**

Heteroatom-Doped Graphitic Carbon

Energy storage materials, whether in the form of ion-storing battery electrodes or gas-storing porous scaffolds, are dominated by the element carbon, specifically its graphitic-amorphous sp^2 hybridization state. We seek to tune both the electronic and physical properties of graphitic carbon materials via controlled, substitutional replacement of the carbon atoms by heteroatom dopants.

We routinely investigate materials containing a wide range of compositions of BC_x, NC_x, and PC_x, where x is above 3. The facilities at ICAL crucially assist in both chemical and structural characterization: compositional analysis (also in profile), impurity analysis (oxygen/halide content), surface/bulk morphology, and chemical environment (chemical bonding analysis).





Left: Scanning electron micrograph of a crystalline region of high-boron content graphitic carbon (~BC_3). Right: X-ray photoelectron spectra of ~PC_5 showing very low oxygen impurities and confirming the presence of P-C bonding.

Devin McGlamery, Julie Muretta, and Nicholas P. Stadie, Montana State University
Work performed at Montana State's Imaging and Chemical Analysis Laboratory (ICAL)

Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

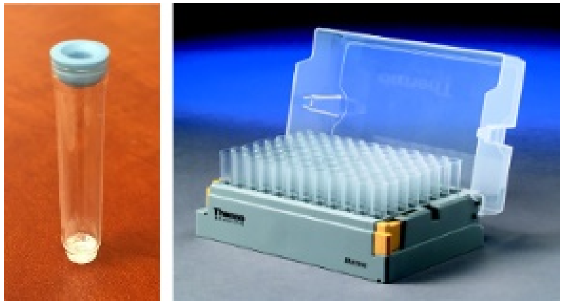
Parylene Coating of Miniaturized VacuStor^{TM} Tubes for Biodosimetry Logistics for Radiation Countermeasures

In case of a radiation exposure emergency (such as dirty bomb) in a large metropolitan area, a self administered blood collector can streamline the logistics of biodosimetry assays for high throughput triage of affected people for the right treatment. 96-well formation VacuStor^{TM} tube (a miniaturized vacutainer) can be a critical component in such device. However, short shelf life due to gas leakage to the small volume of the tube is a big issue. Using permeation theory, ideal gas law and mathematical curve fitting, we have shown that the shelf life of the VacuStor^{TM} tubes can be extended significantly by parylene coating (or low temperature storage), from ~ 2 months to several years. This paves the way for development and eventual translation of the self administered blood collector for high throughput biodosimetry for radiation countermeasures, and point-of-care molecular diagnosis.

Jian Gu, Frederic Zenhausern, Center for Applied Nanobioscience and Medicine, University of Arizona College of Medicine - Phoenix

A

B



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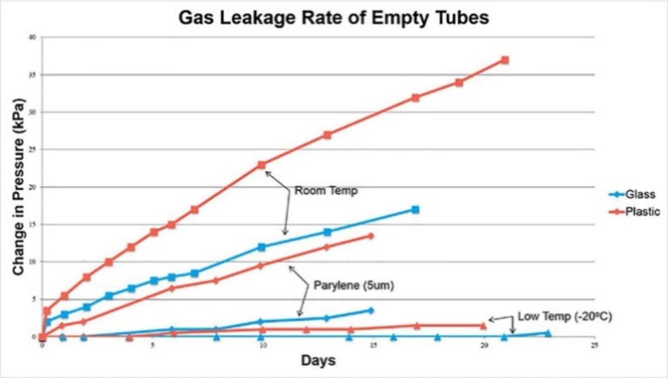


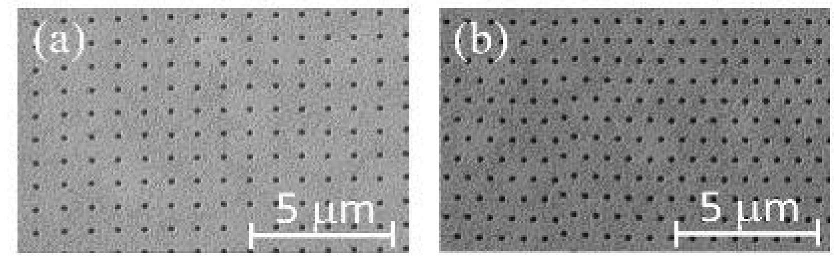
Parylene coating for long shelf life of VacuStor^{TM} tubes for biodosimetry logistics for radiation countermeasures. (A) a 3D printed prototype of self administered blood collector where VacuStor^{TM} tubes are critical components; (B) Images of 96-well format miniaturized VacuStor^{TM} tubes; (C) Gas leakage rate of glass and plastic VacuStor^{TM} tubes under different conditions (room temperature storage, parylene coating of tubes, and low temperature storage).

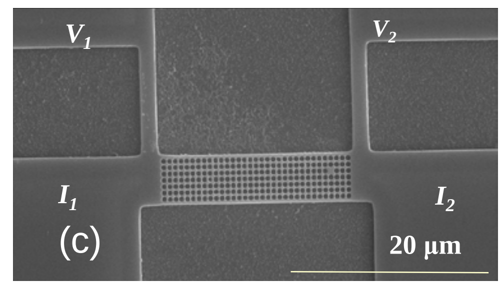
National Nanotechnology Coordinated Infrastructure

NCI Southwest

Study of Nanoporous and Nanograined Materials for Thermoelectric Applications

Solid-state thermoelectric (TE) devices have the ability to directly convert heat into electricity for power generation. A good TE material should possess a high electrical conductivity *σ*, a high Seebeck coefficient *S*, and a low thermal conductivity *k*. This requirement is hard to satisfy within the same material. To address this issue, a nanostructuring approach has been widely used to reduce the thermal conductivity but still maintain the bulk electrical properties. High TE performance has thus been achieved in various nanostructured materials, such as nanoporous and nanograined bulk materials. Our research focus is to better understand how these nanostructures affect the thermal transport.





Hao et al., 2015 MRS Spring Meeting & Exhibit, **1779**, mrss15-2137995 (2015).

Various nanostructured materials: (a), (b) nanoporous $In_{0.1}Ga_{0.9}N$ films. (c) A suspended nanoporous Si film. (d) Nanograined BiSbTe alloys.

Qing Hao, Aerospace and Mechanical Engineering, University of Arizona

Organic Passivation of Silicon Surfaces and Fabrication of a Hybrid Organic/Semiconductor Solar Cells

Benzoquinone has been demonstrated to provide a remarkable surface passivation and to induce a junction on n-type silicon wafers. Silicon/Organic material-hybrid devices , as schematically shown in Fig1, were fabricated. These devices showed the power efficiencies of 11%. This structure/process is unique that it doesn't need boron diffusion to create a p^+n junction. In addition to this, the organic layer itself acts as a surface passivation layer. This device was used to explore eventual commercialization of this potentially high efficiency, low-cost process.

The comparison of quantum efficiency of the hybrid device with conventional diffused junction solar cells (Fig2) shows that the front response of this device is significantly better than the diffused junction Al-BSF solar cells.

Abhishek Iyer and Robert Opila
University of Delaware

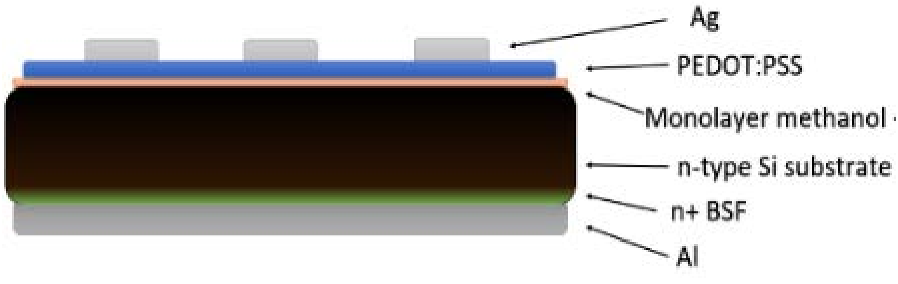


Fig1.Schematic device structure of a silicon-organic heterojunction solar cell with an inversion layer induced by organic passivants, using PEDOT:PSS as the hole-transfer layer

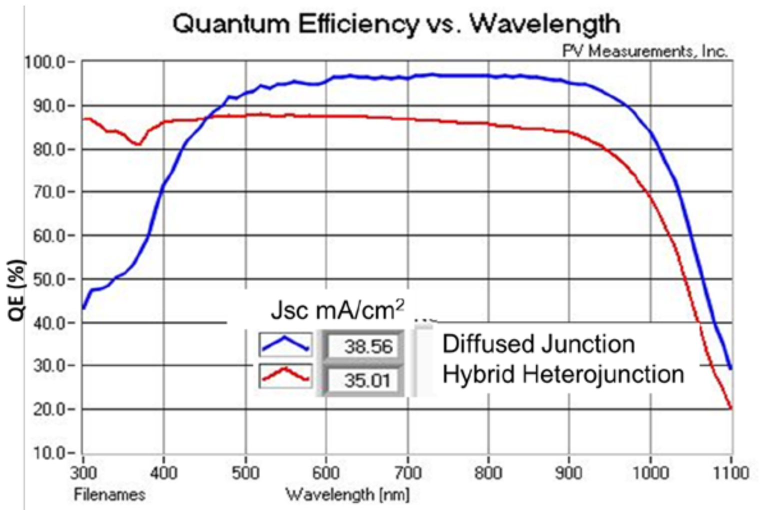
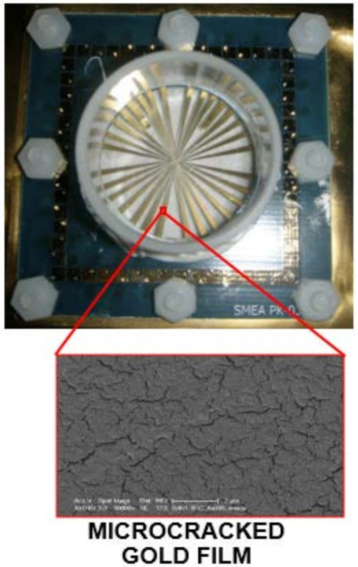


Fig2.Quantum Efficiency comparisons of hybrid cell compared with conventional diffused junction cell, hybrid cell showing high power conversion at low wavelengths.

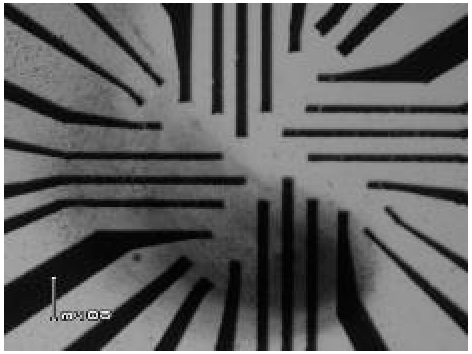
Stretchable Microelectrode Array (sMEA)

BMSEED has developed a reliable, cost-effective process to produce stretchable microelectrode arrays (sMEAs) at quantities, quality, and reproducibility suitable for commercial operation. The sMEAs are incorporated into BMSEED'S **M**icro**E**lectrode **A**rray **S**tretching **S**timulating **u**nd **R**ecording **E**quipment (**MEASSuRE**), which reproduces in vitro the mechanical and electrical environment of cells inside the body (in vivo). MEASSuRE allows the application of a controlled stretch (strain, strain rate) to a cell culture while simultaneously recording and/or stimulating electrophysiological activity. This capability is enabled by incorporating BMSEED's proprietary elastically stretchable microelectrodes. In addition, the cells can be optically imaged to verify the strain on the cells, and to detect morphological changes. Applications for MEASSuRE are tissue engineering, neurotrauma research, and improving the efficiency of pre-clinical drug testing.

Oliver Graudejus, BMSEED LLC, Tempe, AZ



Stretchable Microelectrode array and scanning electron microscope image of the surface of the gold film



Hippocampal tissue slice on sMEA during recording of neural activity

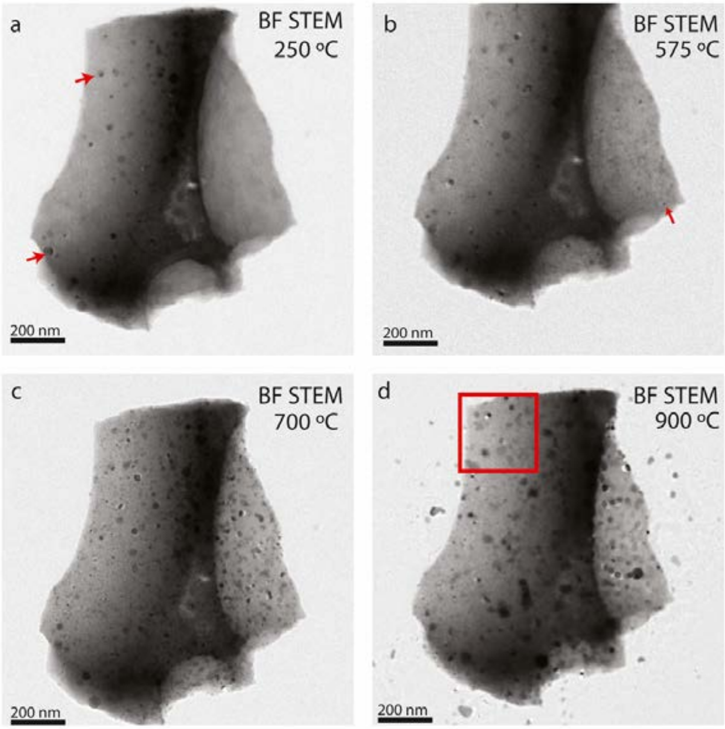
National Nanotechnology Coordinated Infrastructure

NCI Southwest

In situ experimental formation and growth of Fe nanoparticles and vesicles in lunar soil

Slow- and rapid-heating experiments were preformed inside the transmission electron microscope to understand the chemical and microstructural changes in surface soils resulting from space-weathering processes. Slow-heating experiments show that the formation of Fe nanoparticles begins at ~575^{0}C.

Electron energy loss spectroscopy measurements indicate the Fe nanoparticles are composed entirely of Fe_0, suggesting this simulation accurately mimics micrometeorite space-weathering processes occurring on airless body surfaces.



TEM images of a soil grain with Fe nanoparticles that was slow heated.

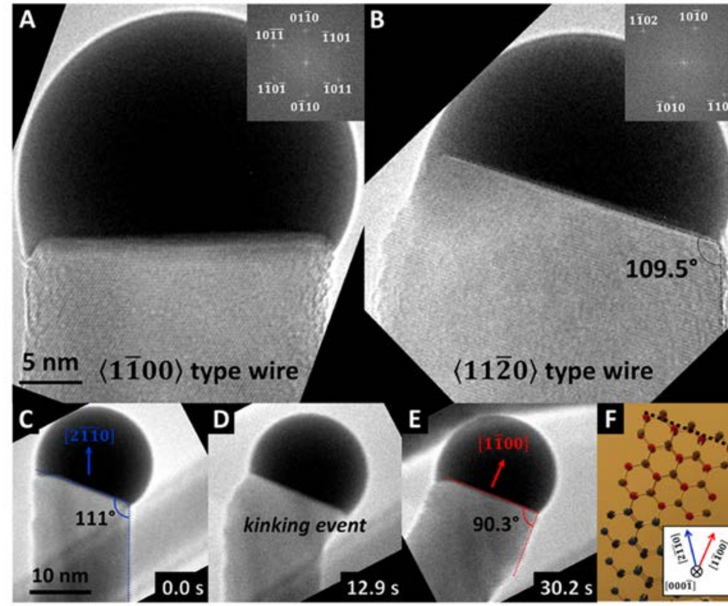
M. S. Thompson, T. J. Zega, University of Arizona
Jane Y. Howe, University of Toronto

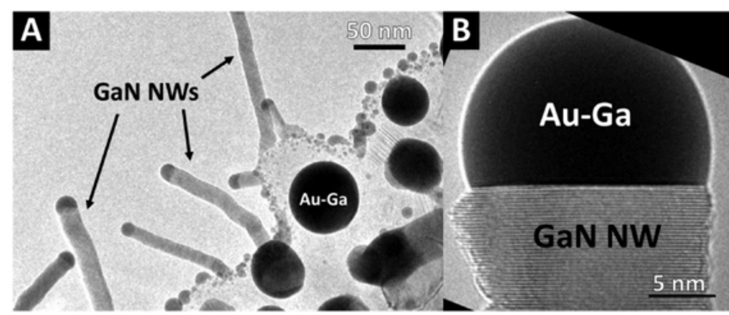
Atomic Resolution in Situ Imaging of a Double-Bilayer Multistep Growth Mode in Gallium Nitride Nanowires

GaN nanowires were grown from liquid Au−Ga catalysts using environmental transmission electron microscopy. They grow in either $\langle 11\bar{2}0\rangle$ or $\langle 1\bar{1}00\rangle$ directions, by the addition of $\{1\bar{1}00\}$ double bilayers via step flow with multiple steps.

Step-train growth is suggested to result from low step mobility.

A. D. Gamalski and E. A. Stach,
Brookhaven National Laboratory, NY
J. Tersoff, IBM Research Division,
T. J. Watson Research Center, NY





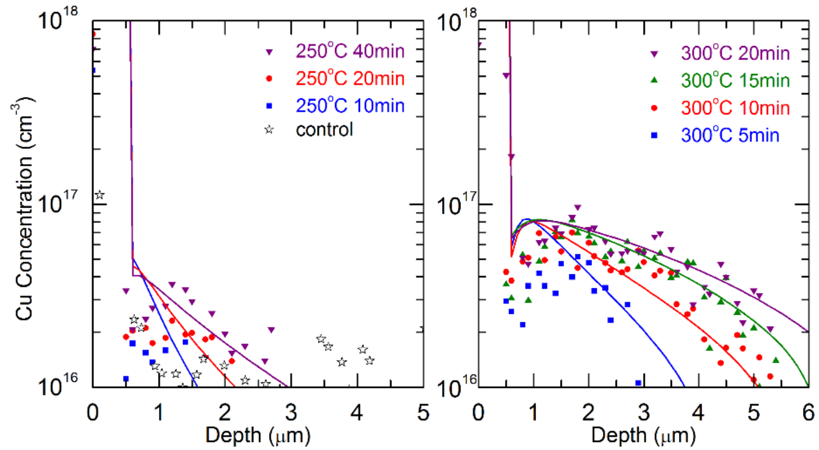
Environmental TEM images of GaN nanowires growing in situ from Au-Ga liquid.

National Nanotechnology Coordinated Infrastructure

NCI Southwest

Modeling the Diffusion of Copper in Thin Film CdTe Solar Cells

CdTe solar cells that are doped with copper display metastable phenomena characterized by temperature-dependent time constants (activation energies). The origin of the metastabilities and associated reliability issues is the presence of native or foreign point defects. Understanding the fundamentals behind the performance and metastability of CdTe solar cells requires a model that captures the most relevant processes at the lowest level specific to CdTe system. An experimental study of Cu migration in single crystal CdTe was completed at First Solar Inc. In this experiment, a thin Cu-containing ZnTe layer was deposited on CdTe substrates. Diffusion anneals were performed at 250^{0}C, 300^{0}C and 350^{0}C for four different durations at each temperature. Simulations of the copper diffusion confirm that most of Cu species are engaged in neutral donor-acceptor pairs even at diffusion temperatures.

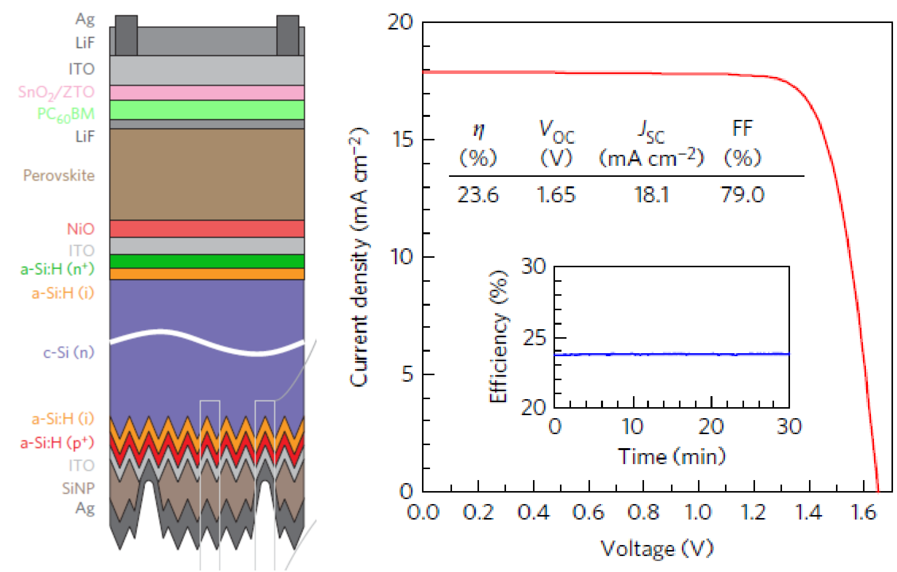


Atomic Cu profiles achieved with different annealing recipes. Black pentagrams represent the control sample without any annealing. Solid lines represent the simulated Cu profiles.

Igor Sankin, First Solar Inc.
Dragica Vasliska, ASU

Record 23.6%-efficient monolithic perovskite/silicon tandem solar cells

Layers of SnO_2 and zinc tin oxide (ZTO) have been deposited as the window layer of a combined perovskite/silicon tandem solar cell with minimal parasitic absorption, efficient electron extraction, and sufficient buffer properties to prevent the organic and perovskite layers from damage during the subsequent sputter deposition of a transparent ITO electrode. These layers, when used in an excellent mixed-cation perovskite solar cell atop a silicon heterojunction solar cell tuned to the infrared spectrum, enable highly efficient perovskite/silicon tandem solar cells with enhanced thermal and environmental stability. The J-V characteristic of the champion tandem cell, certified at NREL, with an open-circuit voltage of 1.65V and short-circuit current density of 18.1 $mA.cm^{-2}$ demonstrates a record-breaking efficiency of 23.6%.



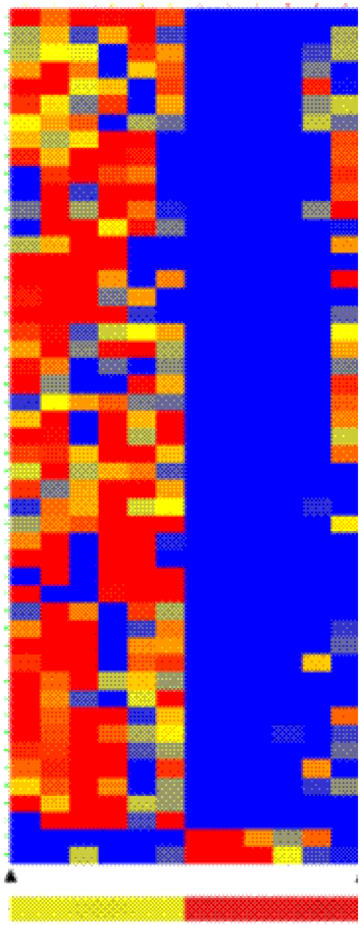
Atomic Cu profiles achieved with different annealing recipes. Black pentagrams represent the control sample without any annealing. Solid lines represent the simulated Cu profiles.

M.D. McGehee, Stanford University
Z. Holman, School of Electrical, Computer and Energy Engineering ASU

A Blood Test Capable of Discriminating Between Real Strokes and Mimics

Stroke diagnosis can be difficult since many non-vascular medical and neurological problems can mimic stroke symptoms. This study demonstrates the first application of an antibody-profiling platform called immunosignaturing to the study of ischemic stroke and its imitators

Plasma samples from 12 patients brought to the emergency room because of a stroke code were analyzed. Six were diagnosed with acute ischemic stroke and six with seizures mimicking a stroke. 12 samples from healthy volunteers were used as controls. Immuno-signatures use microarrays random sequence peptides, which behave as antibody mimotopes. Antibody binding to microarray peptides is detected with secondary antibodies labeled with fluorescent dyes, then scanned with a laser. Resulting profiles are unique to each individual. Analysis of signature profiles revealed striking separation between stroke and seizure cases.



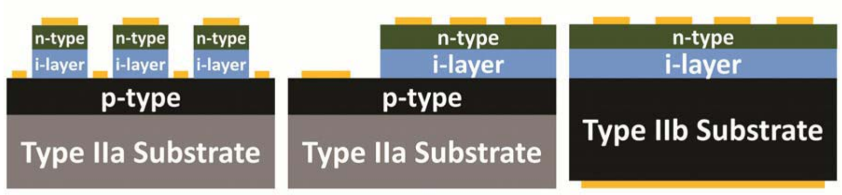
A heatmap comparing the stroke (yellow bar underneath) and seizure patients. Peptides with QADAP or QADLP motifs helped differentiate the groups.

L. Restrepo, A Sheth, J Saver Dept. of Neurology, UCLA Medical Center
P. Stafford, S A Johnston, Biodesign Institute, ASU

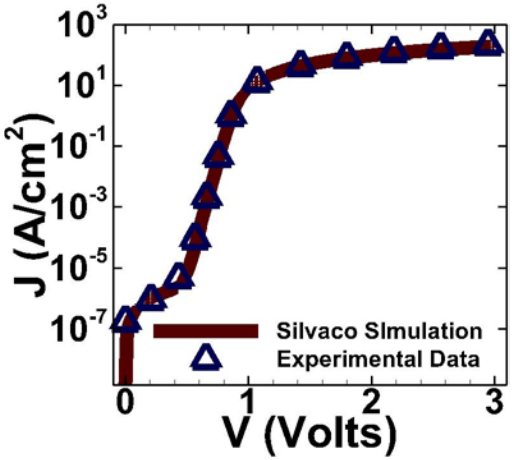
Demonstration of Diamond-Based Schottky p-i-n Diode With Blocking Voltage > 500 V

Diamond is considered to be the ultimate semiconductor for power devices due to its high breakdown electric field, high carrier mobility, and superior thermal properties. The success of diamond-based electronic devices has been difficult due to critical challenges involved with poor doping efficiency and achievement of ohmic contacts. Achieving n-type diamond has proved to be more difficult over p-type so far. In this letter, we report the achievement of n-type doping in diamond, verified using Hall measurements, which was then used to fabricate Schottky p-i-n diodes measuring a forward current density greater than 300 A/cm2 at 4 V and breakdown voltage of over 500 V with a 3.5-μm-thick drift layer. A numerical simulation was performed which agreed well with the experimental data showing turn-on voltage of 1 V and an ideality factor of 1.04, consistent with the model of a p-i-n diode with a fully depleted n-type contact.

Robert J. Nemanich, Dept. of Physics , ASU
Srabanti Chowdhury, University of California at Davis



Schematic representation of (a) conventional mesa etch (b) edge contact (c) back contact diode structures.



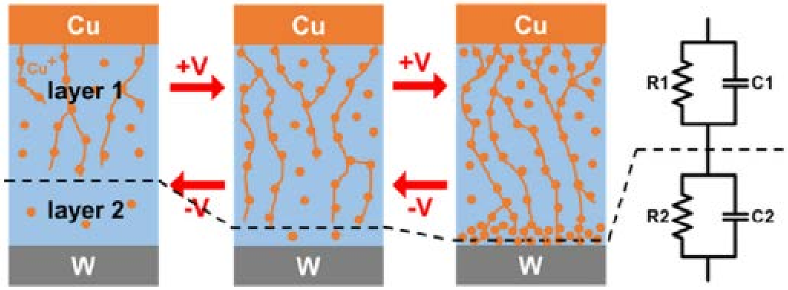
Comparison plot between a numerical simulation of a PIN diode with fully depleted n-layer and the corresponding experimental data.

National Nanotechnology Coordinated Infrastructure

NCI Southwest

A CMOS-compatible electronic synapse based on programmable metallization cells

The resistance plasticity of Cu/SiO2/W programmable metallization cell (PMC) devices is experimentally explored for the emulation of biological synapses. PMC devices were fabricated with foundry friendly materials using standard processes using the ASU NanoFab. The resistance of the PMCs can be continuously increased or decreased with both DC and voltage pulse programming. Impedance spectroscopy results indicate that the gradual change of resistance is attributable to the expansion or contraction of a Cu-rich layer within the device. Pulse programming experiments further show that the pulse amplitude plays a more important role in resistance change than pulse width, which is consistent with the proposed 'dual-layer' device model. The dense resistance-state distribution, 1 V operating voltage and inherent CMOS-compatibility suggests its potential application as an electronic synapse in neuromorphic computing



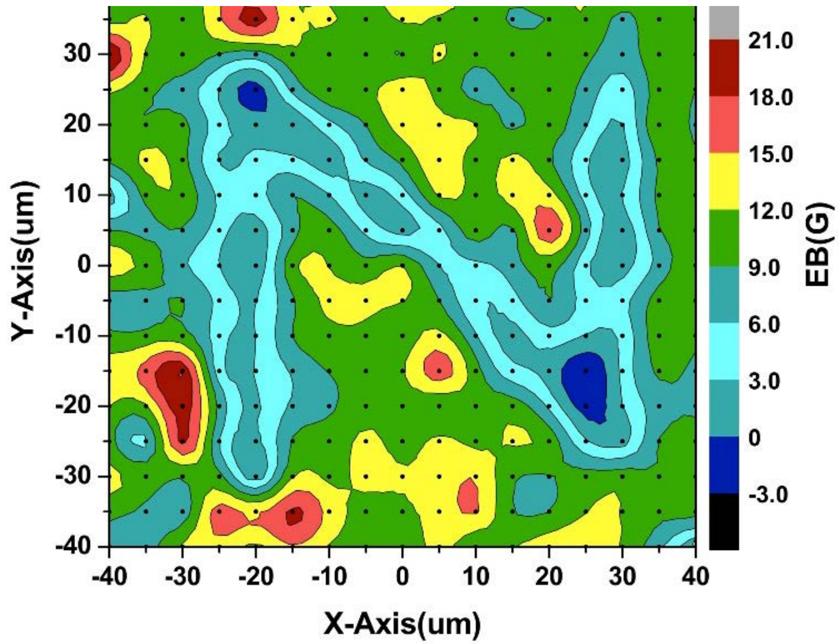
An illustration of the mechanism of analog behavior in a Cu–SiO2 PMC
.

Michael Kozicki and Hugh Barnaby,
School of Electrical, Computer and Energy Engineering, ASU

Nebraska Nanoscale Facility (NNF)

Local Writing of Exchange-Biased Domains

The objective of this work is to demonstrate the capability of local writing and reading of magnetic states. The figure displays the Nebraska N written in terms of a local exchange bias effect using a bilayer of antiferromagnetic (AFM) chromia and a thin film of ferromagnetic CoPd. Similar to the methodology of heat assisted magnetic recording (HAMR), local heating has been utilized to write an AFM domain in Cr_2O_3. The orientation of the selected AFM order parameter determines the orientation of the AFM interface magnetization which in turn determines the sign of the exchange bias field. Reading of exchange bias, i.e., the shift of the ferromagnetic hysteresis loop along the magnetic field axis, takes place magnetooptically. Resolution of this technique is determined by the Gaussian laser profile. The work has been published in *Adv. Funct. Mater.* **26**, 7470 (2016).



Magnetooptical map of local exchange bias written in a chromia/CoPd exchange bias heterostructure via local laser heating.

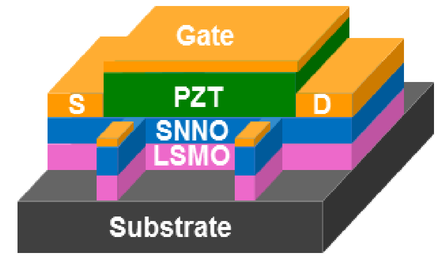
Uday Singh, W. Echtenkamp, M. Street, Ch. Binek, and S. Adenwalla, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

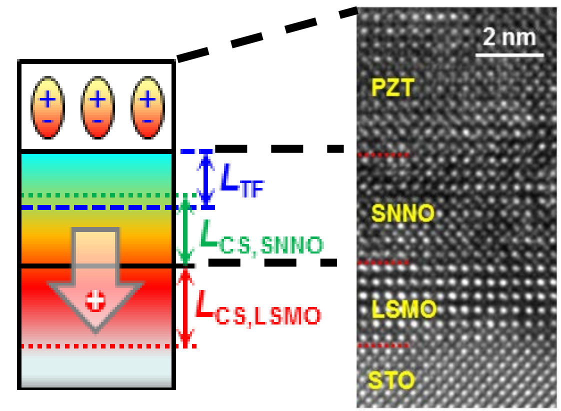
National Nanotechnology Coordinated Infrastructure

Nebraska Nanoscale Facility

Interfacial Charge Engineering for Ferroelectric Control of Mott Transistors

The objective of this work is to engineer complex oxide interfaces for enhancement of the ferroelectric (FE) field effect in a prototype Mott field-effect transistor. By switching the polarization field of a FE PZT gate, nonvolatile resistance modulation is induced. The device concept has been investigated over the last two decades for examining charge density-driven quantum phase transitions and interfacial magnetoelectric coupling. It also has promising application potential in nonvolatile memory and logic. However, the intrinsically high charge carrier density of the Mott channel makes it challenging to achieve substantial field effect modulation at room temperature. Here a PZT gated Mott transistors based on a couple of nmr-thick $Sm_{0.5}Nd_{0.5}NiO_3$ (SNNO) and $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) composite channels is fabricated. It employs the charge transfer effect at the SNNO/LSMO interface to engineer the carrier density profile in the channel. It leads to up to two orders of magnitude enhancement in the room temperature resistance switching ratio. This study shows how tailored electronic states can be achieved through atomistic design of complex oxide interfaces. The work has been published in *Adv. Funct. Mater.* **29**, 1701385 (2017).





PZT-gated ferroelectric FET (top) with the key innovation of an engineered complex oxide heterostructure (bottom) for enhanced ferroelectric field control.

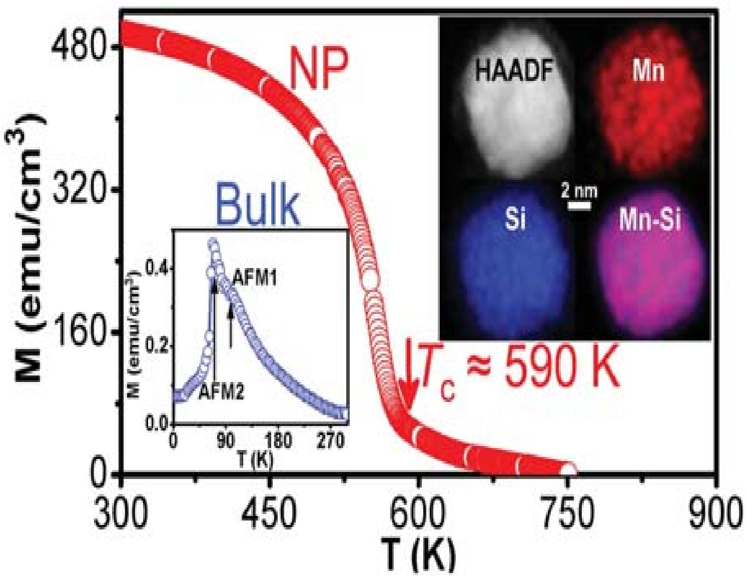
X. Chen, X. Zhang, M.A. Koten, H. Chen, Z. Xiao, L. Zhang, J.E. Shield, P.A. Dowben, X. Hong, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

National Nanotechnology Coordinated Infrastructure

Nebraska Nanoscale Facility

Mn_5Si_3 Nanoparticles: Synthesis and Size-Induced Ferromagnetism

Mn-based silicides are fascinating due to their exotic spin textures and unique crystal structures, but the low magnetic ordering temperatures and/or small magnetic moments of bulk alloys are major impediments to their use in practical applications. Synthesis of Mn_5Si_3 nanoparticles and size-induced ferro-magnetism has been discovered. In sharp contrast to bulk Mn_5Si_3, which is paramagnetic at room temperature and exhibits low-temperature antiferromagnetic ordering, we show ferromagnetic ordering in Mn_5Si_3 nanoparticles with a high Curie temperature ($T_c \approx$ 590 K). Low-temperature antiferromagnetism in the bulk was converted into high-temperature ferromagnetism (T_c = 590 K) by low-dimensional and quantum-confinement effects, evident from first-principle density-functional theory calculations. The work has been published in *Nano Letters* **16**, 1132 (2016).

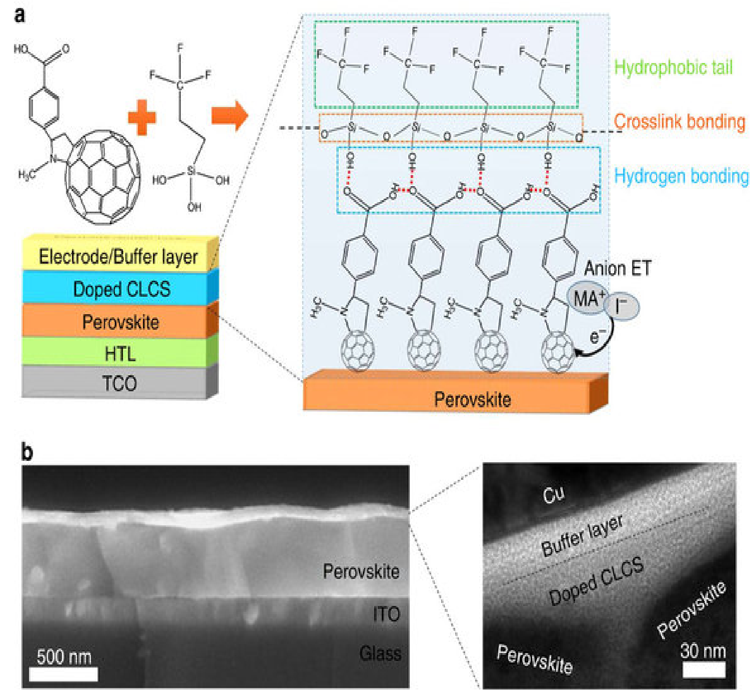


M(T) in bulk and nanoparticle (NP) Mn_5Si_3, and TEM (inset).

B. Das, B. Balasubramanian, P. Manchanda, P. Mukherjee, R. Skomski, G. C. Hadjipanayis, D. Sellmyer, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

Enhancing Stability and Efficiency of Perovskite Solar Cells with Crosslinkable Silane-Functionalized and Doped Fullerene

Nebraska researchers have used NNF to develop a strategy to overcome the water and moisture related stability issues of high efficiency perovskite solar cells. Water-resistant silane molecules with hydrophobic groups were attached to fullerene thereby making it highly water-resistant and resulted in enhanced stability of p–i–n planar heterojunction-structure perovskite devices. With crosslinkable silane-functionalized and doped fullerene electron transport layer, the perovskite devices delivered an efficiency of 19.5% with a high fill factor of 80.6%. The crosslinked silane-modified fullerene layer enhanced the water and moisture stability of the non-sealed perovskite devices by retaining nearly 90% of their original efficiencies after 30 days' exposure in an ambient environment. This work has been published in *Nature Communications* **7**, 12806 (2016).

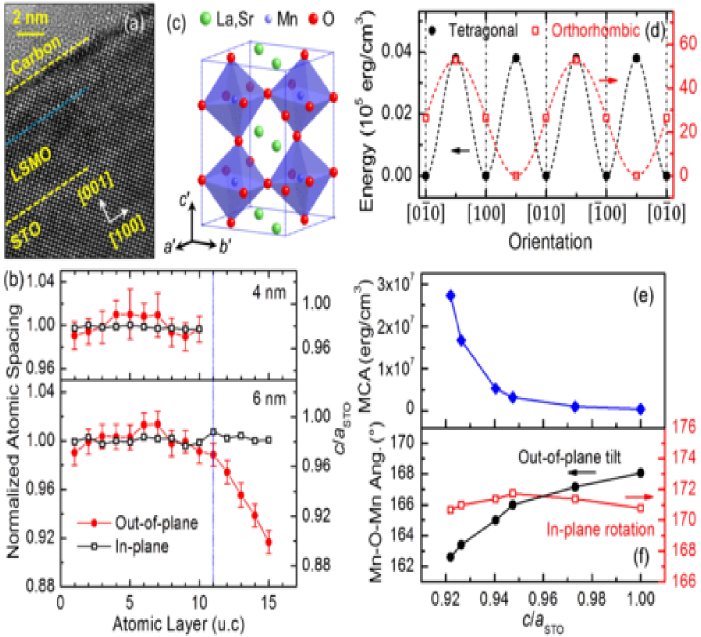


Schematics of perovskite solar cell and cross section images.

Y. Bai, Q. Dong, Y. Shao, Y. Deng, Q. Wang, L. Shen, D. Wang, W. Wei and J. Huang, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

Giant Enhancement of Magnetic Anisotropy in Ultrathin Manganite Films via Nanoscale 1D Periodic Depth Modulation

A group in the Nebraska MRSEC has used NNF to study an unusual, giant enhancement of in-plane magnetocrytalline anisotropy (MCA) in 6 nm $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) films grown on $SrTiO_3$ substrates when the top 2 nm is patterned into periodic stripes of 100 or 200 nm width. Planar Hall effect measurements reveal an emergent uniaxial anisotropy superimposed on one of the original biaxial easy axes for unpatterned LSMO along ⟨110⟩ directions, with a 50-fold enhanced anisotropy energy density of 5.6 × 106 erg/cm3 within the nanostripes, comparable to the value for cobalt. HRTEM studies revealed a nonequilibrium strain distribution and drastic suppression in the c-axis lattice constant within the nanostructures, which is the driving mechanism for the enhanced uniaxial MCA, as suggested by first-principles density functional calculations. This work has been published in *Phys. Rev. Lett.* **116**, 187201 (2016).



a) HRTEM of LSMO, b) Normalized atomic spacing and the corresponding c/a_{STO} ratio, c) Schematic view of the orthorhombic LSMO unit cell, d) calculated magnetic energy, e) calculated MCA, f) MnO_6 tilt and rotation angles for LSMO as a function of c/a_{STO}.

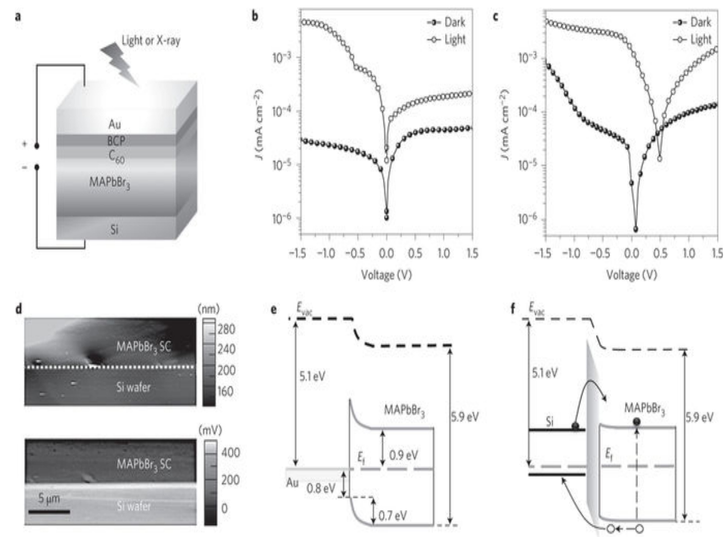
A. Rajapitamahuni, L. Zhang, M. A. Koten, V. R. Singh, J. D. Burton, E. Y. Tsymbal, J. E. Shield, and X. Hong, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

National Nanotechnology Coordinated Infrastructure

Nebraska Nanoscale Facility

Monolithic Integration of Hybrid Perovskite Single Crystals with Heterogenous Substrate for Highly Sensitive X-ray Imaging

The monolithic integration of new optoelectronic materials with well-established inexpensive silicon circuitry is leading to new applications, functionality and simple readouts. This work has shown that single crystals of hybrid perovskites can be integrated onto virtually any substrate, including silicon wafers, through facile, low-temperature, solution-processed molecular bonding. The brominated (3-aminopropyl) triethoxysilane molecule binds the native oxide of silicon and participates in the perovskite crystal with its ammonium bromide group, yielding a solid mechanical and electrical connection. The dipole of the bonding molecule reduces device noise while retaining signal intensity. The reduction of dark current enables the detectors to be operated at increased bias, resulting in a sensitivity of 2.1 × 10^4 μC Gy_{air}^{-1} cm^{-2} under 8 keV X-ray radiation, which is over a thousand times higher than the sensitivity of amorphous selenium detectors. X-ray imaging with both perovskite pixel detectors and linear array detectors reduces the total dose by 15–120-fold compared with state-of-the-art X-ray imaging systems. This work has been published in *Nature Photonics* **11**, 315 (2017).



Properties of the interfacial connection in the Si-integrated $MAPbBr_3$ single crystal device

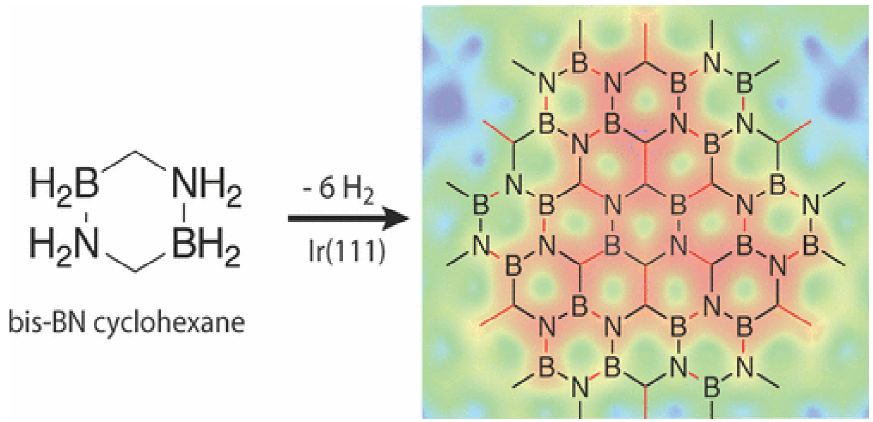
W. Wei, Y. Zhang, Q. Xu, H. Wei, Y. Fang, Q. Wang, Y. Deng, T. Li, A. Gruverman, L. Cao, and J. Huang, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

National Nanotechnology Coordinated Infrastructure

Nebraska Nanoscale Facility

Graphene-like Boron–Carbon–Nitrogen Monolayers

A new 2D material, monolayer hexagonal boron-carbon-nitrogen (h-BCN), with potential for developments in ultrathin technologies, has been developed. The synthesis utilizes bis-BN cyclohexane, $B_2N_2C_2H_{12}$, as a precursor molecule and relies on thermally induced dehydrogenation of the precursor molecules and the formation of an epitaxial monolayer on Ir(111) through covalent bond formation. The lattice mismatch between the film and substrate causes a strain-driven periodic buckling of the film. The structure of the film and its corrugated morphology is discussed based on comprehensive data from molecular-resolved scanning tunneling microscopy imaging, X-ray photoelectron spectroscopy, low-energy electron diffraction, and density-functional theory. First-principles calculations further predict a direct electronic band gap that is intermediate between gapless graphene and insulating *h*-BN. This work has been published in *ACS Nano* **11**, 2486 (2017).

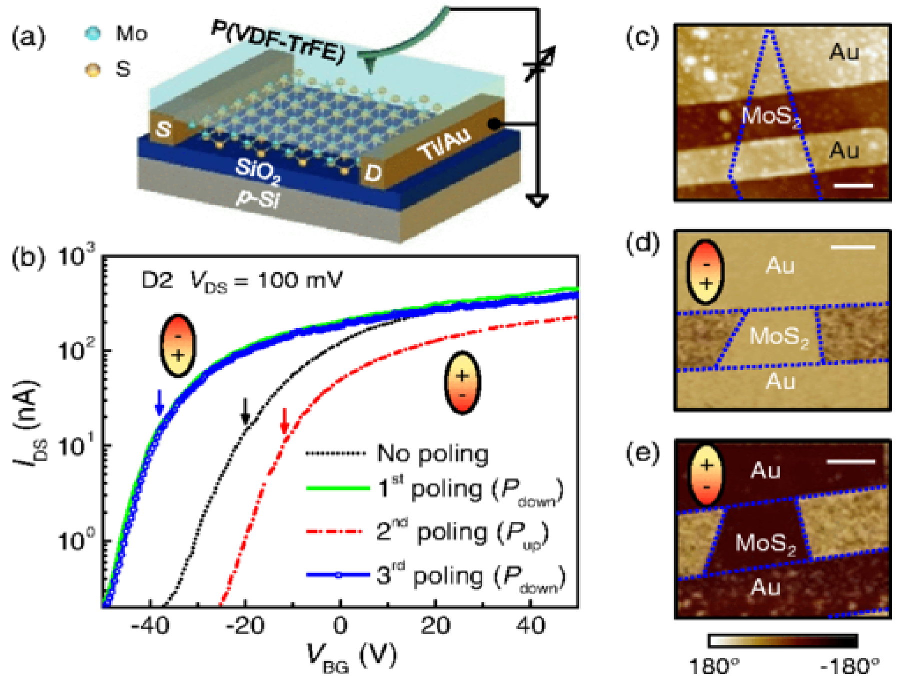


Thermally induced dehydrogenation of the precursor molecule bis-BN cyclohexane for the formation of h-BCN monolayer.

S. Beniwal, J. Hooper, D. P. Miller, P. S. Costa, G. Chen, S. Y. Liu, P. A. Dowben, E. C. H. Sykes, E. Zurek, and A. Enders, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

Ferroelectric-Domain-Patterning-Controlled Schottky Junction State in Monolayer MoS2

Scanning-probe-controlled domain patterning in a ferroelectric top layer has been exploited to induce nonvolatile modulation of the conduction characteristic of monolayer MoS2 between a transistor and a junction state. In the presence of a domain wall, MoS2 exhibits rectified I−V characteristics that are well described by the thermionic emission model. The induced Schottky barrier height ΦeffB varies from 0.38 to 0.57 eV and is tunable by a SiO2 global back gate, while the tuning range of ΦeffB depends sensitively on the conduction-band-tail trapping states. Our work points to a new route to achieving programmable functionalities in van der Waals materials and sheds light on the critical performance limiting factors in these hybrid system This work has been published in *Phys. Rev. Lett.* **118**, 236801 (2017).

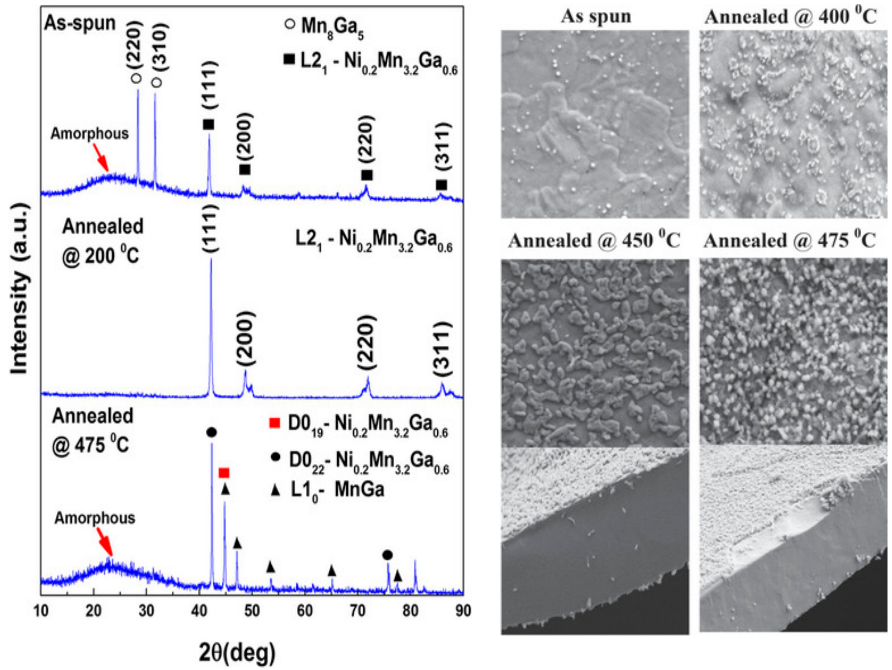


(a) Device schematic. (b) Room-temperature transfer characteristics for sample D2 in the initial no poling state, and after writing P(VDF-TrFE) with +10 V (1st poling), −10 V (2nd poling), and +10 V (3rd poling) tip bias. The arrows mark the corresponding Vt's. (c) The AFM image of the sample and the PFM phase images after (d) the 1st and (e) 2nd poling.

Z. Xiao, J. Song, D. K. Ferry, S. Ducharme, and X. Hong, Nebraska Center for Materials and Nanoscience, University of Nebraska. Work performed in part at Nebraska Nanoscale Facility.

Controlling the Microstructure and Associated Magnetic Properties of $Ni_{0.2}Mn_{3.2}Ga_{0.6}$ Melt-Spun Ribbons by Annealing

The structural and magnetic properties of $Ni_{0.2}Mn_{3.2}Ga_{0.6}$ melt-spun ribbons were investigated by researchers from Miami University, Ohio. The as-spun ribbons were found to exhibit mixed cubic phases that transform to non-cubic structure upon annealing. Additionally, an amorphous phase was found to co-exist in all ribbons. The formation of extensive nano-grains was observed on the surfaces of the annealed ribbons. While the as-spun ribbons exhibit predominantly paramagnetic behavior, the ribbons annealed under various thermal conditions were found to be ferromagnetic with a Curie temperature of about 380 K. The ribbons annealed at 450 ° C for 30 minutes exhibit a large coercive field of about 2500 Oe. The experimental results show that the microstructure and associated magnetic properties of the ribbons can be controlled by annealing techniques. This work has been published in *AIP Advances* **7**, 056230 (2017).

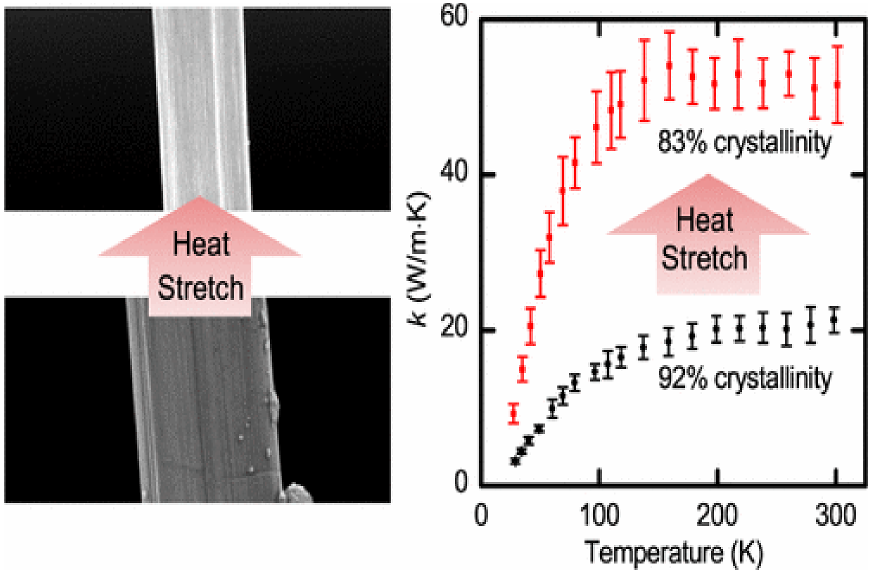


Room temperature XRD patterns of selected $Ni_{0.2}Mn_{3.2}Ga_{0.6}$ ribbons annealed at various temperatures and SEM micrographs of selected $Ni_{0.2}Mn_{3.2}Ga_{0.6}$ ribbons annealed at various temperatures.

M. Khan, O. Alshammari, B. Balasubramanian, B. Das, D. J. Sellmyer, A. U. Saleheen and S. Stadler, Department of Physics, Miami University, Ohio. Work performed in part at Nebraska Nanoscale Facility.

Novel Polyethylene Fibers of Very High Thermal Conductivity Enabled by Amorphous Restructuring

High-thermal-conductivity polymers are very sought after for applications in various thermal management systems. Researchers from Iowa State University observed a significant *k* enhancement by heat-stretching a highly crystalline microfiber. More interestingly, it coincides with a reduction in crystallinity. The sample is a Spectra S-900 ultrahigh-molecular-weight polyethylene (UHMW-PE) microfiber of 92% crystallinity and high degree of orientation. The optimum stretching condition is 131.5 ° C, with a strain rate of 0.0129 s^{-1} to a low strain ratio (~6.6) followed by air quenching. The *k* enhancement is from 21 to 51 W/(m·K), the highest value for UHMW-PE microfibers reported to date. X-ray diffraction study finds that the crystallinity reduces to 83% after stretching, whereas the crystallite size and crystallite orientation are not changed. Polarization Raman spectroscopy finds enhanced alignment of amorphous chains, which could be the main reason for the *k* enhancement. This work has been published in *ACS Omega* **2**, 3931 (2017).



SEM images of microfibers and increase in k due to heat stretch.

B. Zhu, J. Liu, T. Wang, M. Han, S. Valloppilly, S. Xu, and X. Wang, Dept. of Mech. Eng., Iowa State University, Ames, Iowa. Work performed in part at Nebraska Nanoscale Facility.

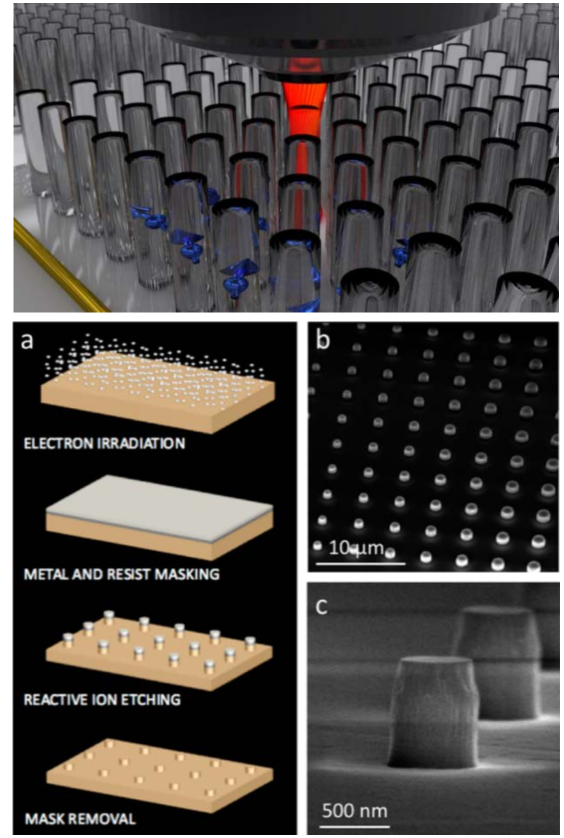
National Nanotechnology Coordinated Infrastructure

Nebraska Nanoscale Facility

NNCI Site @ Stanford (nano@stanford)

Scalable Quantum Photonics

Silicon carbide is a promising platform for single photon sources, quantum bits (qubits), and nanoscale sensors based on individual color centers. A scalable array of nanopillars incorporating single silicon vacancy centers in 4H-SiC, readily available for efficient interfacing with free-space objective and lensed-fibers was developed. The group obtained high collection efficiency of up to 22 kcounts/s optical saturation rates from a single silicon vacancy center while preserving the single photon emission and the optically induced electron-spin polarization properties.



Top: Schematic of the color center in SiC nanopillars. (a) Lithographic process for fabrication of nanopillars in 4HSiC. (b) SEM images of fabricated array of nanopillars with variable diameters. (c) SEM image of a 600 nm wide and 800 nm tall nanopillar.

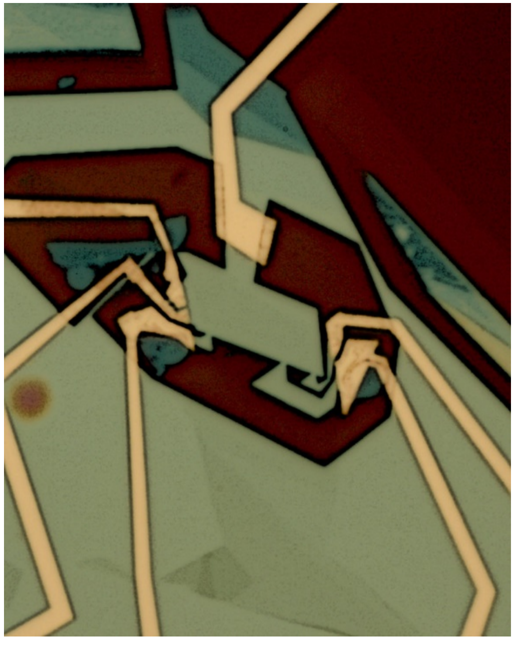
Marina Radulaski, Matthias Widmann, Matthias Niethammer, Jingyuan Linda Zhang, Sang-Yun Lee, Torsten Rendler, Konstantinos G. Lagoudakis, et al. 2017. “Scalable Quantum Photonics with Single Color Centers in Silicon Carbide.” Nano Letters 17 (3): 1782–86. doi:10.1021/acs.nanolett.6b05102.

National Nanotechnology Coordinated Infrastructure

nano@stanford

Ballistic miniband conduction in a graphene superlattice

A two-dimensional superlattice by sandwiching a sheet of atomically thin graphene in between two sheets of electrically insulating boron nitride was created. The atoms in the graphene and boron nitride have slightly different spacing, so when they are stacked on top of each other they create a special wave interference pattern called a moiré pattern. Electrons in the graphene flow along smooth paths without deflection, exactly as theory suggested would be needed to conduct terahertz signals. The researchers were able to send electrons through the graphene sheet, collect them on the other side and use them to thus infer the activity of the electrons along the way. In this moiré superlattice, researchers showed that the electrons can be confined to narrower bands of energy. Combined with very long times between deflections, this should lead the electrons to oscillate in place and emit radiation in the terahertz frequency range.

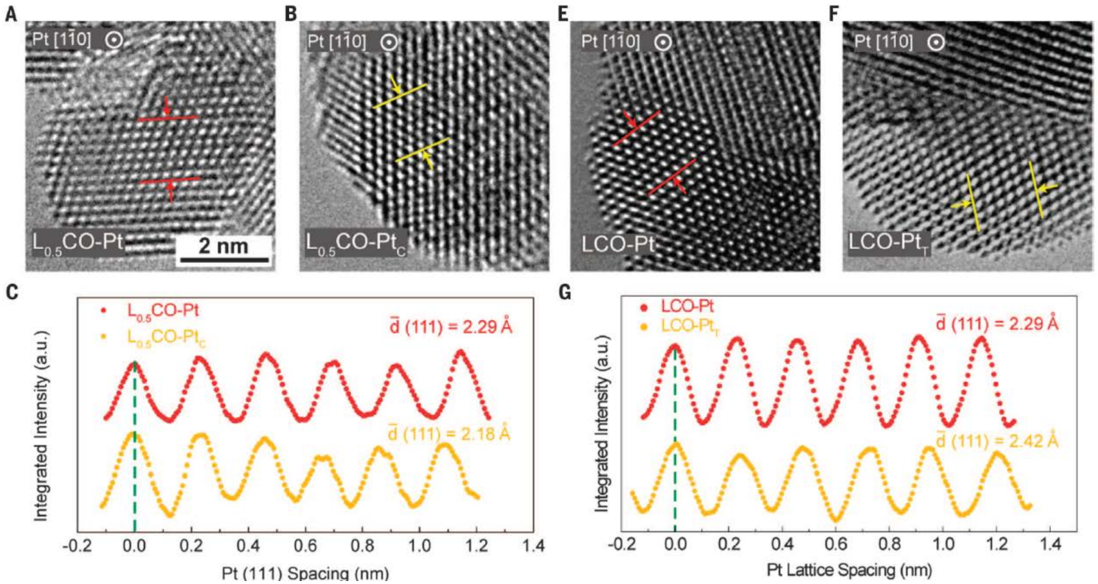


Optical image of the graphene superlattice in which Stanford researchers measured conduction behaviors. Two-dimensional material is shown in green.

Lee, Wallbank, Gallagher, Watanabe, Taniguchi, Falko, and Goldhaber-Gordon. 2016. “Ballistic Miniband Conduction in a Graphene Superlattice.” Science 353 (6307): 1526–29. doi:10.1126/science.aaf1095.

Fine-tuning of metal catalysts at the atomic scale

A method for using battery electrode materials to directly and continuously control the lattice strain of platinum (Pt) catalyst and thus tune its catalytic activity for the oxygen reduction reaction (ORR) was reported. Whereas the common approach of using metal overlayers introduces ligand effects in addition to strain, by electrochemically switching between the charging and discharging status of battery electrodes the change in volume can be precisely controlled to induce either compressive or tensile strain on supported catalysts.



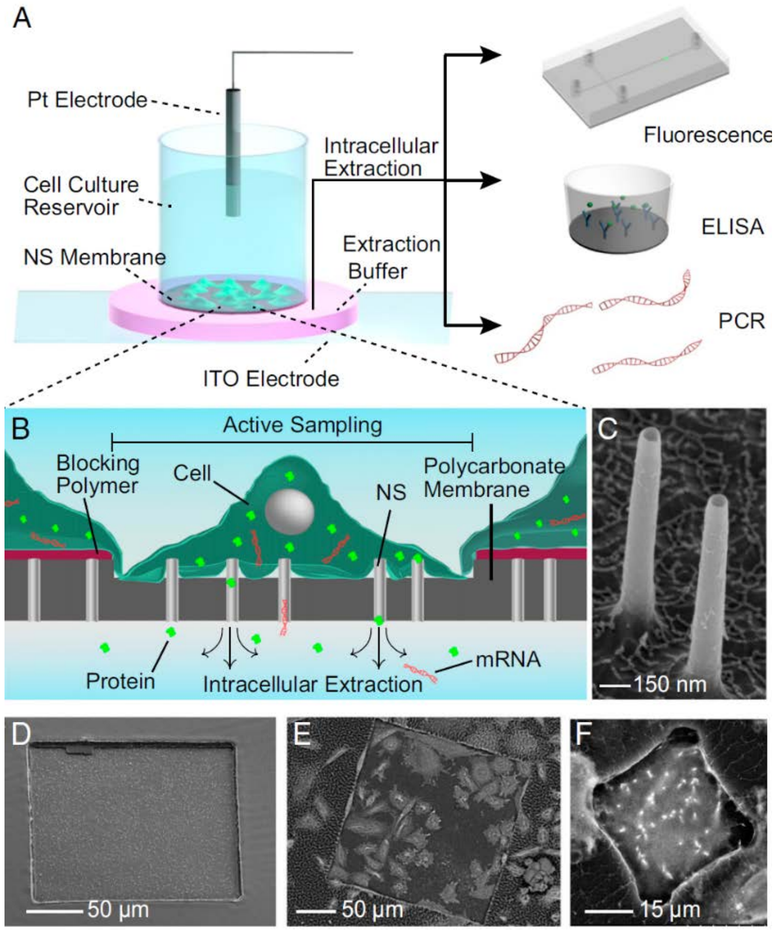
High-resolution TEM images of pristine and strained Pt NPs with (111) lattice compression and tension. TEM images of L0.5CO-Pt and L0.5CO-PtC. The red and yellow bars denote the areas we analyzed for (111) spacing. (C) The integrated pixel intensities of pristine and compressed Pt along (111) spacing directions (which is perpendicular to the facets).The peaks and valleys represent the atoms and gaps, respectively. The spacing of Pt (111) facets is averaged over six atomic layers for high accuracy .The pristine (111) is measured to be 2.29 Å, whereas the constrained (111) shows only 2.18 Å. (E and F) TEM images of LCO-Pt and LCO-PtT. (G) More than 5%tensile strain is observed with an increased (111) spacing of 2.42 Å.

Wang, Haotian, Shicheng Xu, Charlie Tsai, Yuzhang Li, Chong Liu, Jie Zhao, Yayuan Liu, et al. 2016. “Direct and Continuous Strain Control of Catalysts with Tunable Battery Electrode Materials.” Science 354 (6315): 1031–36. doi:10.1126/science.aaf7680.

Non-destructive Cell Content Analysis

Motivation: non-destructive cell content analysis

Technique: fabrication of analysis platform that can sample repeatedly and accurately from the same single cell or group of cells over a long time period; the device makes use of 150-nm diameter nanostraws (NS)



The device consists of a polymer membrane with protruding 150-nm diameter NS attached to the bottom of a cell-culture dish. (B) During sampling, intracellular species within the cell diffuse through the NS and into the extraction buffer below the membrane. The size of the sampling region can be defined lithographically so that only the cells that grow in the active regions are sampled.

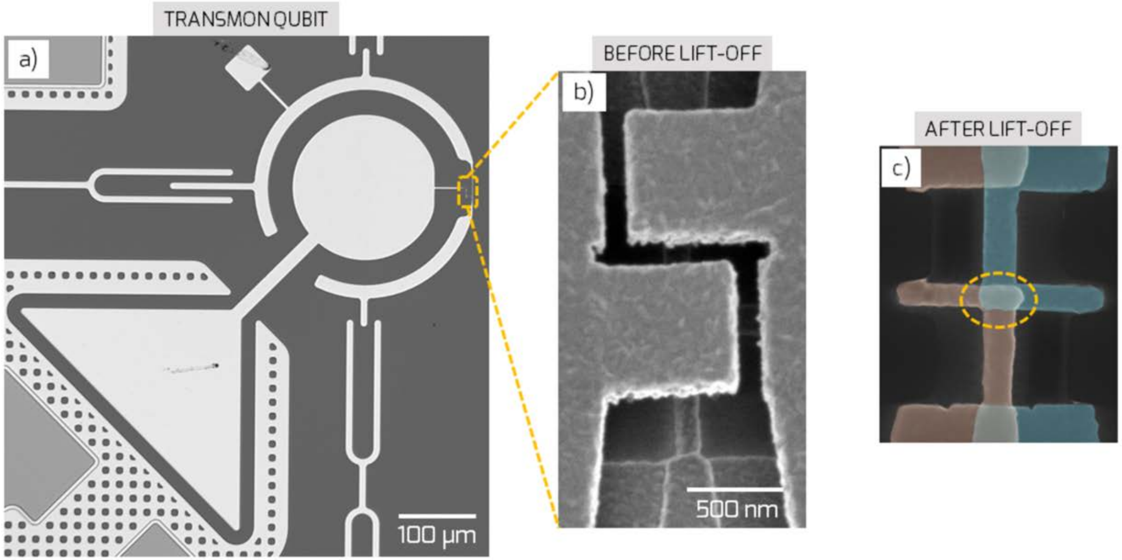
Profs. Santiago, Wu, Melosh research groups
Proceedings of the National Academy of Sciences 114 (2017)

External User: Rigetti Computing

Motivation: develop a scalable quantum computing platform for artificial intelligence and computational chemistry

Technique: fabrication of nanoscale Josephson junctions, comprised of aluminum electrodes separated by a thin insulating barrier

a) Fabricated transmon qubit. b) Bilayer e-beam resist stack after JEOL 6300FS e-beam patterning and double-angle aluminum evaporation. c) False color image of the Josephson junction at the end of the fabrication process.

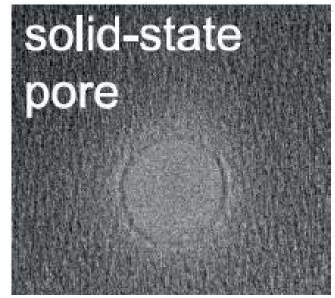


Rigetti Computing is a leading quantum computing start-up which recently raised $64M in Series A and B funding. The company was founded in 2013 and has currently about 50 employees.
http://www.rigetti.com

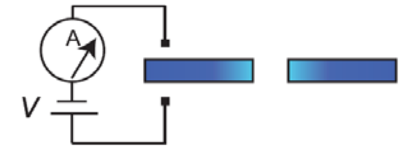
External User: Two Pore Guys

Motivation: single molecule detection platform based solid- state nanopore technology

Technique: fabrication of nanopore using e-beam lithography



Single-molecule sensing with a nanopore device.



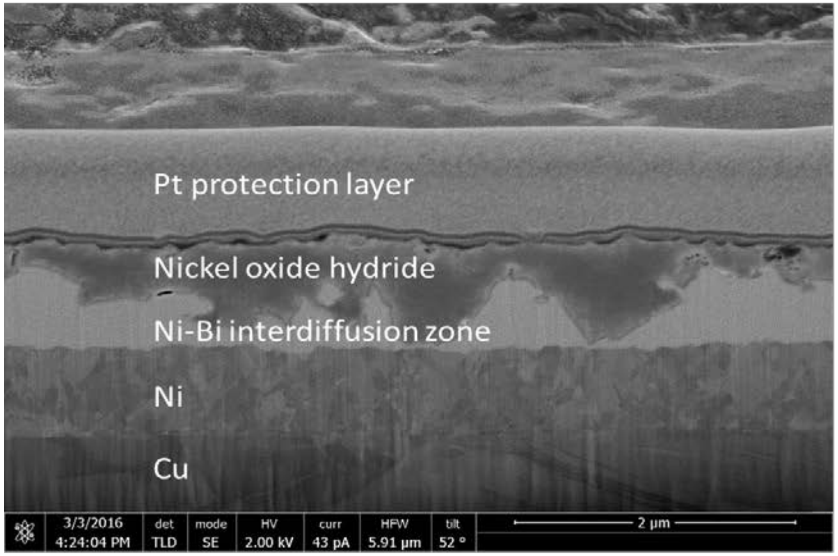
Voltage V applied across a single 27nm diameter nanopore, while measuring current through the pore

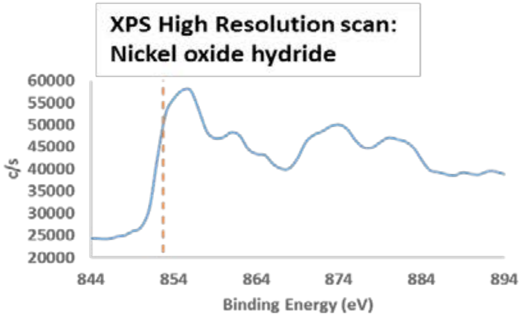
Two Pore Guys makes a digital, hand-held, testing platforms. Closed a $24.5 million Series A round in April 2017. The company was founded in 2011 and has currently about 72 employees. http://twoporeguys.com

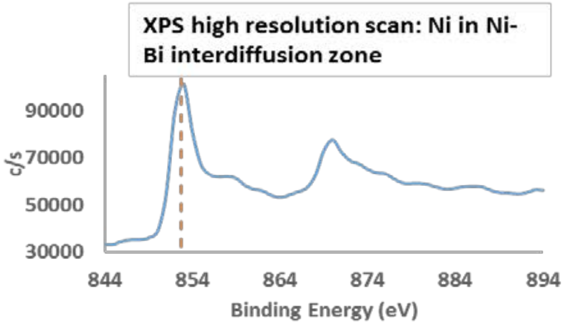
External User: TE Connectivity

Motivation: to study the failure analysis and understand the structure-process-performance relationship in materials

Technique: used Focused ion beam (FIB) and X-ray photon spectroscopy (XPS)







TE Connectivity has been a world leader in connectivity and sensors. The company was founded in 2007 and has > 10,000 employees with current revenue $12 billion.
http://www.te.com

National Nanotechnology Coordinated Infrastructure

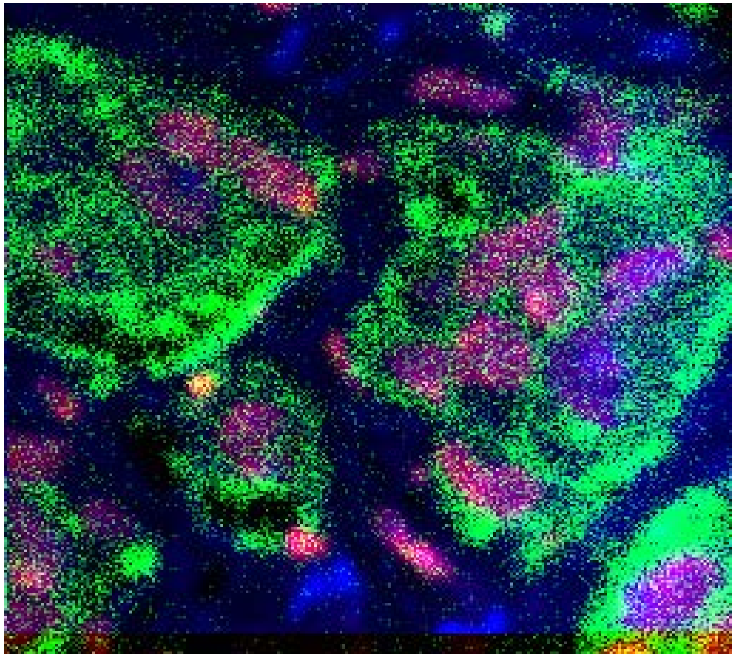
nano@stanford

External User: Genentech Pathology

Genentech
IN BUSINESS FOR LIFE

Motivation: develop technology for tissue section-based diagnostics

Technique: ion-beam imaging using NanoSIMS



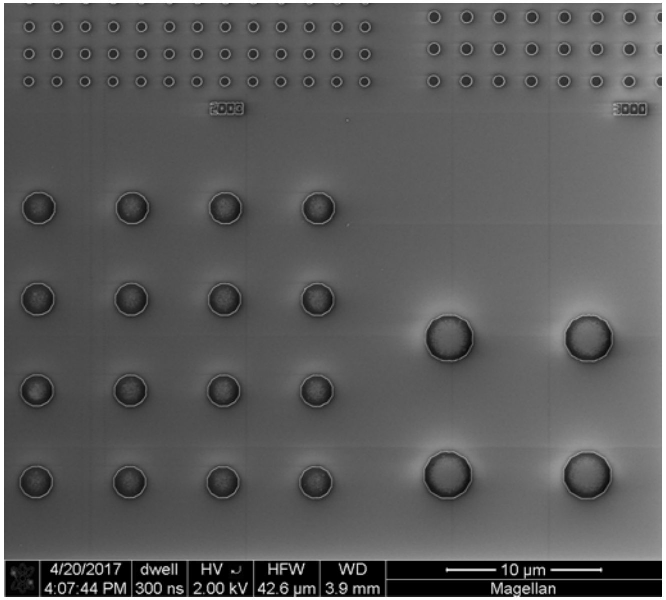
NanoSIMS image of breast cancer tissue sample.
Field of view: 100 um x 100 um

Genentech is the world's leading biotechnology company that discovers, develops, manufactures medicines to treat patients with serious or life-threatening medical conditions. The company was founded in 1976 and has ~ 14,000 employees. The company become a member of Roche Group in 2009.
https://www.gene.com

External User: UC Berkeley

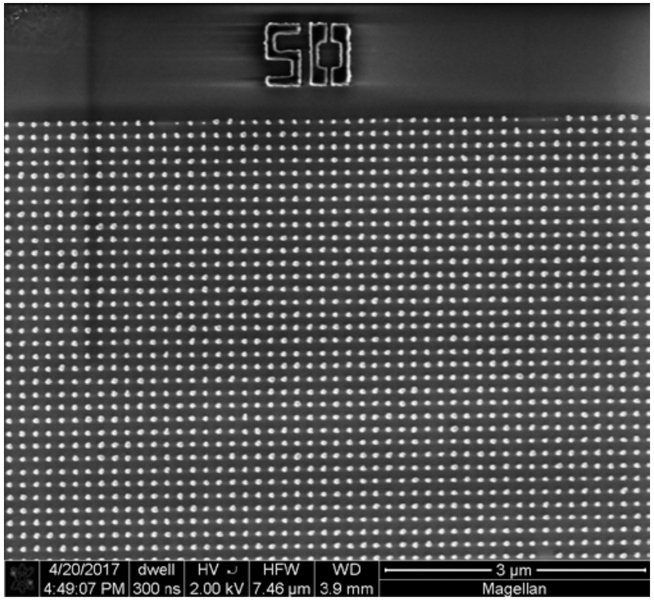
Motivation: Ultrafast electrical switching

Technique: Fabrication of magnetic nanodots



Left: Magnetic (Ta/GdFe/Co/Pt) dot sizes, ranging from 5 um down to 20 nm, were fabricated in arrays using the JEOL 6300FS e-beam lithography system.

Right: 50 nm diameter ion milled Ta (5nm)/GdFeCo (20 nm)/Pt (5 nm) dots.



Prof. Bokor's research group at UC Berkeley specializes in nanomagnetics and nanoelectronics
http://orange.eecs.berkeley.edu

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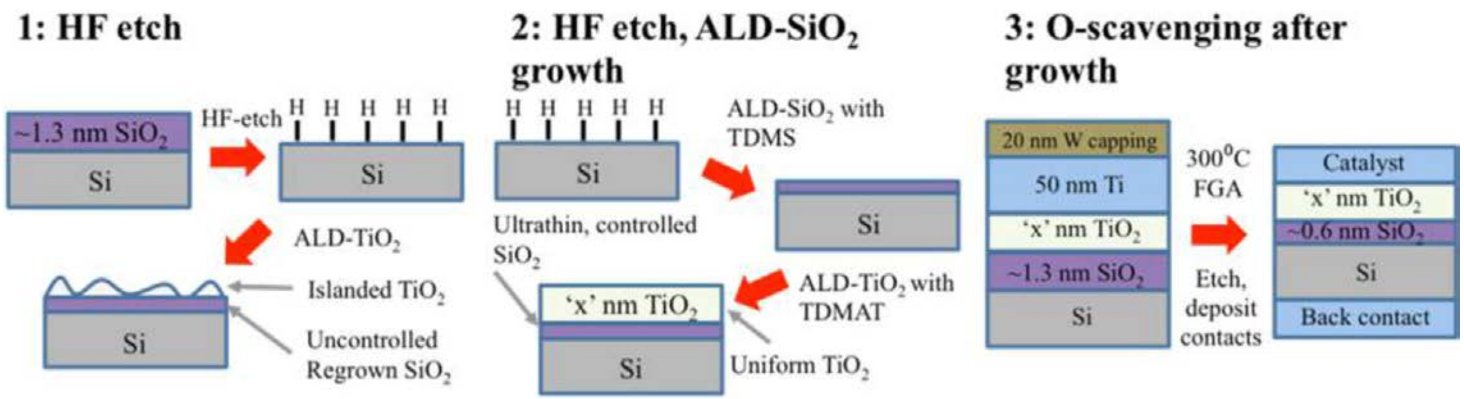
nano@stanford

Undergraduate Research

A research paper by undergraduate student Peter Satterthwaite shows the engagement and opportunities that the NNCI Site @ Stanford provides to undergraduate students. The research was conducted by Peter who authored the paper as an undergraduate student, expanding on a project he started as part of the Materials Science & Engineering REU program with Professor Paul McIntyre.

Photoelectrochemical water splitting cells have attracted research interest because of their potential to simultaneously harvest and store solar energy.



Fabrication methods. (1) Growth on an HF-last surface, resulting in regrowth of the SiO2 IL and uneven, islanded TiO2 growth. (2) SiO2 ALD using the tris(dimethylamino)silane (TDMS) precursor on an HF-last surface resulting in an ultrathin, controlled SiO2 IL after TiO2 ALD using the TDMAT precursor. (3) Titanium assisted oxygen-scavenging after-TiO2 deposition allows thinning of the SiO2 IL.

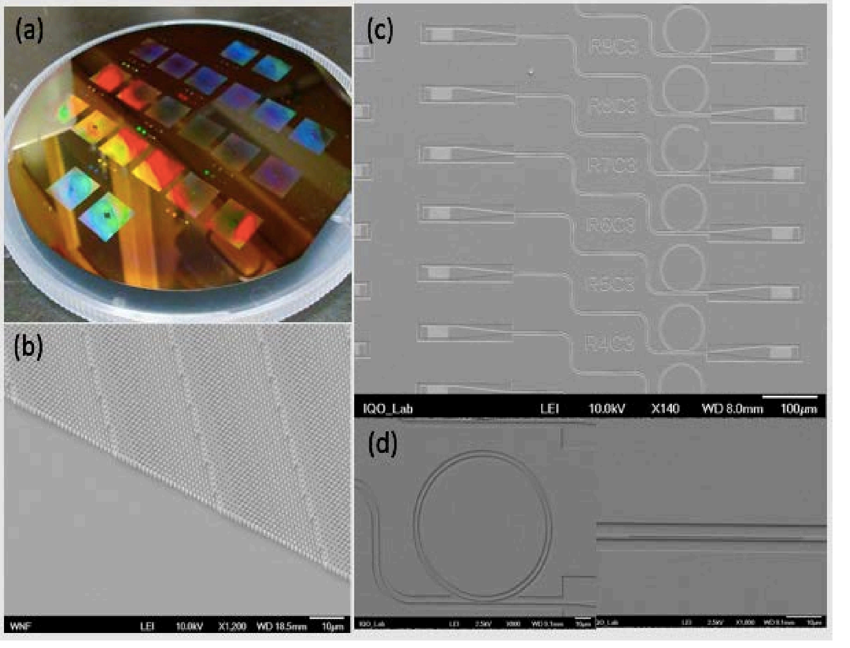
Satterthwaite, Scheuermann, Hurley, Chidsey, and McIntyre. 2016. ACS Applied Materials & Interfaces 8 (20): 13140–49. doi:10.1021/acsami.6b03029.

Northwest Nanotechnology Infrastructure (NNI)

National Nanotechnology Coordinated Infrastructure

SiN devices for optical computing, communication, and sensing

The N.O.I.S.E. (Nano Optoelectronic Integrated System Engineering) Lab group is building nano-scale sub-wavelength patterned photonic devices to transform the current state of optical computing, communication and sensing. One project is focused on fabricating ultra-thin optical elements for optical sensors while a parallel project is integrating new materials on the existing large-scale photonic devices. Figure 1a shows the optical image of fabricated large area metasurfaces in silicon nitride with an SEM close up in 1b. The group has designed and fabricated SiN integrated photonic circuits; demonstrating coupling between a ring resonator and a photonic crystal nanobeam resonator as shown in Figures 1c,d.

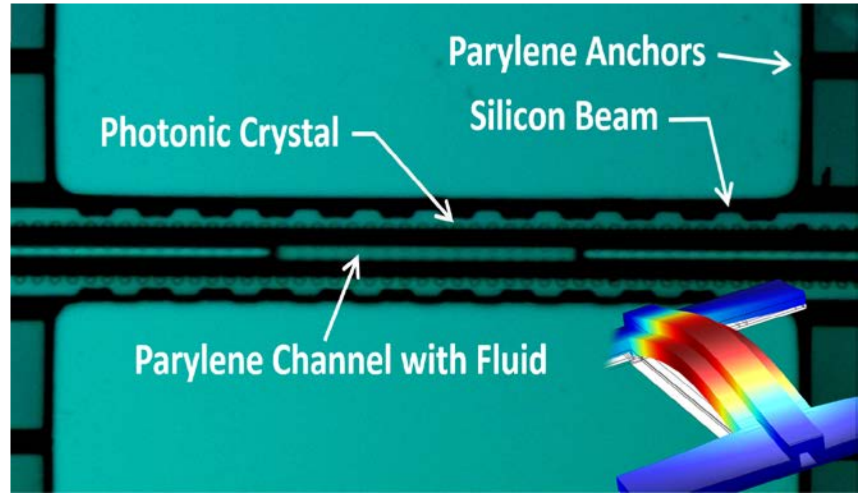


Micrograph images of thin-film ring resonator, MEMS and metamaterial photonic devices.

Arka Majumdar, The University of Washington
Work performed at The University of Washington's Washington Nanofabrication Facility (WNF)

Optical trapping and Mass Sensing of biological cells and small particles via silicon MEMS devices

This work focuses on fabricating devices to enable optical trapping of biological cells and small particles for the purpose of high resolution and precise mass sensing (on the order of 10^{-12} grams). By leveraging photonic crystals (PhC), optical trapping forces are achieved at reduced optical intensities that facilitate manipulation of the particles within the channel. The channel conveys fluid and suspended particles onto the structure for serial experiments while the anchor structures ensure parylene adhesion. Integrated MEMS bridge resonators subsequently measure the mass on the trapped particle.



Pictured is a silicon MEMS bridge resonator (illustrated by simulation) with an integrated parylene channel showing trapped fluid and the underlying photonic crystal (PhC).

Lih Lin, The University of Washington
Work performed at The University of Washington's Washington Nanofabrication Facility (WNF)

Detecting Explosive Molecules from Nanoliter Solution

This work demonstrates a photonic crystal biosilica surface-enhanced Raman scattering (SERS) substrate based on a diatom frustule with in-situ synthesized silver nanoparticles (Ag NPs) to detect explosive molecules from nanoliter (nL) solution. By integrating high density Ag NPs inside the nanopores of diatom biosilica, which is not achievable by traditional self-assembly techniques, we obtained ultra-high SERS sensitivity due to dual enhancement mechanisms. The results illustrate a new paradigm of SERS sensing to detect trace level of chemical compounds with minimum analyte consumption using nature created nanophotonic materials.

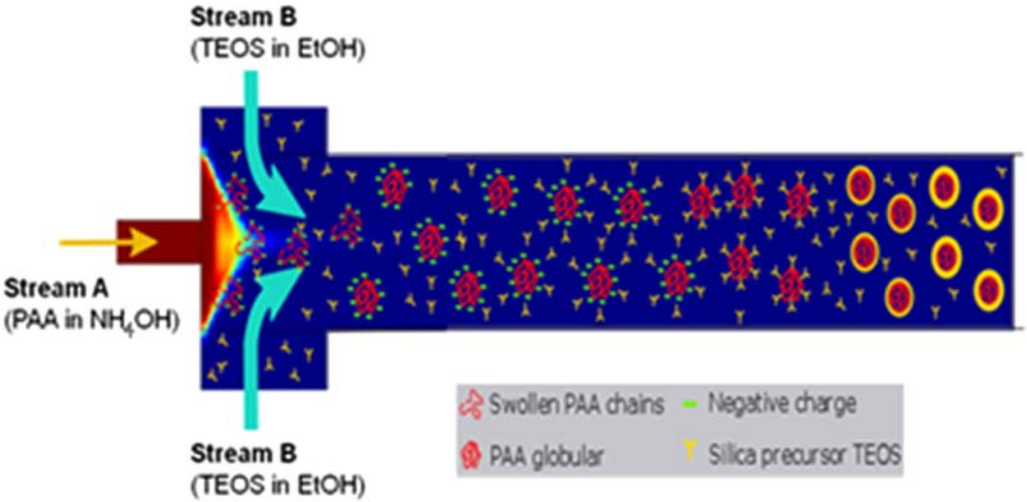
Illustration of in-situ growth of Ag NPs in pores of the diatom frustule with hydrophilic surface and combined with inkjet printing technology for ultrasensitive TNT detection at nanoliter volume scale.

Xianming Kong, Yuting Xi, Paul Le Duff, Xinyuan Chong, Erwen Li, Fanghui Ren, Gregory L. Rorrer, and Alan X. Wang, Oregon State University
Work performed at the Materials Synthesis and Characterization Facility.

Continuous, Size and Shape-Control Synthesis of Hollow Silica Nanoparticles

Hollow silica nanoparticles (HSNPs) were synthesized using a microreactor-assisted system with a hydrodynamic focusing micromixer. Due to the fast mixing of each precursor in the system, the poly(acrylic acid) (PAA) thermodynamic-locked (TML) conformations were protected from their random aggregations by the immediately initiated growth of silica shells.

Uniform HSNPs with an average diameter ~ 30 nm were produced from this system. The quality and utility of these uniform HSNPs were demonstrated by the fabrication of antireflective thin films on monocrystalline photovoltaic cells which showed a 3.8% increase in power conversion efficiency.



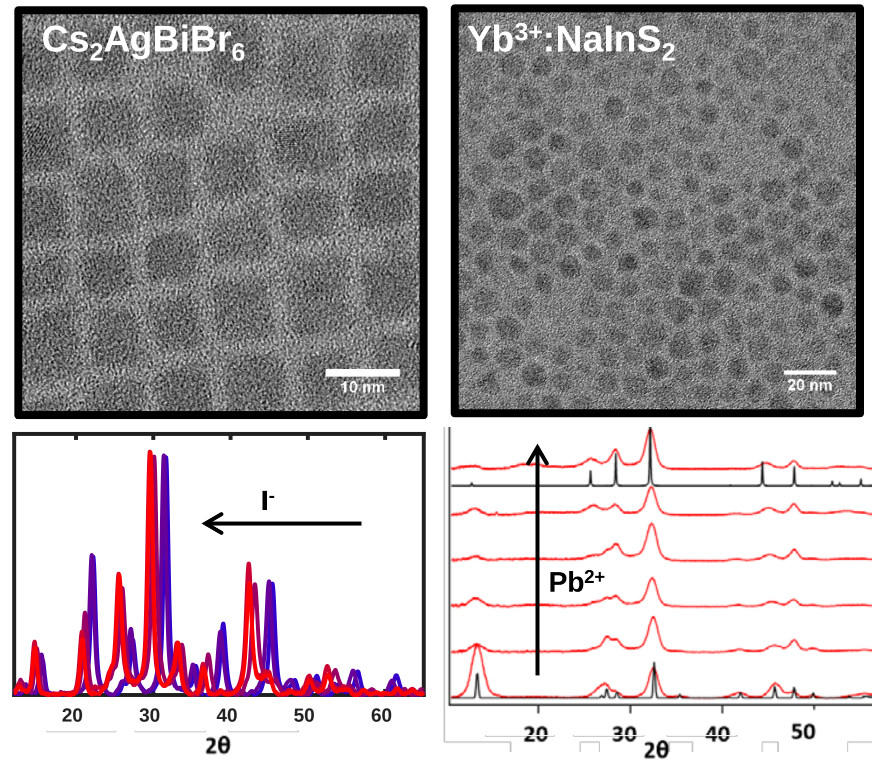
Formation pathway of PAA spherical templates in the microreactor with HFM for the synthesis of HSNPs. Mixing profile of the solutions was computed from a COMSOL model

Yujuan He, Ki-Joong Kim, and Chih-Hung Chang, Oregon State University
Work performed at the Oregon Process Innovation Center.

Characterization of Novel Colloidal Nanocrystal Materials with Photovoltaics Applications

Our work seeks to develop new types of semiconductor nanocrystals, including transition metal- or lanthanide-doped nanocrystals, with potential applications as absorbers in solar cells or as spectral converters. We are using new synthetic approaches, including post-synthetic anion and cation exchange, to develop ytterbium-doped medium-bandgap semiconductor nanocrystals as phosphors for luminescent solar concentrators, and to provide unprecedented access to new types of lead-free perovskite materials.

Characterization of nanocrystal materials by powder XRD and TEM allows us to better understand their properties, elucidate the structure of novel materials, and understand the mechanisms of the new synthetic pathways we are developing.



(Left) TEM image of $Cs_2AgBiBr_6$ (lead-free perovskite) nanocrystals and powder XRD showing transformation to Cs_2AgBiI_6. (Right) TEM image of Yb^{3+}-doped $NaInS_2$ nanocrystals and powder XRD showing transformation into Yb^{3+}-doped $PbIn_2S_4$

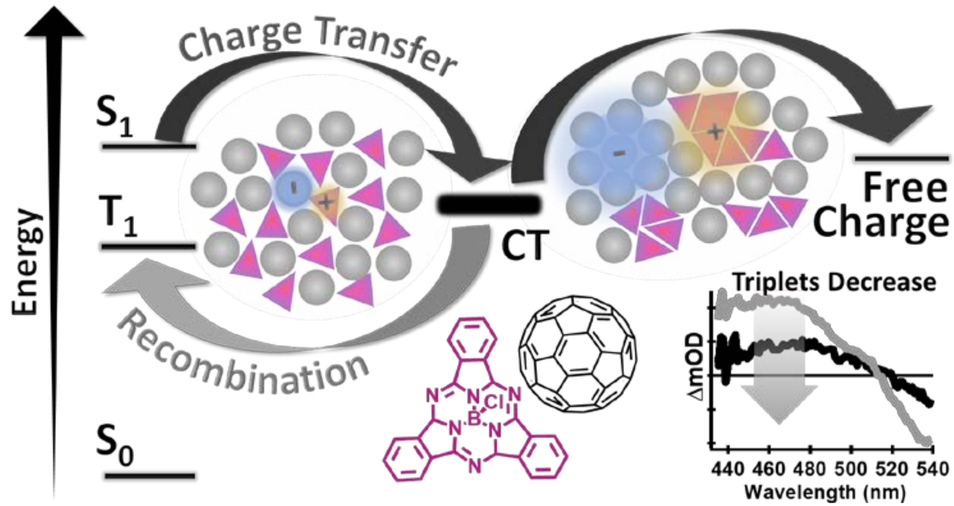
Daniel Gamelin, University of Washington
Work performed at University of Washington's Molecular Analysis Facility (MAF)

National Nanotechnology Coordinated Infrastructure

NNCI NORTHWEST NANOTECHNOLOGY INFRASTRUCTURE

Kinetic Competition Between Charge Separation and Triplet Formation in Small-Molecule Organic Photovoltaics

This work uses transient absorption, time-resolved photoluminescence, and device measurements to relate molecular aggregation in organic photovoltaic blends to the photophysical pathways that enable or detract from photocurrent generation. We characterize the femtosecond to microsecond dynamic processes that occur in these materials following photon absorption. Our spectroscopic results show that aggregation aids in sustaining free charge by inhibiting recombination to low-energy triplet states. Our findings suggest new avenues for improving solar cell performance by kinetically avoiding recombination to triplet states, despite the presence of multiple thermodynamically accessible pathways for triplet formation in these photovoltaic materials.

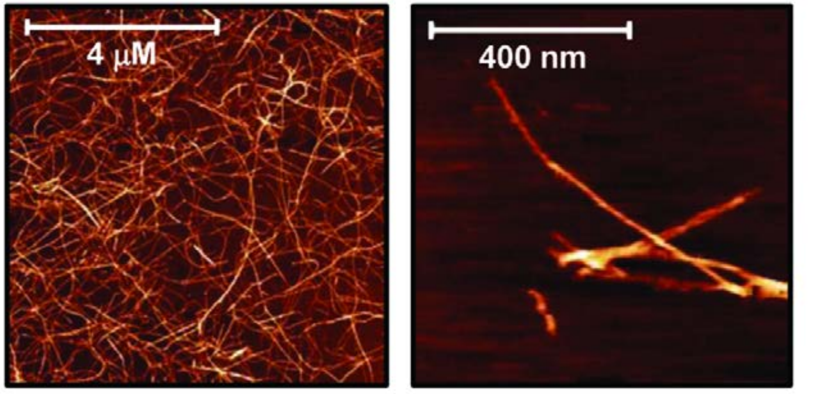


Energy landscape and transient absorption spectra of small-molecule organic photovoltaic blends, highlighting that enhanced molecular packing promotes charge generation by inhibiting detrimental recombination to triplet states

Dana B. Sulas, Emily J. Rabe, and Cody W. Schlenker
Work performed at University of Washington's Molecular Analysis Facility

Imaging bacterial amyloid fibers using AFM

Amyloid fibrils are β-sheet-rich protein structures that form through the aggregation of normally soluble proteins and peptides. These fibrils are typically associated with neurodegenerative diseases like Alzheimer’s Disease, but a growing body of research suggests that bacteria utilize amyloid fibrils as a structural component of the extracellular matrix. Here, we used atomic force microscopy (AFM) to visualize the morphology of phenol soluble modulin α1 (PSMα1) amyloid fibrils, which are produced by the bacterium *Staphylococcus aureus*. Dried samples were analyzed on a Bruker ICON atomic force microscope using tapping mode and a ScanAsyst silicon tip. The images reveal extensive surface coverage, with individual fibrils measuring ~10 nm in diameter and 0.1-4.0 μm in length.



AFM micrographs of PSMα1 amyloid fibrils.

Alissa Bleem, Nathan L. Maris, and Valerie Daggett, University of Washington
Work performed at University of Washington’s Molecular Analysis Facility (MAF)

Study of Organic Photovoltaic cells

Chitra Solomonson, Physics Instructor (Green River College) and Prof. Christine Luscombe (Materials Science and Engineering, University of WA) have collaborated on an NSF TUES project (NSF DUE 1141339) to introduce students to research methods in a cutting edge field e.g. organic photovoltaics. Students learn to fabricate organic solar cells and optimize their efficiency by varying parameters like the

1. Thickness of the active layer
2. Time of annealing for the active layer
3. Ratio of the two components of the active layer.

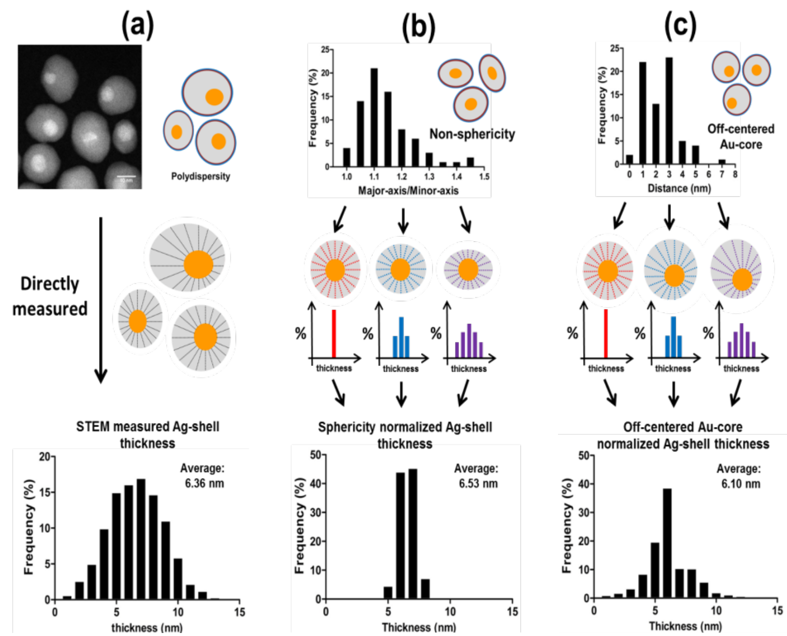
Green River College received supplemental funding for an Atomic Force Microscope so students could study the morphology of the active layer. Chitra Solomonson received preliminary training on the use of the microscope at the Molecular Analysis Facility.

Students fabricate and test organic solar cells at Green River College.

Chitra Solomonson, Green River College; Christine Luscombe, University of WA
Work performed at University of Washington's Molecular Analysis Facility (MAF)

Characterization of Nanoparticle Structure and Surface Chemistry

This work characterized the structure and surface chemistry of citrate stabilized Au/Ag-core/shell nanoparticles (NPs) that were polydispersed in size, non-spherical, and contained off-centered Au-cores. It was determined Au/Ag-core shell NPs were covered with a 0.8 nm layer of sodium citrate and a thin (<0.05 nm) layer of adventitious hydrocarbon. A series of spectral simulations were required to properly account for contributions of the NP non-sphericity and off-centered Au-cores, with the off-centered cores having the greatest impact. This work demonstrates how spectral simulations combined with experimental XPS and STEM measurements provides quantitative assessment of overlayer thicknesses and accurately deals with non-ideal, multilayer core-shell NPs.



Schematic illustration of the Ag-shell thickness normalization using: (a) the experimentally measured distribution from STEM analysis, (b) only the NPs non-sphericity and (c) only the degree of off-centered for the Au-core.

Yung-Cheng Wang,[1] Mark H. Engelhard,[2] Donald R. Baer[2] and David G. Castner,[1]
[1]University of Washington; [2]Pacific Northwest National Laboratory

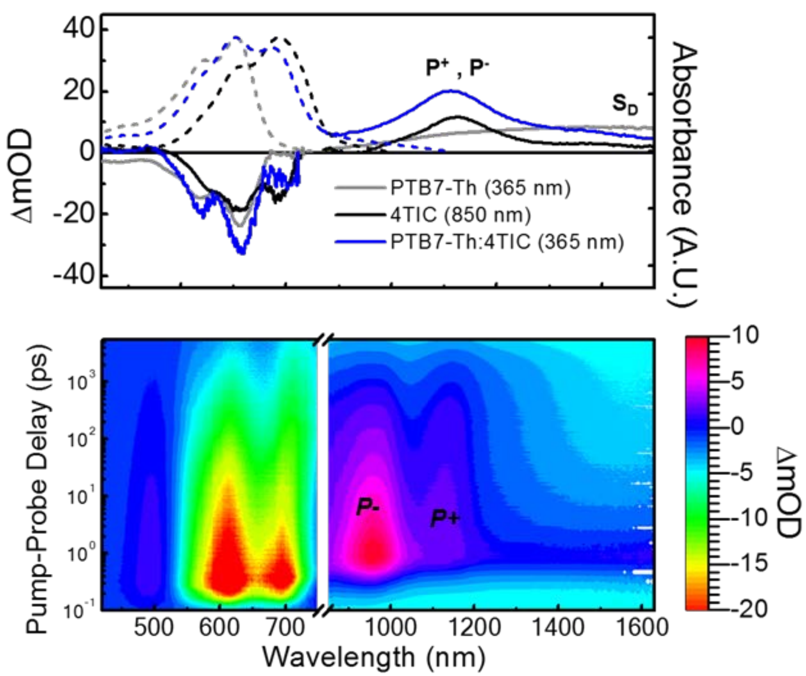
Work performed at University of Washington's Molecular Analysis Facility (MAF)

National Nanotechnology Coordinated Infrastructure

NNCI NORTHWEST NANOTECHNOLOGY INFRASTRUCTURE

Design of a Highly Crystalline Fused-ring Organic Semiconductor for Solar Cells

This work targets a rational design of organic semiconductors for solar cell applications by understanding structure-property relationships. Femtosecond pump-probe spectroscopy revealed that a rigid ladder-type conjugated molecule based on fused heterocyclic structure features a strong intermolecular coupling through their high crystallinity, giving a broad delocalization of excited state molecular orbitals. This delocalization process effectively waivered the severe inherent energy loss within organic solar cells by weakening the Coulombic binding of electron-hole pairs. Using these designs, a bulk heterojunction based organic solar cell device exhibited reduced non-ideal energy loss down to 0.25 eV, with highly efficient power conversion efficiency up to 11%.



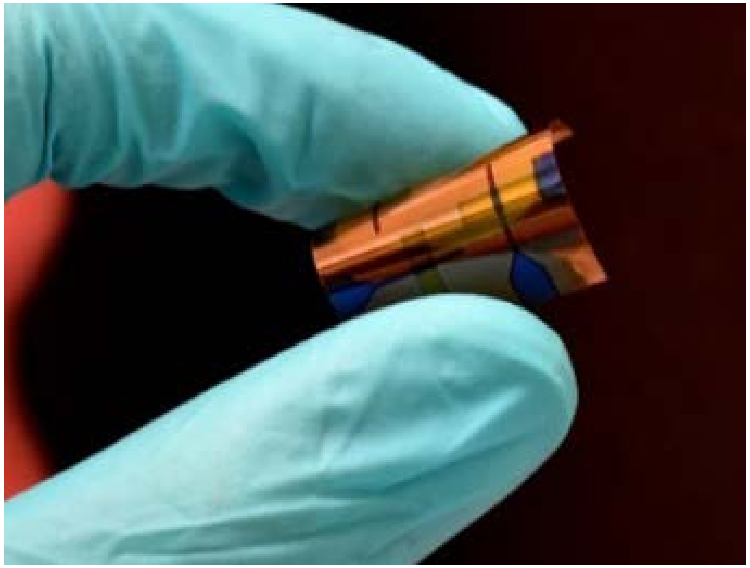
Femtosecond transient absorption spectroscopy of organic semiconductors and their bulk heterojunction blend to monitor the excited state dielectric environment.

Xueliang Shi, Lijian Zuo, Sae Byeok Jo and Alex K.-Y. Jen, University of Washington
Work performed at University of Washington's Molecular Analysis Facility

Research Triangle Nanotechnology Network (RTNN)

Flexible Ferroelectric Material for Memory Devices

- Created flexible films for non-volatile memory devices that are wearable and resilient
- Ferroelectric materials can store charge (ideal for non-volatile memory devices), are typically brittle, and are usually made at high temperatures, which would destroy most polymers
- Researchers grew an extremely thin film of hafnia (20-50 nm) onto plastic substrates at low temperatures
- Prototype remained stable and flexible during testing
- Useful in numerous applications including defense and space



Flexible ferroelectric material

Yu, H. et al.. Adv. Funct. Mater. (2017). doi:10.1002/adfm.201700461

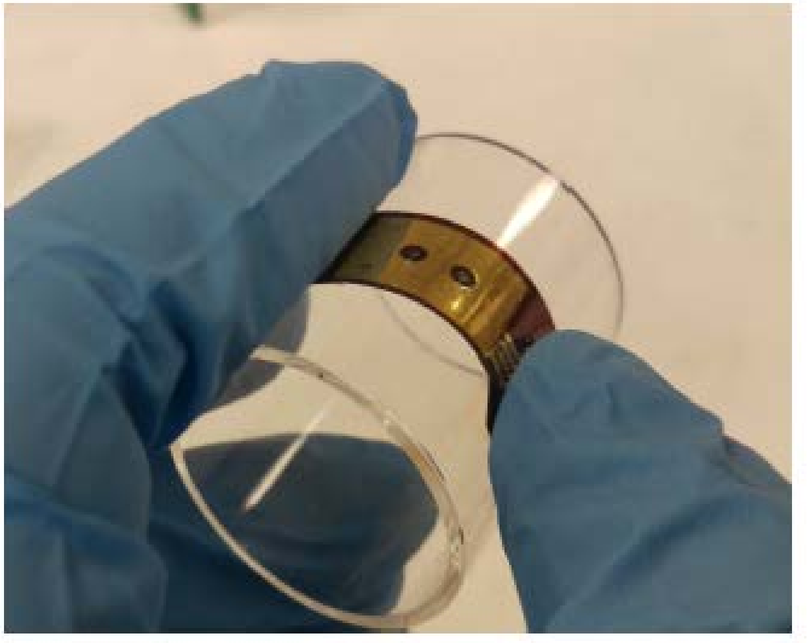
Hyeonggeun Yu, Ching-Chang Chung, Nate Shewmon, Szuheng Ho, Joshua H. Carpenter, Ryan Larrabee, Tianlei Sun, Jacob L. Jones, Harald Ade, Brendan T. O'Connor, and Franky So, North Carolina State University

Work performed at NC State’s Analytical Instrumentation Facility

Flexible Silicon Sensors for Diffuse Reflectance Spectroscopy of Tissue

- Diffuse reflectance spectroscopy (DRS) is used in cancer margin assessment in excised tissue
- DRS measures refracted light from the sample
  - Depends on tissue structure and chemistry
- Engineers created flexible silicon sensor for DRS
- Thin film Si photodetectors (PDs) bonded to a flexible Kapton polymer substrate
  - Conforms to tissue
  - Reduces data anomalies
- Flexible sensor's responsivity and performance were equal to that of rigid PDs

Miller, D. M. & Jokerst, N. M. Biomed. Opt. Express (2017). doi: 10.1364/BOE.8.001512



Diffuse reflectance spectroscopy sensor

David Miller and Nan Jokerst, Duke University

Work performed at Duke's Shared Materials Instrumentation Facility

National Nanotechnology Coordinated Infrastructure

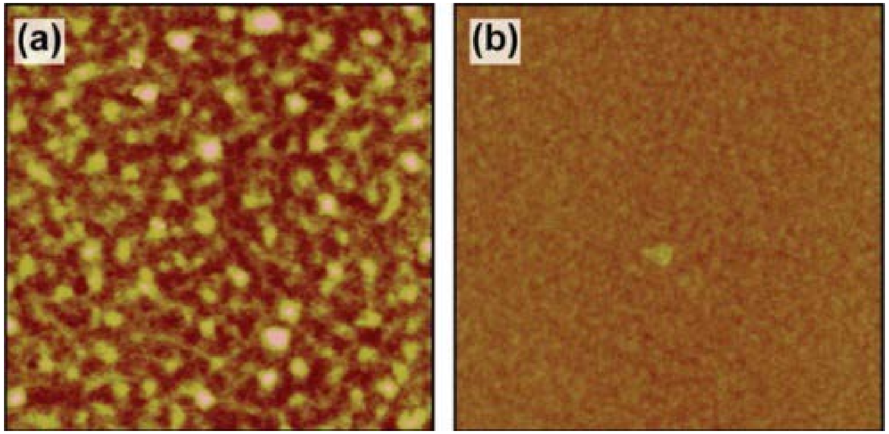
RTNN

Significantly Increasing the Ductility of High Performance Polymer Semiconductors

- Polymer semiconductor PCDTPT* blended with ductile polymer P3HT [poly(3-hexylthiophene)]
- Polymer blend was more ductile than neat PCDTPT film and retained its charge transport characteristics
- Improved ductility accredited to mixing of polymers through film thickness
- Atomic force microscopy (AFM)
  - 1:1 film has nanoscale nodules attributed to lateral segregation of PCDTPT within film
  - 1:4 film is smooth with no signs of lateral segregation

** PCDTPT: (poly[4-(4,4-dihexadecyl-4H-cyclopenta[1,2-b:5,4-b']dithiophen-2-yl)-alt-[1,2,5]thiadiazolo[3,4-c]pyridine])*

Scott, J. I. et al.. ACS Appl. Mater. Interfaces (2016). doi: 10.1021/acsami.6b01852



AFM images: (a) 1:1 and (b) 1:4 ratio PCDTPT:P3HT blend films
Images are 10 × 10 μm

Joshua I. Scott, Xiao Xue, Benjamin C. Hoffman, Daniel Dougherty, Chuanzhen Zhou, and Brendan T. O'Connor, North Carolina State University

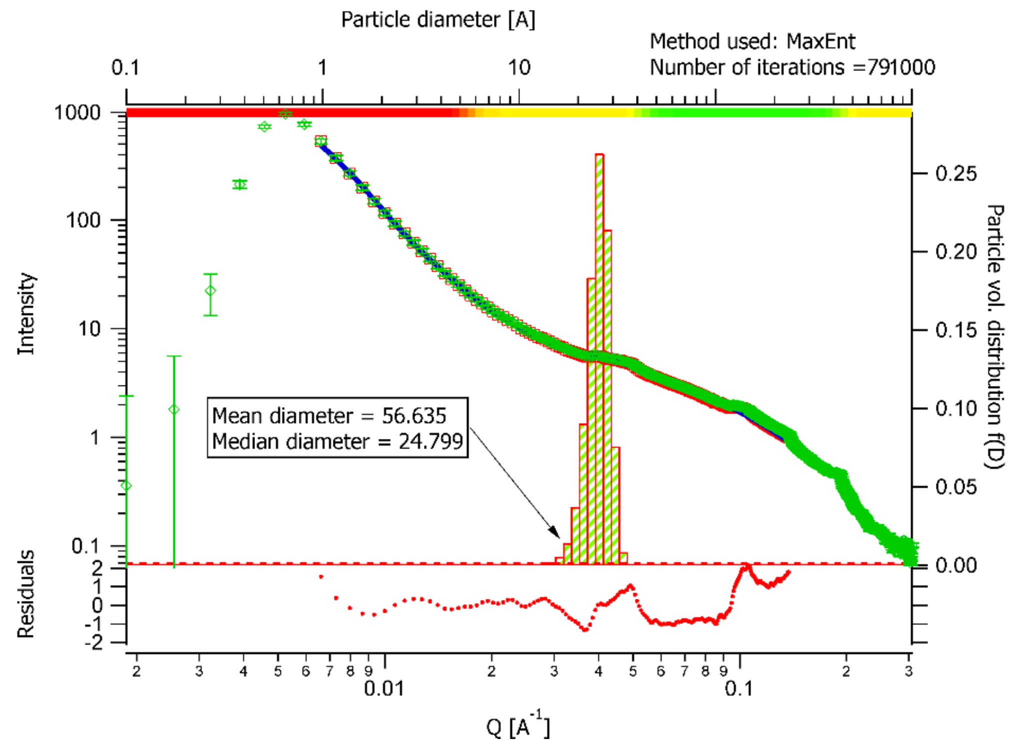
R. Joseph Kline, National Institute of Standards and Technology

Ming Wang and Guillermo Bazan University of California—Santa Barbara

Work performed at NC State's Analytical Instrumentation Facility

Structural Analysis of Carbon Fibers using X-ray Diffraction and X-ray Scattering

- Increased interest in carbon fiber composites due to high strength and low cost
  - Automotive, wind energy, and aerospace industries
- Need to understand relationship between microstructural properties of carbon fibers and their influence on the constitutive behavior of carbon fiber reinforced composites
- Here, both wide-angle diffraction and small angle scattering used to characterize the crystal size and orientation within the carbon fiber and the associated pores from small angle scattering
- Microstructure information used to obtain the process-property relationships for carbon fibers with varying elastic moduli and tensile strength



Pore size distribution from small angle scattering and maximum entropy method

Aashish Sharma, Stephen Young, and Dayakar Penumadu, University of Tennessee
Work performed at Duke's Shared Materials Instrumentation Facility

National Nanotechnology Coordinated Infrastructure

RTNN

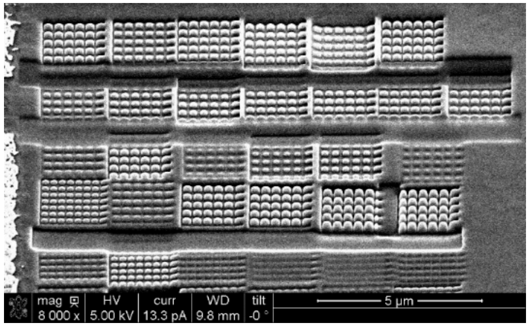
Focused Ion Beam Milling of Sub-Wavelength Patterns into Diamond Dies Used in Nanocoining

Nanocoining Process

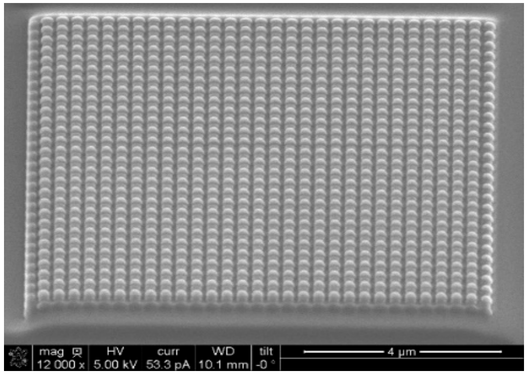
- Sub-wavelength structures cut into a diamond die using a focused ion beam (FIB)
- Die is pressed into metal to rapidly create nano-structured surfaces
- Surface invisible to the eye but can manipulate light or repel water (e.g. anti-reflective to increase the energy of solar cells)
- FIB milling of structures into diamond is challenge

Optimization

- Simulation of milling process enabled design of feature parameters before milling
- Test patterns were used to determine optimum beam parameters for cutting diamond
- Desired pattern was scaled from 2 x 2 µm to 10 x 10 µm to create a final stamping die



SEM image of test patterns cut into diamond stamp during optimization process



SEM image of finished 10 x 10 µm diamond die with 320 nm pitch features

Smart Material Solutions

NSF SBIR Phase II: Award # 1738387

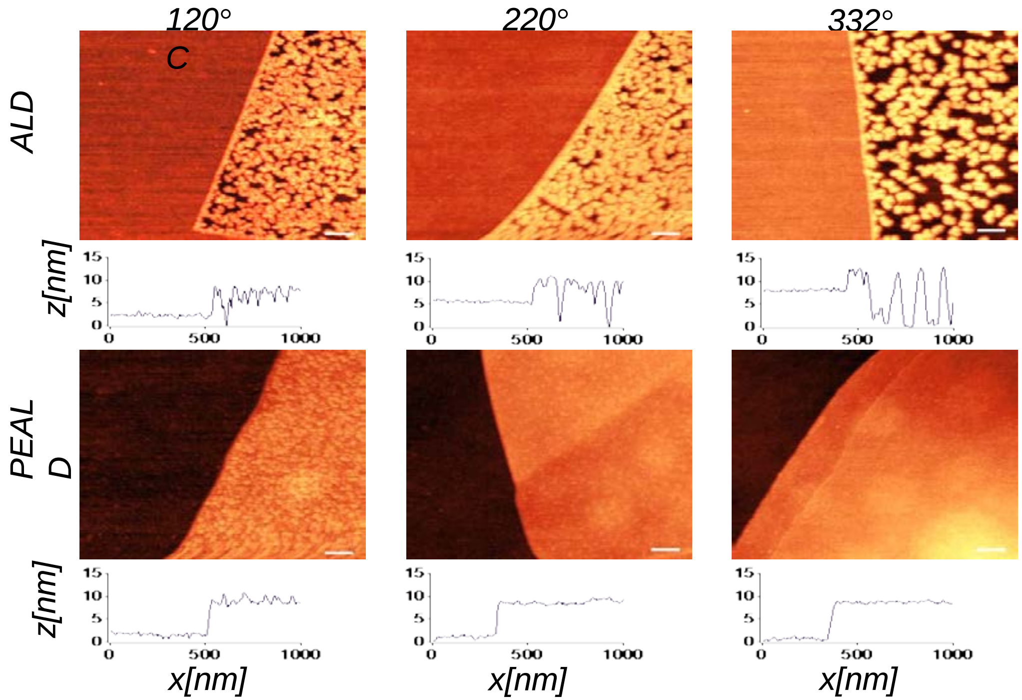
Stephen Furst, Smart Material Solutions
Work performed at NC State's Analytical Instrumentation Facility

National Nanotechnology Coordinated Infrastructure

RTNN

Plasma-enhanced Atomic Layer Deposition (PEALD) for Deposition of Ultra-thin High-k films on 2D Crystals

- 2D crystals require deposition of a high-k dielectric
- In this work, PEALD was used to grow common high-k dielectrics, as thin as ~ 3 nm on 2D crystals
  - Thinnest film deposited to date without addition of buffer layer or extra functionalization steps
- Ultra-thin films integrated into the gate stack of a top gate MoS_2 transistor
  - Superb switching
  - Low gate leakage
- The figure at right shows the difference between the more traditional method of depositing films on MoS_2 (ALD) and the method used in this work (PEALD)



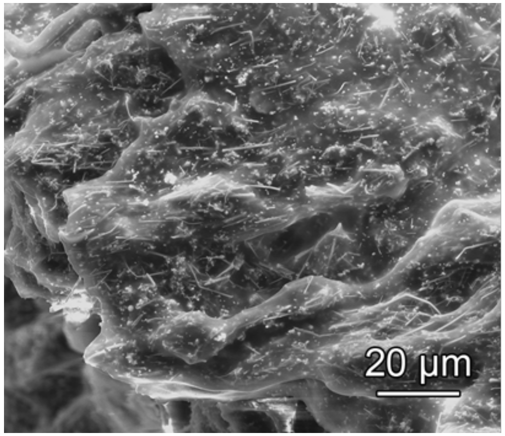
Thin film deposition of high-k dielectrics on MoS_2 using ALD and PEALD

Price, KM et al.. ACS Appl. Mater. Interfaces (2017). doi: 10.1021/acsami.7b00538

Katherine M. Price, Felicia A. McGuire, and Aaron D. Franklin, Duke University
Kirstin E. Schauble, Seattle University; Damon B. Farmer, IBM T.J. Watson Research Center
Work performed at Duke's Shared Materials Instrumentation Facility

Large-Scale Synthesis of Cu-Ag NWs and Its Application in 3D Printing Filament

- Large-scale synthesis of copper-silver core-shell nanowires (Cu-Ag NWs)
  - Faster, greener, and milder reaction conditions than previous synthetic methods
- Cu-Ag NWs were incorporated into poly(caprolactone) (PCL), a common 3D printing thermoplastic, to produce conductive 3D printing filament (0.002 Ω cm) compatible with standard desktop 3D printers
- This work aims to develop practical methods for printing electronic devices without the need for expensive, specialized printers



SEM image of the conductive filament showing even distribution of Cu-Ag NWs throughout the PCL thermoplastic.

Cu-Ag NW filament was printed into an inductive charging coil. The coil powered an LED when paired with a wireless charging dock.

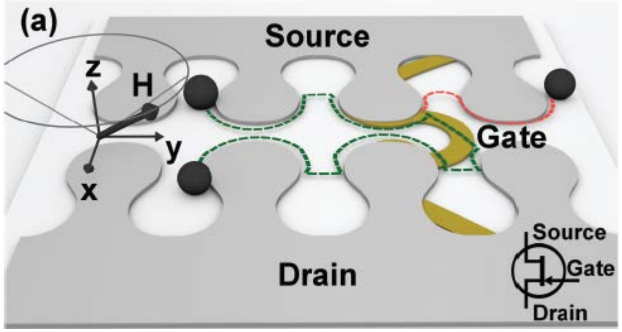
Mutya Cruz and Benjamin Wiley, Duke University
Work performed at Duke's Shared Materials Instrumentation Facility

National Nanotechnology Coordinated Infrastructure

RTNN

Magnetomicrofluidic Circuits for Organizing Bio-particle Arrays

- Magnetomicrofluidic circuits used to manipulate single particles and living cells in microchips
- Chip is composed of hydrodynamic traps as well as magnetic circuits
- Particles of interests are flowed inside microfluidics channels and caught in hydrodynamic traps
- Magnetic field produced by the magnetic circuits moves trapped particles into storage sites
  - Can organize single cells and cell pairs in an array
- Once assembled, it is possible to study cell-cell interactions and their protein secretion profiles



Schematic of particle trajectories within the chip

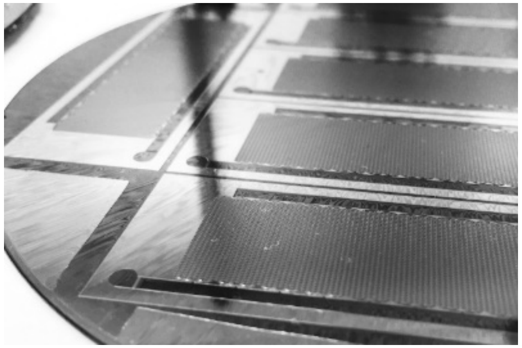


Photo of the fabricated chip

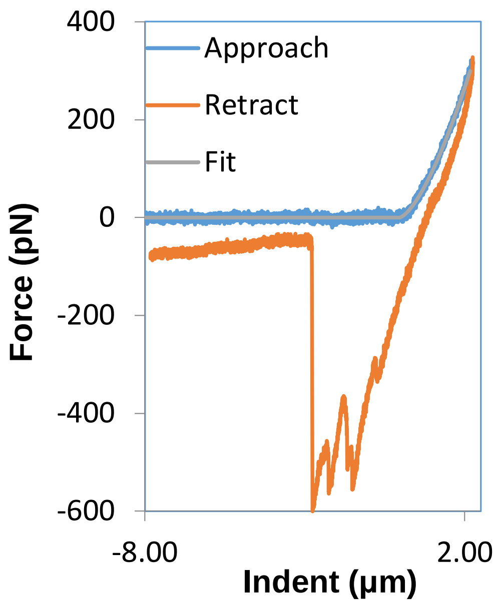
Abedini-Nassab, R. et al. Lab Chip (2016) doi: 10.1039/C6LC00878J; Abedini-Nassab, R. et al. Adv. Funct. Mater. (2015). doi: 10.1002/adfm.201503898; Abedini-Nassab, R. et al. Adv. Mater. (2015). doi: 10.1002/adma.201502352

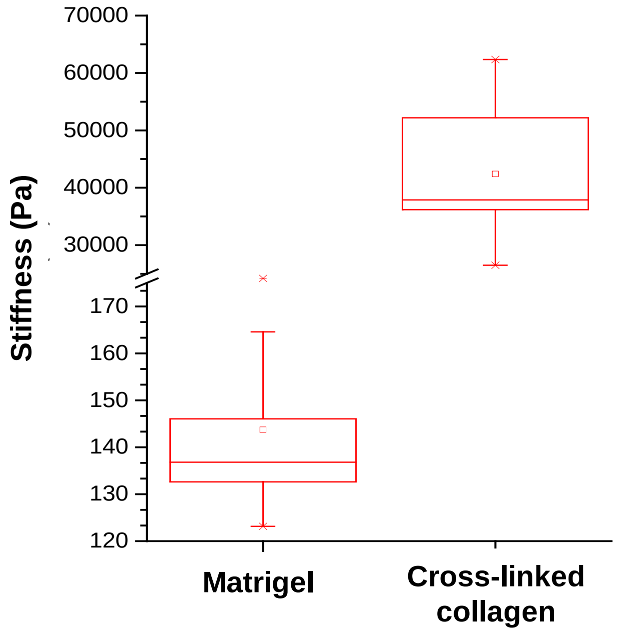
Roozbeh Abedini-Nassab, Daniel Y. Joh, Faris Albarghouthi, Ashutosh Chilkoti, David M. Murdoch, and Benjamin B. Yellen, Duke University

Work performed at Duke's Shared Materials Instrumentation Facility

Elastic Modulus Measurements on Soft/Sticky Materials in Fluid

- "Organ-on-a-Chip" platforms provide exquisite control of experimental variables yet recapitulate much of the physiology of an intact organ
- Ability to monitor and control the environment at the cellular and tissue level is critical for these systems
- In this work, researchers developed a method to measure the elastic moduli of soft materials using an atomic force microscope equipped with a large colloid probe tip
- Extracellular matrices (Matrigel and cross-linked collagen) used to support cell growth were analyzed
  - Samples were soft and sticky and measured in fluid to retain hydration





Left: *Representative force curve for a Matrigel sample. The large negative forces indicate the adhesion forces between the tip and the sample surface before the tip finally pulls out of the sample.*

Right: *Stiffness comparison of a soft extracellular matrix (Matrigel, 39 spots) and chemically cross-linked calf-skin collagen surface (59 spots).*

Nicole Smiddy, Dulan Gunasekara, and Nancy Allbritton UNC-Chapel Hill

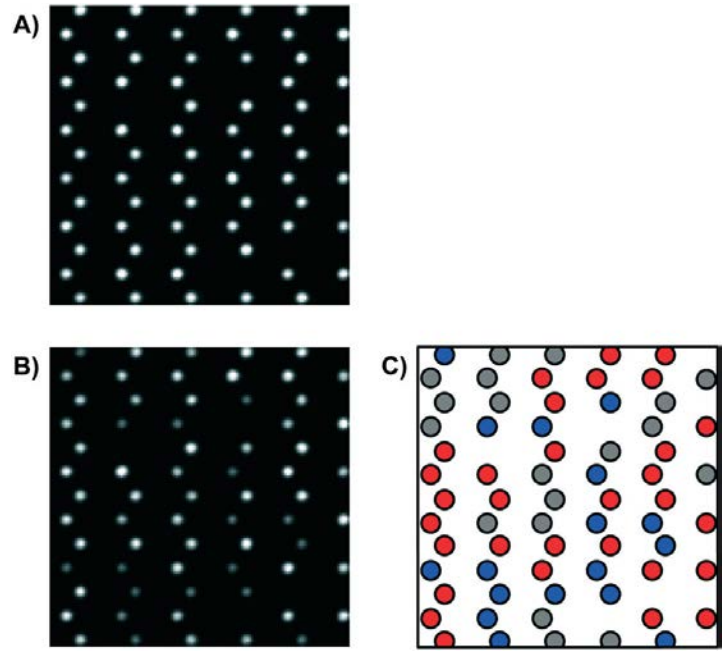
Work performed at UNC's Chapel Hill Analytical and Nanofabrication Laboratory

National Nanotechnology Coordinated Infrastructure

RTNN

Photobleaching Kinetics-based Bead Encoding for Multiplexed Bioassays

- Multiplexing bead-based bioassays requires that each type of microsphere be uniquely encoded
- Microspheres typically encoded using fluorescent dyes with different spectral properties and concentrations
- To expand the number of encoding levels, method developed that incorporated photobleaching kinetics
- Beads encoded with two dyes having overlapping fluorescence excitation and emission wavelengths but different photostabilities
- Multiple populations identified upon comparison of original fluorescence emission intensity to that obtained after photobleaching
- Using only a single excitation/emission band, two different initial intensity levels were optimized to produce six uniquely identifiable bead populations whereas only two could have been achieved with conventional methods
- This strategy increases the number of encoding levels without increasing complexity of imaging instrumentation



***A.** All beads initially exhibited similar fluorescence intensities*

***B.** After exposure, the less photostable dye had reduced emission intensity due to photobleaching*

***C.** Map depicting the position and identity of individual beads in the array wells*

Thomas Linz, W. Hampton Henley, and J. Michael Ramsey, UNC-Chapel Hill
Work performed at UNC's Chapel Hill Analytical and Nanofabrication Laboratory

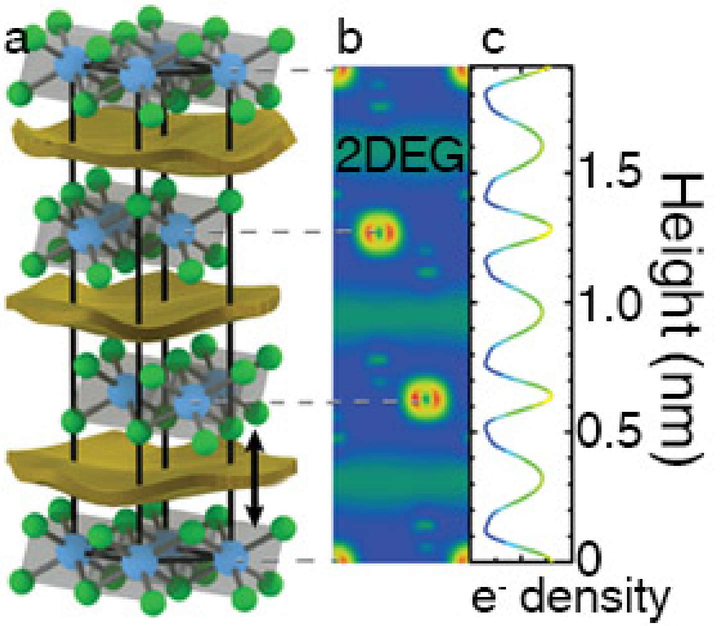
Linz, T. H., Hampton Henley, W. & Michael Ramsey, J. Lab Chip (2017). doi: 10.1039/C6LC01415A

National Nanotechnology Coordinated Infrastructure

RTNN

Experimental Demonstration of an Electride as a 2D Material

- Ca_2N has enormous 4 Å gap between layers filled by an exotic, highly conductive cloud of electrons
  - Possible to pull apart these layers, yielding a 2D material that still retains the electron cloud
  - This material is more conductive and transparent than graphene
- Ca_2N is an ionic solid called an electride
  - In electrides, the "anion" is simply an electron without a nucleus
- In Ca_2N, the electrons are grouped into layers where their wavefunction overlaps, giving metallic character: a 2D electron gas (2DEG)
- Attempted to exfoliate Ca_2N in a wide variety of solvents: Ca_2N exhibited long term stability in 1,3-dioxolane
- With 2D Ca_2N now available, numerous studies into the chemical and physical behavior are possible



***a.** Structure of Ca_2N*

***b.** Density functional theory calculation of electron density*

***c.** Integrated height profile of the electron density*

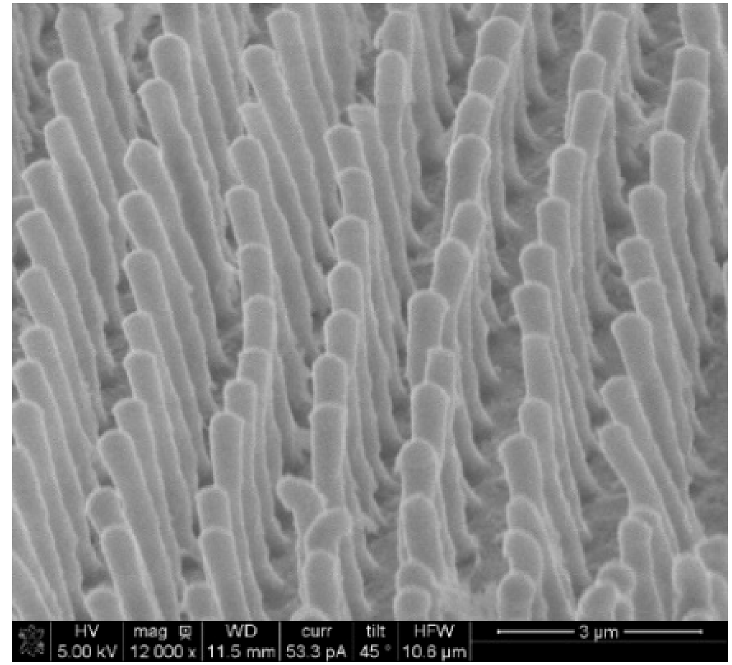
Daniel L. Druffel, Kaci L. Kuntz, Adam H. Woomer, Francis M. Alcorn, Jun Hu, Carrie L. Donley, and Scott C. Warren, UNC-Chapel Hill

Work performed at UNC's Chapel Hill Analytical and Nanofabrication Laboratory

Druffel, D. L. et al. J. Am. Chem. Soc. 138 (2016).

Tunable Nanostructures with Dynamic Optical Properties

- This work focuses on making nano-pillar array structures mixed with magnetic particles such as Ni, Co, and Fe3O4
- These structures have different reflection, namely different colors, when pillar arrays are actuated to tilt to a certain angle
- The proposed tunable surface nanostructure can be widely applied to any surfaces.
- This research will greatly enhance capabilities in adaptive camouflage that can simultaneously change color, surface texture, and reflectivity, which can be widely applied to clothing, vehicle, and infrastructure surfaces



SEM image of the magnetic nano-pillar array. The pillar height is about 4.9 µm, and the diameter is about 0.5 µm.

Zhiren Luo and Chih-Hao Chang, North Carolina State University
Work performed at NC State's Analytical Instrumentation Facility

National Nanotechnology Coordinated Infrastructure

RTNN

Fabrication and Characterization of Electronic and Optoelectronic Device Prototypes

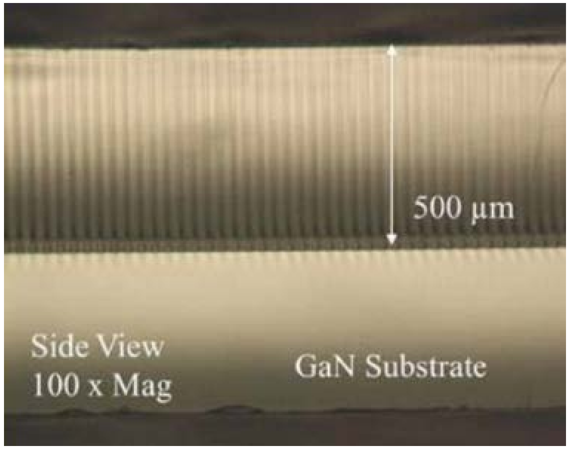
Kyma Technologies uses the facilities to fabricate and characterize prototypes of a number of electronic and optoelectronic devices

The optical device shown at right consists of a series of gallium nitride layers which serve as a nonlinear optical crystal for photons ranging from the infrared to the ultraviolet

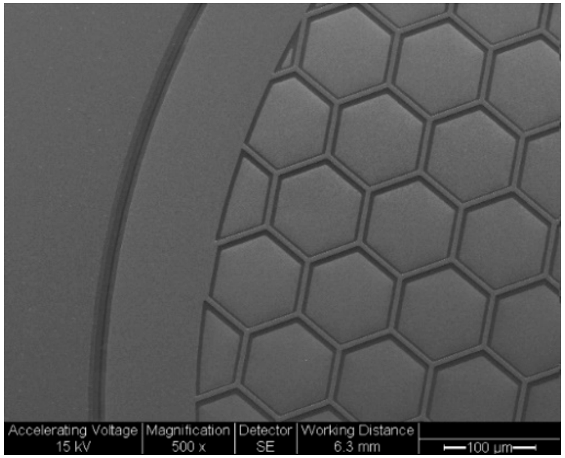
The 500 µm active layer region consists of alternating crystalline polarities of GaN (the Ga-face and the N-face), which under the proper conditions constitute a quasi-phase matched system for frequency doubling

Jaime Rumsey and Jacob Leach, Kyma Technologies

Work performed at Duke's Shared Materials Instrumentation Facility



The periodic oscillating polarity GaN crystal



Elaborate electronic device

Brown, C. G. et al. Proc. SPIE (2016). doi: 10.1117/12.2213447

National Nanotechnology Coordinated Infrastructure

RTNN

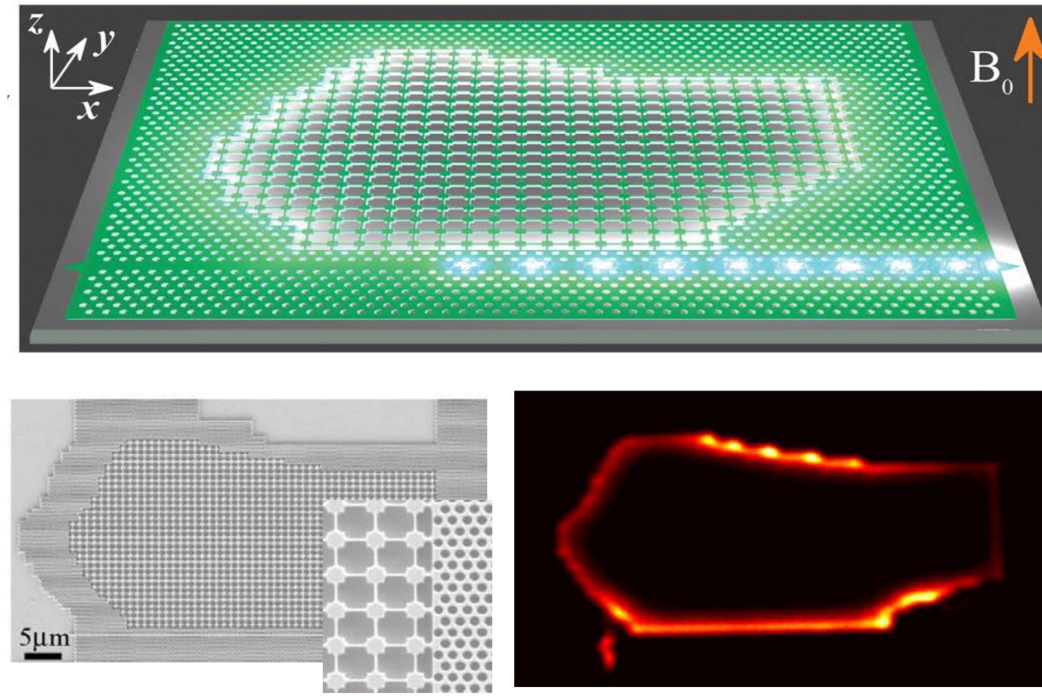
San Diego Nanotechnology Infrastructure (SDNI)

World's First Nonreciprocal Topological Laser (Top 10 Physics Breakthrough in 2017, Physics World)

A new kind of laser, in which light snakes around a cavity of any shape without scattering, has been developed as "topological laser" which could allow improved miniaturization of silicon photonics or protect quantum information from scattering.

Although photons do not respond directly to a magnetic field, electrons excited by incident light respond differently to a magnetic field than if they had not been excited, and in turn influence the light differently.

By placing one photonic crystal inside the other on top of a layer of the magnetic mineral yttrium iron garnet, the interface between the two crystals forms the laser cavity. When excited by a laser, InGaAsP spontaneously emits light populating the edge state between the topologically distinct materials. This edge state makes a scattering-proof laser cavity of any shape.



Design, fabrication, and demonstration of nonreciprocal topological laser. Science 10/1126 (2017)

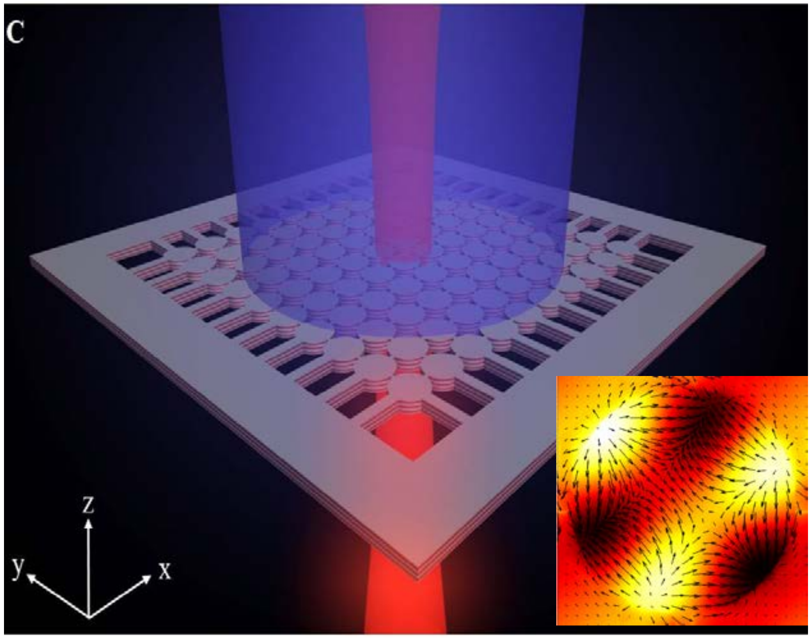
Babak Bahari, Abdoulaye Ndao, Felipe Vallini, Abdelkrim El Amili, Yeshaiahu Fainman, Boubacar Kanté, UCSD
Work performed at San Diego Nanotechnology Infrastructure (SDNI)

National Nanotechnology Coordinated Infrastructure

sdni San Diego Nanotechnology Infrastructure

World's First Bound State In Continuum (BIC) Laser

Bound state in the continuum (BIC), initially believed to be a mathematical curiosity in quantum mechanics, can now be employed to build unprecedented photonic cavities and systems with unique optical responses. Applications of these systems include novel light sources with intriguing polarization singularities, surface lasers, sensing, or chip scale communications. BIC have been shown to carry topological charges and thus constitutes robust states that are not destroyed when the system is modified.



Tilted electron micrograph of cylindrical nanoresonator array suspended in air. ***b,*** *Top view of an 8-by-8 array with supporting bridges, used for the mechanical stability of the membrane. The dimensions of the structure are: period = 1200 nm, thickness = 300 nm, and bridge width = 200 nm.* ***c,*** *Schematic of the fabricated system illustrating the pump beam (blue) and lasing from the bound state in the continuum (BIC) mode (red).* *Nature **541**, 196-199 (2017)*

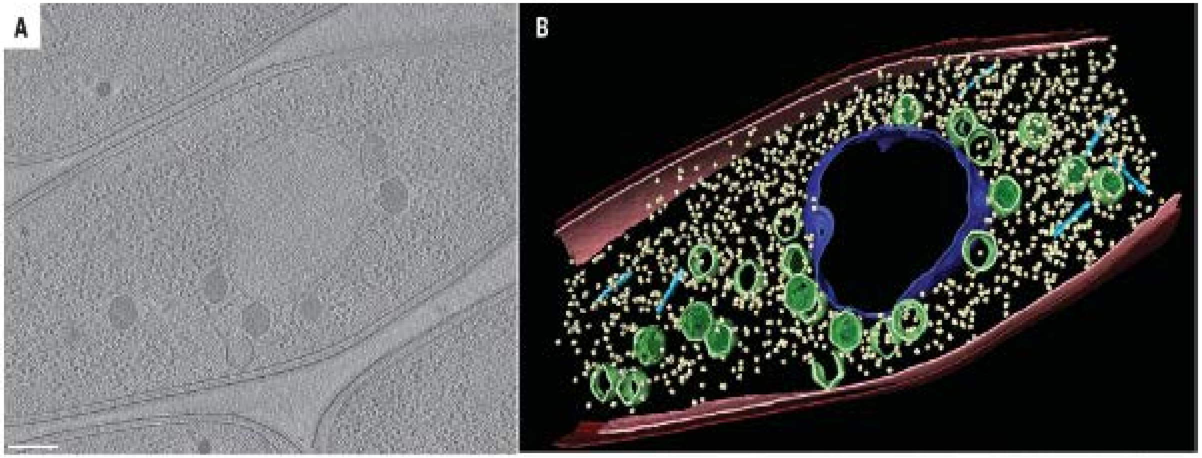
Kodigala, T. Lepetit, Q. Gu, B. Bahari, Y. Fainman, and B. Kanté, UCSD
Work performed at San Diego Nanotechnology Infrastructure (SDNI)

National Nanotechnology Coordinated Infrastructure

sdni San Diego Nanotechnology Infrastructure

Assembly of a Nucleus-Like Structure During Viral Replication in Bacteria

Researchers observed that during viral replication in bacteria, the viral DNA was separated from the cytoplasm and enclosed in a central nucleus-like compartment and the compartment was pushed to the center by bacterial cytoskeletal filaments. Also for the very first time, scientists observed different stages of capsid assembly, from partially constructed capsids to fully assembled capsids with tails in the cytoplasm. The work provides us with a deeper understanding of the mechanisms by which phages have evolved reproduction pathways by spatial and temporal organization of DNA replication, transcription and translational machineries.



Tomography for assembly of nucleus-like compartment during viral replication in bacteria. The TEM samples are prepared by Cryo-Focused-Ion-Beam Milling of Cells for cryo-Electron Tomography.

V Chaikeeratisak et al. Science 355 (6321), 194-197. 2017 Jan 13

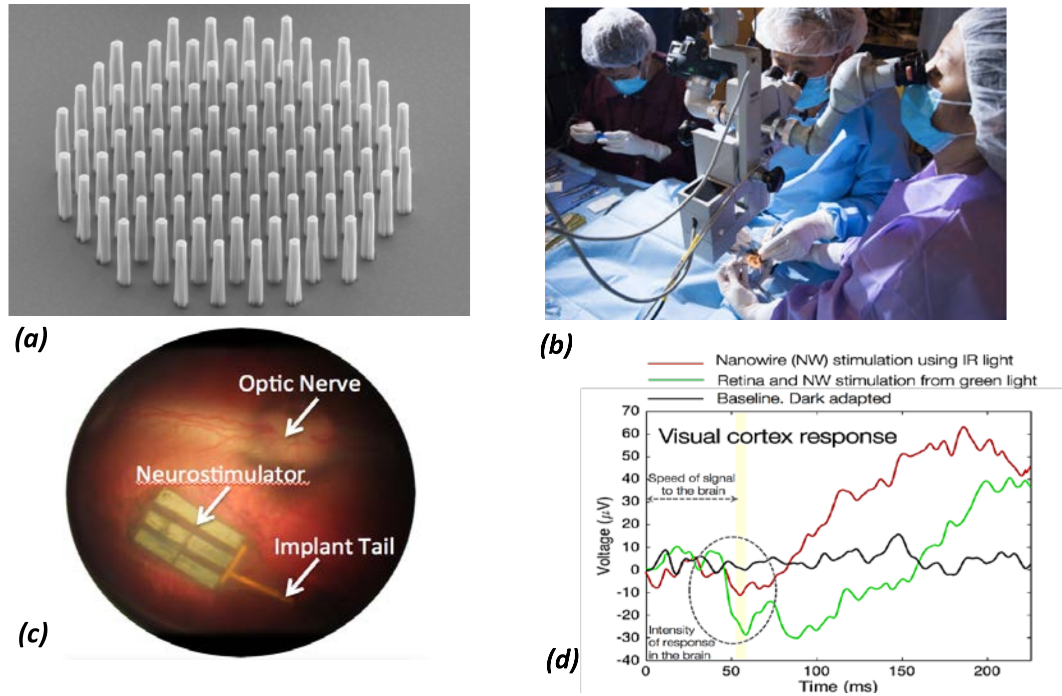
V. Chaikeeratisak*, K. Nguyen, K. Khanna, A. Brilot, M. Erb, J. K. C. Coker, A. Vavilina, G. L. Newton, R. Buschauer, K. Poglino, E. Villa, D. A. Agard, J. Poglina, UCSD*
Sample preparation with dual beam FIB was performed at San Diego Nanotechnology Infrastructure (SDNI)

National Nanotechnology Coordinated Infrastructure

sdni San Diego Nanotechnology Infrastructure

Nanowire Retina Prosthesis for Vision Restoration

Helped by the staff of SDNI, Nanovision, a startup company, has evolved its retinal prosthesis into a sophisticated neurostimulator. The Nanovision team has perfected the surgical technique and tested the device in-vivo in rabbits and pigs and is in preparation for human trials. The visually evoked potential (VEP), a measure of the response in the visual cortex demonstrates that the nanowires are stimulating a visual response, shown in the visual evoked potential (VEP) from visual cortex under optical stimulation.

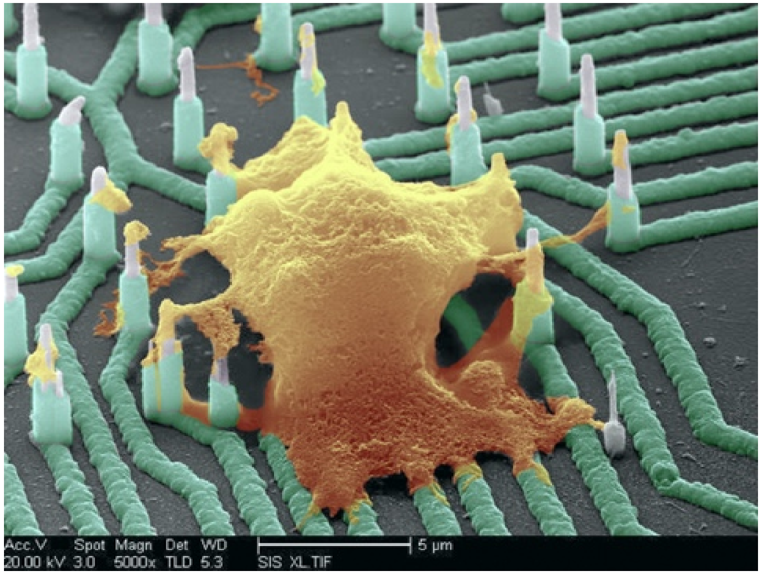


Semiconductor Nanowire Retinal Prosthesis by Nanovision. (a) Si nanowire detectors, (b) surgical implant of the device into rabbit eye, (c) Subretinal implant of the device to cover the macular area, and (d) visual evoked signal produced by the retinal prosthesis (red) and the reference signals (black: dark, green: green light stimulation of photoreceptors in the healthy retina).

Yi Jing, Sue Bauchner, Brandon Bsse (Nanovision) Samir Damle, Lingyun Cheng, Bill Freeman (UCSD)
Work performed at San Diego Nanotechnology Infrastructure (SDNI)

Individually Addressable Nanowire Array Recording Intracellular Neuronal Activity

Dayeh's team has produced individually electrical addressable vertical nanowire arrays with solid-state wafer bonding. These arrays were sensitive to postsynamptic potential oscillations and recorded action potentials with a 99mV swing. The work lays the foundation for building brain-on-chip devices using advances in stem cell technology for drug screening. The work is significant because (a) it shows the first sign of pre-firing potential that has never been observed before, (b) it records simultaneously intracellular and extracellular potential of neurons, and(c) it is highly scalable to record complex, 3D neuronal structures such as a mini-brain on chip.



SEM image showing a human stem cell neuron atop the wire array. Nano Letters (DOI: 10.1021/acs.nanolett.6b04752),

Shadi Dayeh group, UCSD
Work performed at San Diego Nanotechnology Infrastructure (SDNI)

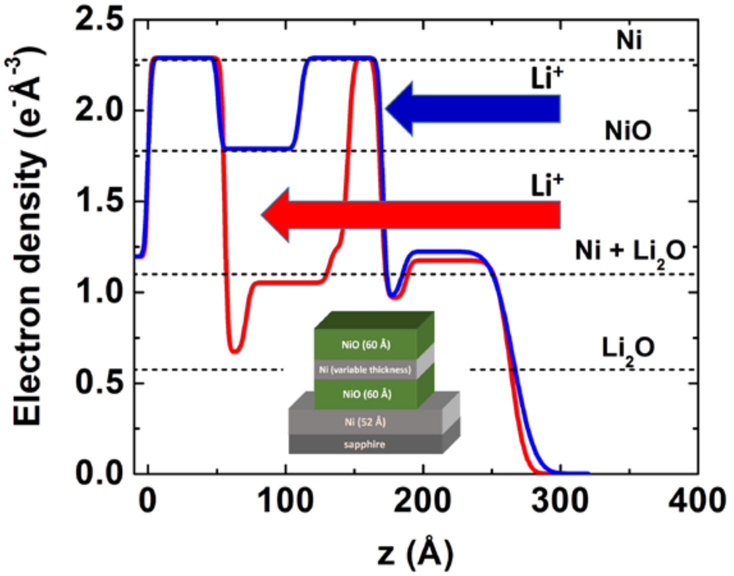
National Nanotechnology Coordinated Infrastructure

sdni San Diego Nanotechnology Infrastructure

Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

Lithiation of Multilayer Ni/NiO Electrodes

The role of nickel buffer layer thicknesses in controlling the Li-ion conversion reaction of Ni/NiO multilayer electrodes is established. The results reveal the topological controls over Li+ transport in digitized architectures for the rational design of multilayer electrodes in lithium ion batteries. Lithiation of multilayer Ni/NiO occurs only when the effective Ni thickness of the bilayer is less than an effective barrier threshold for lithium ion diffusion through Ni. X-ray reflectivity (XRR) data reveal the interfacially-driven phase separation of the NiO at Ni/NiO interfaces that increases the Ni thickness by 3-4 Å and leads to the formation of an adjacent low-density Li_2O layer. Li+ insertion kinetics into the multilayer Ni/NiO electrode is controlled by the charge transfer at the liquid/solid interface rather than diffusion.

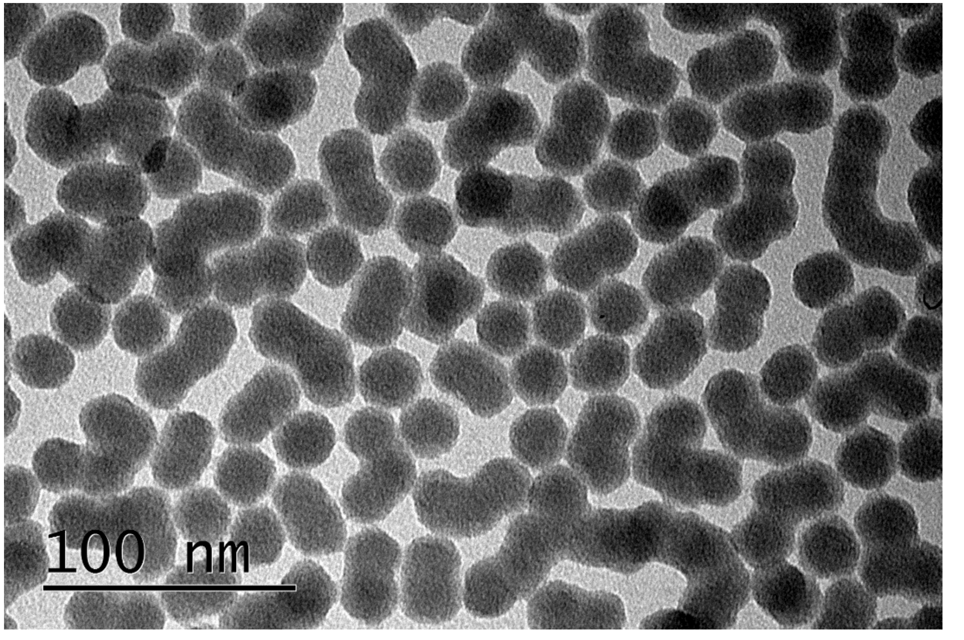


XRR-derived electron density profiles for 2-bilayer Ni/NiO electrodes (16 Å and 58 Å Ni layers) show that Li diffusion is blocked for thicker Ni films.

G. Evmenenko, T.T. Fister, D.B. Buchholz, F.C. Castro, Q. Li, J. Wu, V.P. Dravid,
P. Fenter, M.J. Bedzyk, Northwestern University & Argonne National Laboratory
Work performed in SHyNE Facilities (NU*ANCE* and XRD) & Argonne National Laboratory

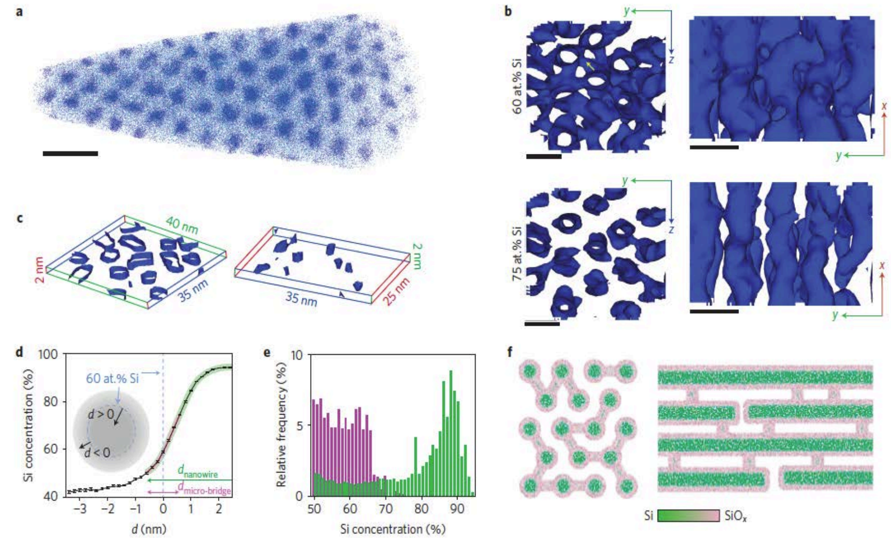
Determination of Silica/Silicon morphology and size distribution

This work applies transmission electron microscopy to identify the structure, morphology, defects and size distribution of powder using in chemical and mechanical polishing, which has wide applications in semiconductor industry. The aggregation, surface structure, defects in the interfaces, etc. are varied and have impacts on the properties. The TEM samples are prepared in the NU*ANCE* Center and the characterization was performed on Hitachi HT-7700 scanning/transmission electron microscope, and Hitachi HD-2300 scanning transmission electron microscope. The TEM images and the analysis on the images provides support product development efforts at Cabot Microelectronics.



Yaobin Xu, Sungkyu Kim, Jinsong Wu, Northwestern University
Work performed in SHyNE Facilities (NU*ANCE*) with Cabot Microelectronics

Heterogeneous and compliant silicon-based mesostructures for phospholipid-supported transient bioelectric devices



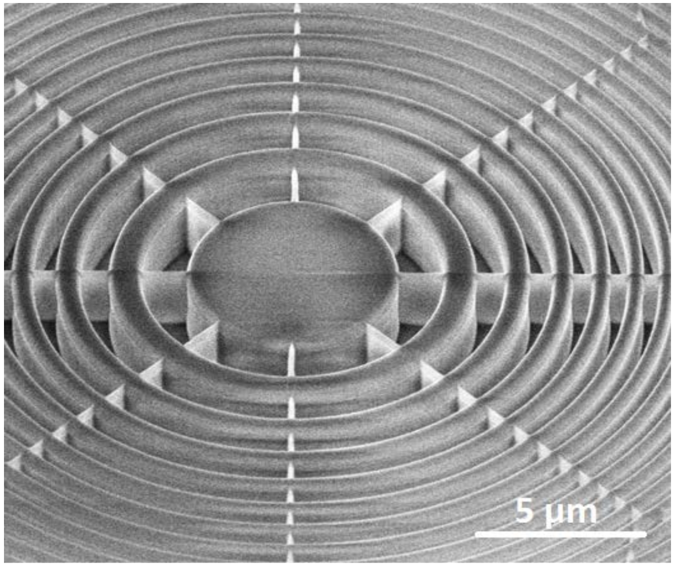
Silicon (Si) is a widely used material in biomedical research because it is biocompatible and biodegradable, and it exhibits a spectrum of important electrical, optical, thermal and mechanical properties. We employed a new nano-casting approach with ordered hexagonal mesoporous silica (SiO2) as a template, in which silane (SiH4) decomposition inside the channels and pores and subsequent etching of the silica generates a nanowire array with self-supporting micro-bridges.

The figure shows mesostructured Si nanowire array with size-dependent chemical heterogeneity. (a) Atom-probe tomography (APT) reconstruction exhibiting hexagonal packing of Si nanowires in meosporous SiO_2 template matrix. Scale bar, 20 nm. (b) The presence of micro-bridges in 60 at.% surfaces (upper) and their absence in 75 at.% surfaces (lower) suggest that the overall Si concentration is less in micro-bridges. Scale bars, 10 nm. (c) Representative slices showing Si nanowires (left) and micro-bridges (right). (d,e) Proximity histogram concentration profiles. (f) End- (left) and side-view (right) schematics of mesostructured Si illustrate the graded Si/SiOx (green/pink) interfaces and the observed chemical heterogeneity between nanowires and micro-bridges.

Y. W. Jiang, J. L. Carvalho-de-Souza, R. C. S. Wong, Z. Q. Luo, J.P. Yue, Y. Wang, X. H. Xiao, L. Navrazhnykh, F. Bezanilla, D. E. Weiss, X. Wu, B. Z. Tian(The University of Chicago), D. Isheim, D. N. Seidman (Northwestern University), X. B. Zuo, I. W. Jung, D.-J. Liu, V. De Andrade, (Argonne National Laboratory), A. W. Nicholls (University of Illinois at Chicago). Work performed in SHyNE Facilities (NUCAPT) in collaboration with UIC and ANL.

Development of ultra-nanocrystalline diamond-based zone plates for hard X-rays focusing

This project aims to fabricate Fresnel zone plates for focusing X-rays in the 2-25 keV photon energy range. The devices are made by deep etching up to 2.5 um of a diamond scaffold with finest structures of 60 nm (aspect ratio >41:1), then cover the scaffold with an atomic layer-deposited absorber metal (W or Pt) and back etch the silicon wafer substrate to form membranes. Figure presents such a structure. Fresnel zone plates are valuable assets for focusing hard X-rays in synchrotron beam lines such as in the Advanced Photon Source (APS) of Argonne National Laboratory and are a part of a strategic development in connection to the latest APS upgrade, aiming to get X-rays focusing to <25 nm at up to 25 keV.

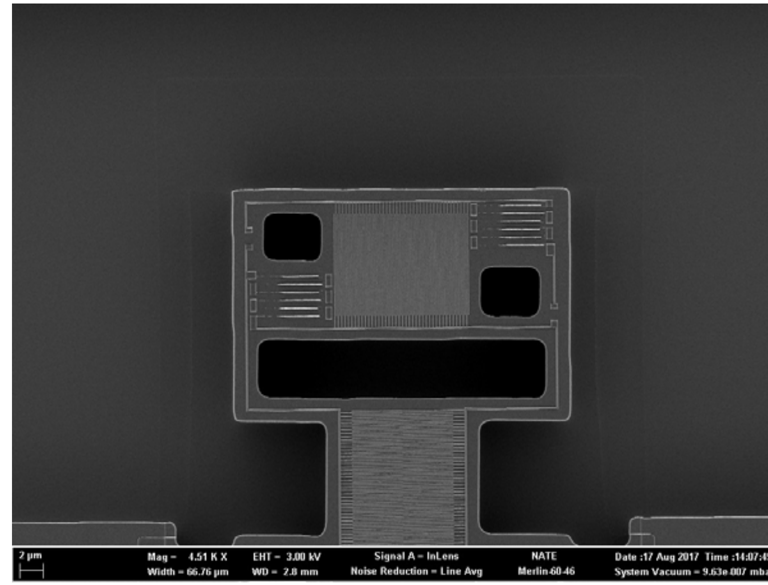


Scaffold for Fresnel zone plate with 2.1-mm-height structures etched into UNCD

Work partially performed in SHyNE Facilities (NUFAB) in collaboration with Nicolaie Moldovan (Advanced Diamond Technologies)

Zero-Pi Device Fabrication

This is a quantum device known as the “Zero-Pi" superconducting circuit. Fabricated in the UChicago Pritzker Nanofabrication Facility, the device includes interdigitated capacitor fingers with a 75nm pitch, stacked Josephson junctions, and a 20um deep Silicon etch. This device is the first of a new class of protected superconducting qubits being developed at the University of Chicago in the lab of Professor David Schuster.

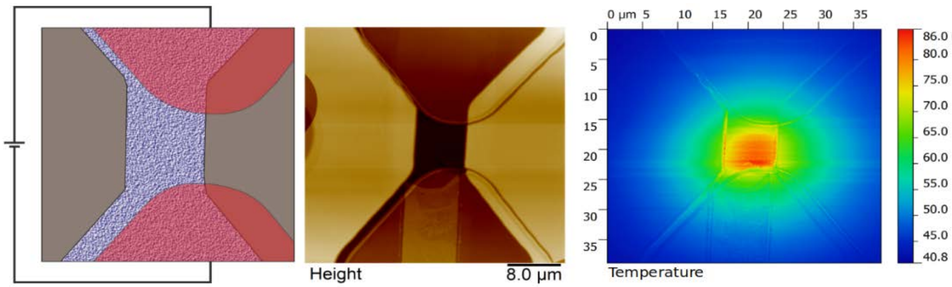


The zero-Pi circuit, fabricated using a 5 layer process involving the PNF’s Heidelberg direct optical writer, the 100 kV Raith ebeam writer, a chlorine ICP plasma etcher, a thermal evaporator, and a deep silicon ICP etch tool.

Nate Earnest, Abigail Shearrow, The University of Chicago
Work performed in SHyNE Facilities (PNF)

Development of Chip-Scale Nanomechanical Thermal Imaging System

The lateral spatial resolution of scanning thermal microscopy (SThM) has hitherto never approached that of mainstream atomic force microscopy, mainly due to poor performance of the thermal sensor. Northwestern team collaborating with Applied Nanostructures developed an innovative nanomechanical system based thermal sensing approach that enables high lateral spatial resolution that is often needed in nanoscale thermal imaging in wide range of applications. This thermocouple-based probe technology delivers excellent lateral spatial resolution (~ 20 nm), extended high temperature measurement of greater than 760° C without cantilever bending, and a very high thermal sensitivity (≈ 0.04 ° C). The origin of significantly improved figures-of-merit lies in the novel probe design that consists of a hollow silicon tip (low thermal mass) integrated with a vertically oriented small thermocouple sensor at the apex which interacts with the sample through a metallic nanowire, thereby offering high lateral resolution. We demonstrated wide range of applications such as thermal failure in polymeric interconnects, thermal transport in layered structures and biomedical imaging. The nanoscale pitch and extremely small thermal mass of the probe promise significant improvements over existing methods and wide range of applications in semiconductor structures/devices, biomedical imaging, and data storage.



Surface temperature mapping of a silicon micro heater. Left panel: schematic of the silicon microheater showing different degrees of ion implanted areas. Gray is plain silicon, blue is low dose implant and pink is high dose implant overlying plain silicon and low dose areas. Middle panel: topography and Right panel: TMM image. The temperature image captures the point-to-point variations in the surface temperature due to joule heating at the center and diffusion of heat by the underlying silicon.

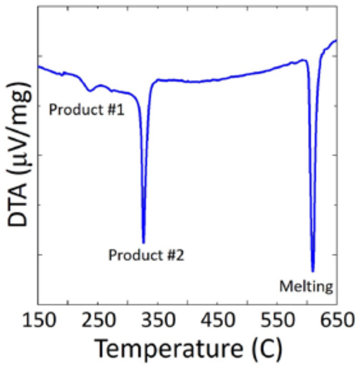
Gajendra Shekhawat, Northwestern University
Work performed in SHyNE Facilities (NU*ANCE*) in collaboration with Applied Nanostructures

National Nanotechnology Coordinated Infrastructure

SHyNE Soft and Hybrid Nanotechnology Experimental Resource

In-situ X-ray powder diffraction

Real time monitoring of the formation of kinetic and thermodynamic products in a reaction is extremely important for the synthesis, isolation, and growth of new materials. Powder X-ray diffraction methods are proven to be an excellent probe for such in-situ experiments. X-ray radiation of an appropriate wavelength can penetrate through the reaction vessel or device and provide diffraction information about solid-to-solid reactions, transformations, gas-to-solid interactions, liquid-to-solid crystal growth processes, and decomposition products. This technique can be used to monitor reactions in real time as a function of time, temperature, pressure, and gas flow/pressure, monitoring crystallization processes, accelerated aging testing, phases identification in small samples (supporting green and combinatorial synthetic schemes and to probe catalytic changes to substrates.

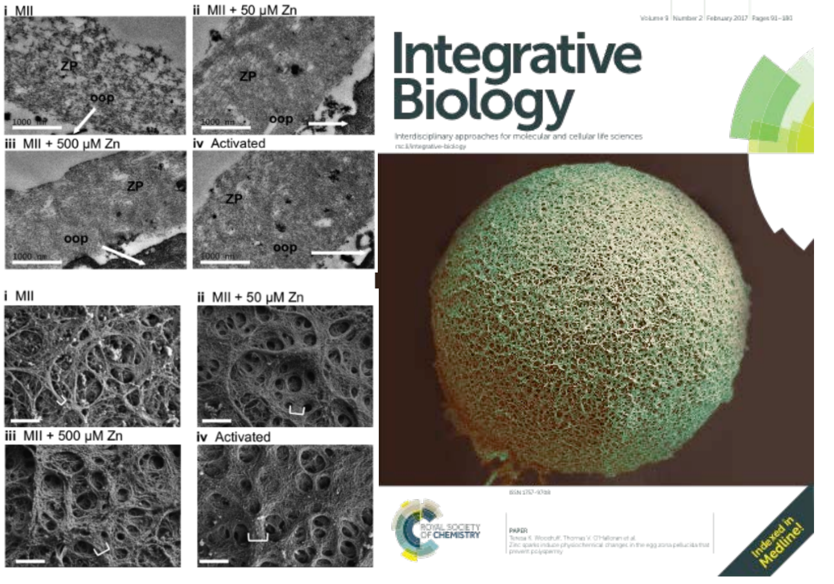


Example of an in-situ diffraction pattern of a mixture of solid starting materials (left plot) showing two transformations and a melting event during heating. Thermal analysis (right plot) is a powerful complementary technique for probing thermal events in unexplored reaction systems.

Christos Malliakas, Northwestern University
Work performed in SHyNE Facilities (IMSERC).

Investigating Physiochemical Changes to Egg Zona Pellucida with TEM and SEM

Mouse eggs were chemically processed for ultramicrotomy/TEM analysis and SEM imaging. Exposure to various concentrations of Zinc induce changes to the structure of the mouse egg zona pellucida. Zinc appears to tighten the structure preventing polyspermy. This work appeared in the February 2017 issue of Integrative Biology.



TEM and SEM micrographs reveal changes to egg coating (zona pellucida) as a result of Zn exposure.

Sample provided by Emily Que, Northwestern University, O'Halloran Lab
Work performed in SHyNE Facilities (NU*ANCE*).

Characterization of High Entropy Alloys

QuesTek INNOVATIONS LLC

QuesTek Innovations LLC has utilized the NU*ANCE* Center for a variety of purposes, including characterization of High Entropy Alloys (HEAs) under an ongoing Department of Energy SBIR program. Under this study, QuesTek made use of the Hitachi S-3400 equipped with a backscatter detector and energy dispersive spectroscopy (EDS) system to obtain images such as the one shown below, and used the data from the images and EDS results to select heat treatments for the alloys. This work was performed by a Northwestern University undergraduate student who was working as a summer intern at QuesTek.

QuesTek has also used the FEI Quanta 650's EBSD capability to analyze texture and recrystallization behavior in metal alloys, and the FEI Helios FIB/SEM to fabricate samples for analysis in the Local Electrode Atom Probe (LEAP), where nanoscale features can be examined with a high level of accuracy.

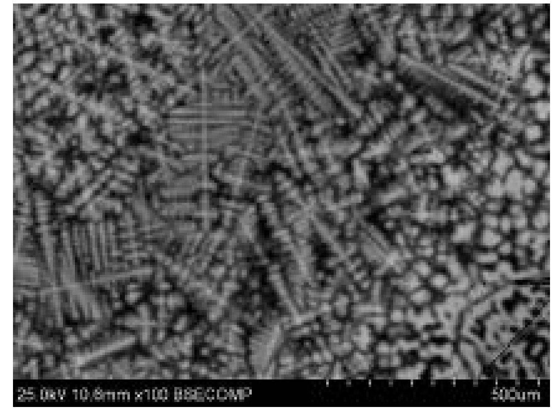
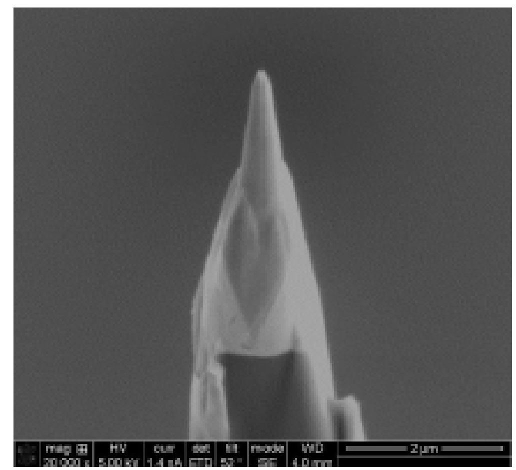


Image taken with the Hitachi S-3400 showing dendritic microstructure



Example image of LEAP sample fabricated in the Helios FIB/SEM

Work performed in SHyNE Facilities (NU*ANCE*) in collaboration with QuesTek Innovations, LLC

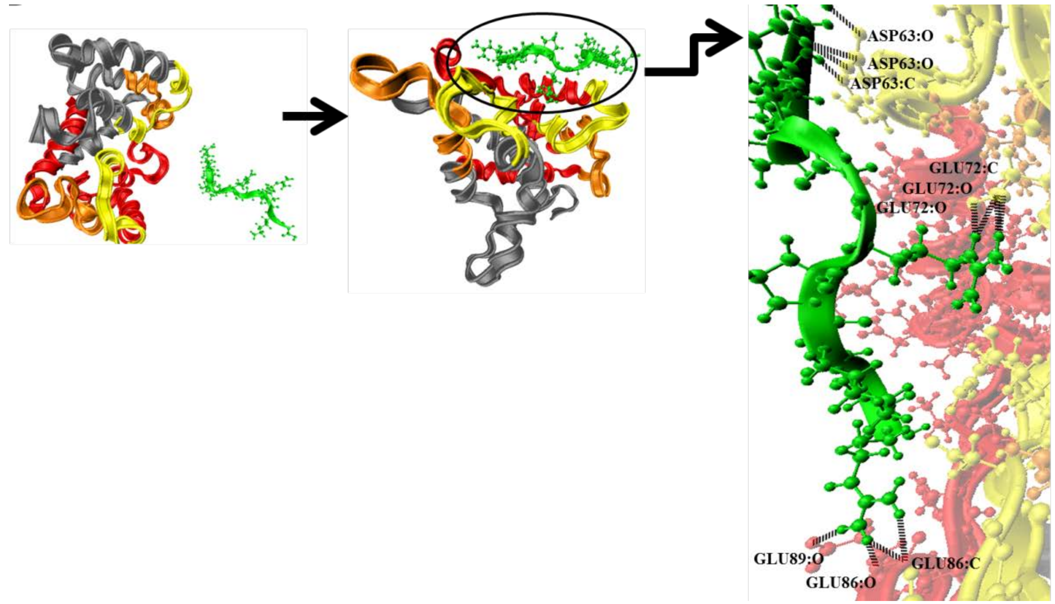
National Nanotechnology Coordinated Infrastructure

SHyNE Soft and Hybrid Nanotechnology Experimental Resource

Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Simulations of S100B Protein with Peptide aptamers

This work highlights the design and modeling of peptide aptamers specific for S100B protein. Multiple aptamers were created in-silico for high affinity binding region (residue 62 to 73) of the S100B protein. These combinations were modeled using GROMACS in saline environment with calcium. The peptides we designed were bound to the S100B protein in the high affinity region. The average binding distance between the atoms was 1.57Å. Variation in the calcium concentration and repeat experiments show continued interaction with the high affinity binding region of the S100B Protein.



A ribbon, ball and stick representation of a molecular dynamics simulation of peptide$_\beta$ (green) with the S100B protein (note the high affinity region is highlighted in yellow). The image shows snapshots on the initial and final conformations with the final binding conformation highlighted

Kristen Rhinehardt, Ram Mohan, North Carolina Agricultural and Technical State University
Work performed at the Joint School of Nanoscience and Nanoengineering

Pitch-Induced Bandgap Tuning in Self-Catalyzed GaAsSb Axial NWs using Molecular Beam Epitaxy

This work targets on the scalability and reliable performance of nanowire (NW)-based electronic device. It explored the pitch-induced effect on the geometry, absorption and band gap tuning in GaAsSb axial and core-shell (C-S) configurations, providing a new pathway for band gap engineering. The optimization of process and growth parameters result in a growth of >90% occupancy of GaAsSb axial and C-S on the patterned holes. The secondary fluxes re-emitted from the side facets of the neighboring NWs were found to contribute substantially towards the growth for smaller pitch lengths, while those from the oxide surface dominate at larger pitch lengths for high V/III beam equivalent pressure ratios. Excellent agreement between the experimental and simulated results have been observed for the pitch dependent axial and radial NW dimensions of the axial and C-S configured GaAsSb NWs.

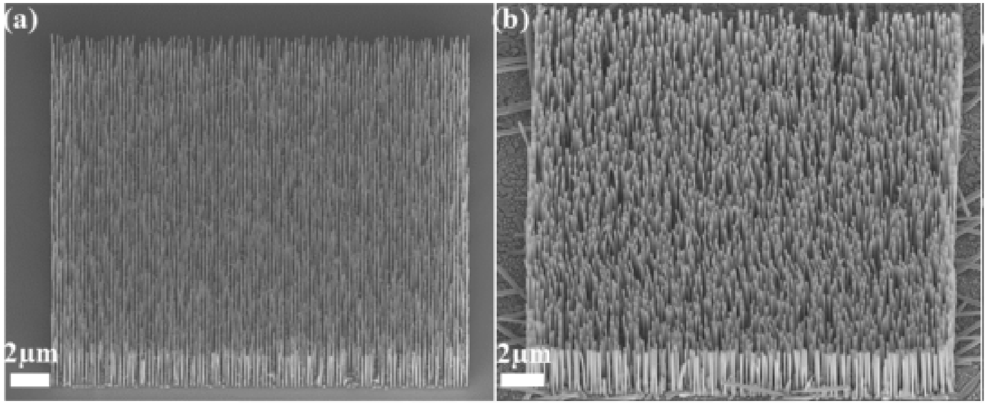


Figure 1: (a) SEM images of patterned growth of GaAsSb (a)axial and (b) core-shell NWs.

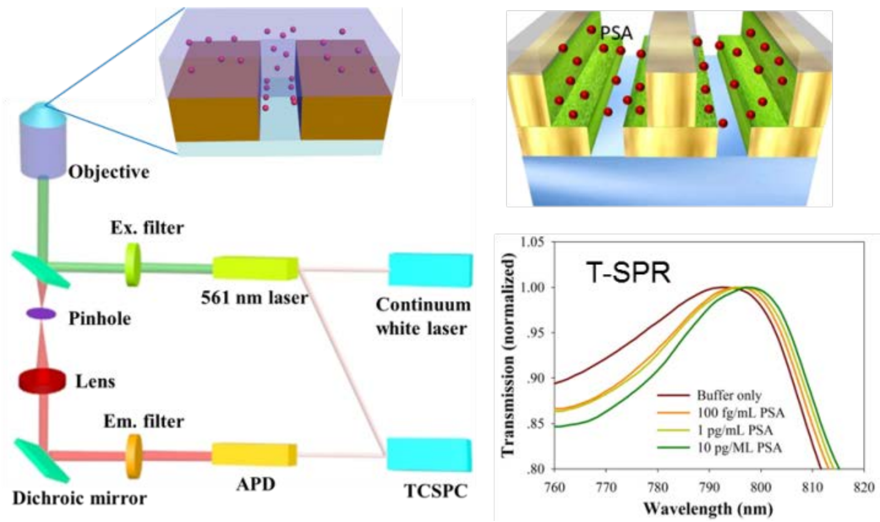
Shanthi Iyer, Manish Sharma, Pavan Kasanabonia, North Carolina A&T State University.

This work is financially supported by Army Research Office and National Science Foundation.

Work performed at the Joint School of Nanoscience and Nanoengineering

Protein Trapping in Plasmonic Nanoslit and Nanoledge Cavities: The Behavior and Sensing

A novel plasmonic nanoledge device was presented to explore the geometry-induced trapping of nanoscale biomolecules and examine a generation of surface plasmon resonance (SPR) for plasmonic sensing. To design an optimal plasmonic device, a semianalytical model was implemented for a quantitative analysis of SPR under plane-wave illumination and a finite-difference time-domain (FDTD) simulation was used to study the optical transmission and refractive index (RI) sensitivity. In addition, total internal reflection fluorescence (TIRF) imaging was used to visualize the migration of fluorescently labeled bovine serum albumin (BSA) into the nanoslits; and fluorescence correlation spectroscopy (FCS) was further used to investigate the diffusion of BSA in the nanoslits. Transmission SPR measurements of free prostate specific antigen (f-PSA), which is similar in size to BSA, were performed to validate the trapping of the molecules via specific binding reactions in the nanoledge cavities. The present study may facilitate further development of single nanomolecule detection and new nanomicrofluidic arrays for effective detection of multiple biomarkers in clinical biofluids.



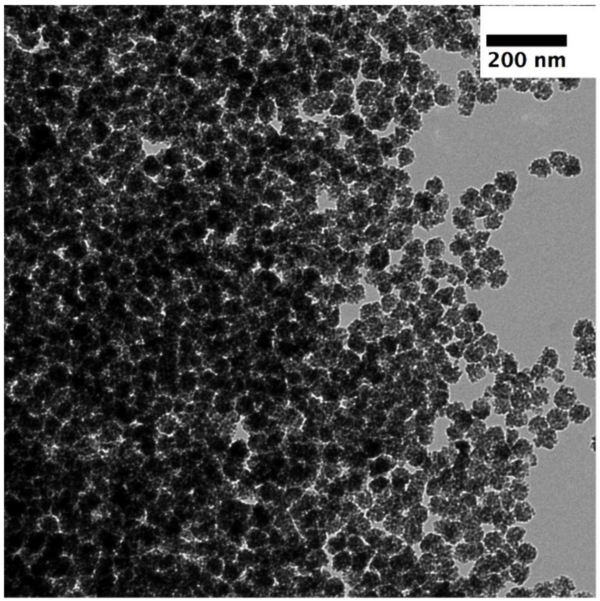
Zheng Zeng, Xiaojun Shi, Taylor Mabe, Adam W. Smith, Jianjun Wei*, *Anal. Chem.*, 2017, 89 (10), pp 5221–5229; University of North Carolina at Greensboro. Work performed at Joint School of Nanoscience and Nanoengineering

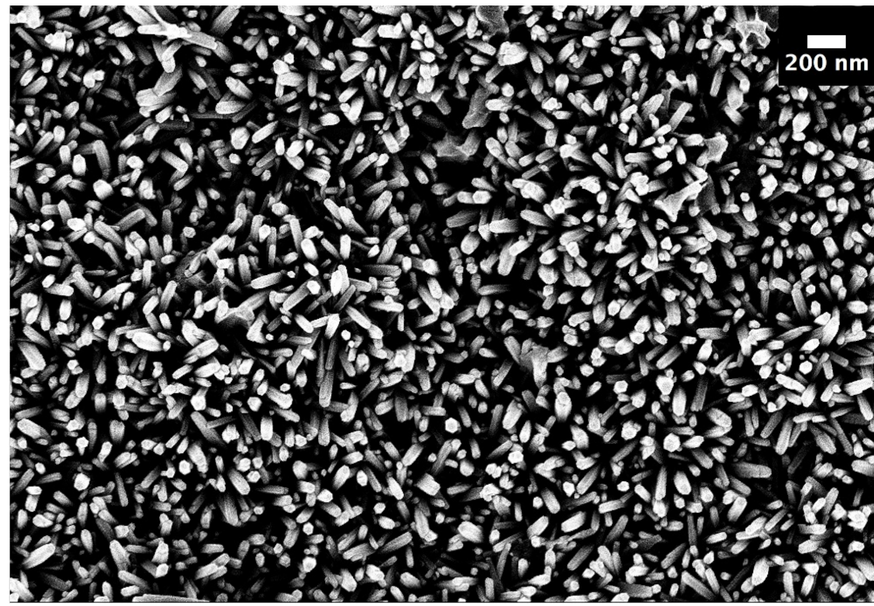
National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

Aligned Zinc Oxide Nanorods as Interfacial Layer for Tandem Solar Cells

This work targets exploring large-scale green synthesis process to make thin films of aligned metal/metal oxide nanorods as potential interfacial layer for solar cells with tandem device architecture. Our group has developed a simple wet-aqueoues based green synthesis method to make metal/metal oxide nanostructures with ordered morphology.



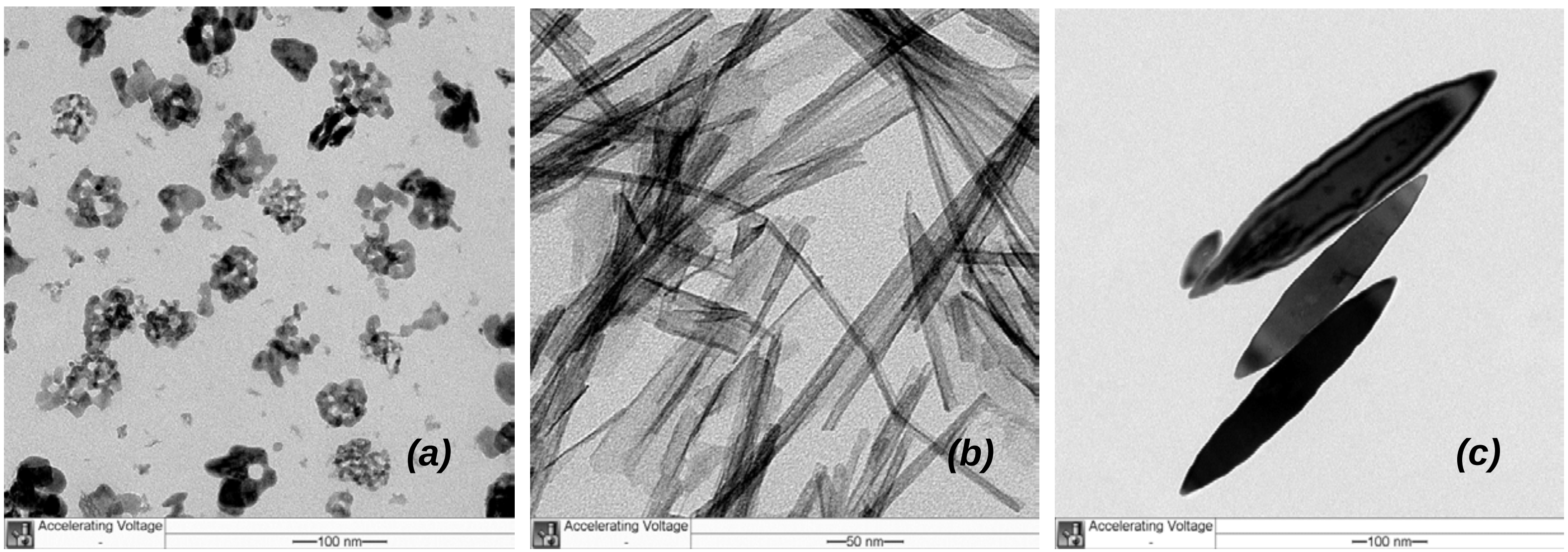


TEM image of ZnO Seeds (left) and SEM micrograph of aligned ZnO Nnaorods (right) on glass susbtrate grew from aquoues sol-gel process.

Klinton Davis and Hemali Rathnayake, Nanoscience Department, University of North Carolina Greensboro.
Work performed at Joint School of Nanoscience and Nanoengineering

Morphology control of TiO_2 based Nanostructures

This work focuses on the morphology control of TiO_2 based nanostructures, thus tailoring the optical performance of these unique nanomaterials. TiO_2 nanoparticles are assembled to black TiO_2 nanocages, titanate nanotubes and TiO_2 nanospindles by hydrothermal processes. The morphology and composition changes in the TiO_2 structure offer distinct optical properties comparing to the spherical TiO_2 analogues.

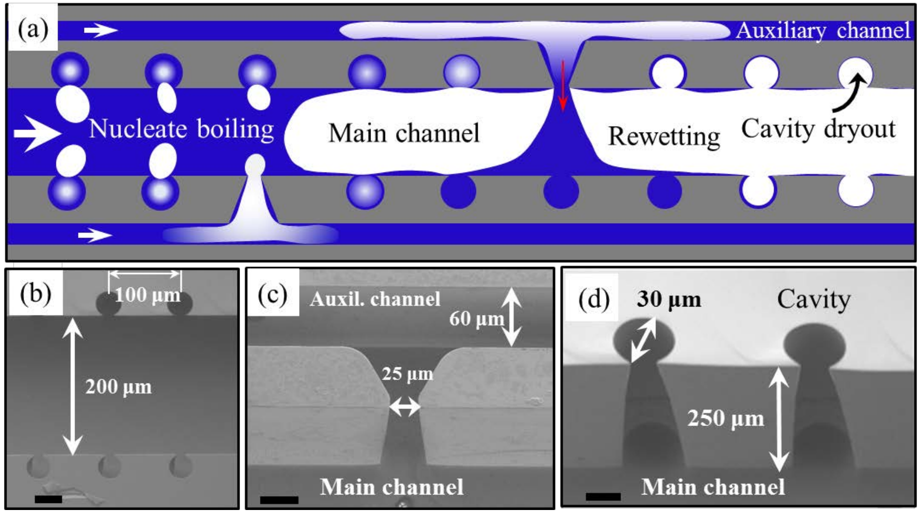


TEM micrographs of TiO_2 based nanostructures synthesized from hydrothermal process for tailoring the optical performance. (a) Black TiO_2 nanocages, (b) Titanate nanotubes, (c) TiO_2 nanospindles.

Nikita Kevlich, Sean Davis, Gordon Zhang and Bryan Koene, Luna Innovations Inc.
Work performed at Joint School of Nanoscience and Nanoengineering

Enhanced Flow Boiling in Microchannels at a Reduced Mass Velocity

In a microchannel configuration, higher mass velocity can lead to enhanced flow boiling performances, but at a cost of two-phase pressure. It is highly desirable to achieve a high heat transfer rate and critical heat flux (CHF) exceeding 1 kW/cm^2 without elevating pressure drop, particularly, at a reduced mass velocity. In this study, we developed a microchannel configuration that enables more efficient utilization of coolant through integrating multiple microscale nozzles connected to auxiliary channels as well as microscale reentry cavities on sidewalls of main microchannels, as shown in Fig. 1. Two primary enhancement mechanisms are: (a) the enhanced global liquid supply by four evenly-distributed micronozzles, particularly near outlet region, and (b) the effective management of local dryout by capillary flow-induced sustainable thin liquid film resulting from an array of microscale cavities. This project was supported by ONR under N00014-12-10724



Concept and structure of the microchannel with integrated multiple microscale nozzles and reentry cavities. (a) Improved global liquid supply to main channels through auxiliary channels via nozzles, the bubbles nucleate from nozzles and cavities, and local liquid spreading by microscale reentry cavity-induced capillary flows. (b) SEM (Scanning Electron Microscope) image of a top view of the main channel integrated with embedded reentry cavities (cavity dimensions: diameter = 30 µm, opening =6 µm, distance = 100 µm). (c) SEM of a micronozzle from aerial view of 45o, which connects both auxiliary and main channels. (d) SEM of two reentry cavities inside the sidewall. (All scale bars are 40 µm).

Wenming Li, Fanghao Yang, and Chen Li, University of South Carolina
Work performed at GT Institute for Electronics and Nanotechnology

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor

Submicron area resonant tunnelling diodes defined through ohmic contacts

The most common means of isolating the active area of resonant tunnelling diodes (RTDs) is through mesa etching. Such a process, especially when done with reactive ion etching, leaves space-charge regions on the sidewalls of the mesa structure. This introduces an additional current component through the RTD, degenerating the peak-to-valley current ratio (PVCR).

In literature it has been shown that the PCVR of the RTD can be preserved when scaling below submicron dimensions by a simple shallow etch, only removing material from the doped contact layers. Submicron dimensions have also been achieved through the use of Schottky contacts, although this would not preserve the symmetrical characteristic curve of the RTD.

In our work, we propose the use of annealed ohmic contacts to replace the doped contact layers of the RTD. Annealing of Germanium into semi-insulating Gallium Arsenide layers has shown a sharp change in doping concentration as the depth of the contact is examined. This sharp doping change is the key to submicron active area isolation.

A. Gaskell, T. Stander, W. E. Meyer, and H. E. Beere, Carl and Emily Fuchs Institute for Microelectronics (CEFIM), University of Pretoria, South Africa
Work performed at GT Institute for Electronics and Nanotechnology

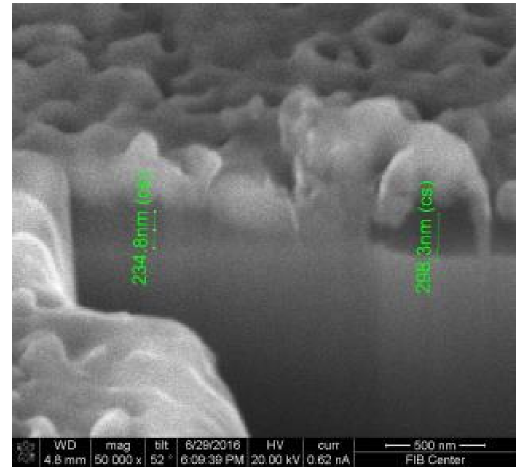


Figure 1: A SEM cross-section of a 400 nm contact hole in silicon dioxide, filled with copper to mimic the contact.

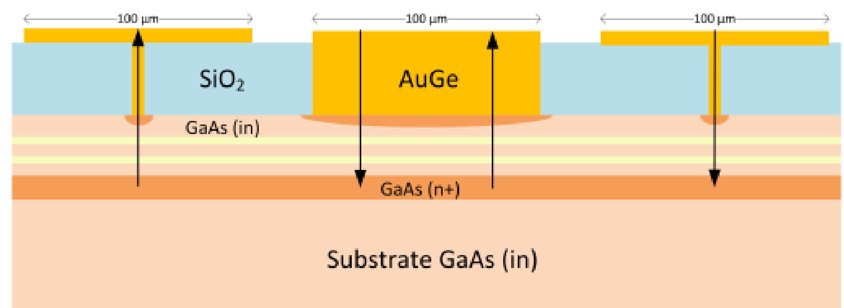
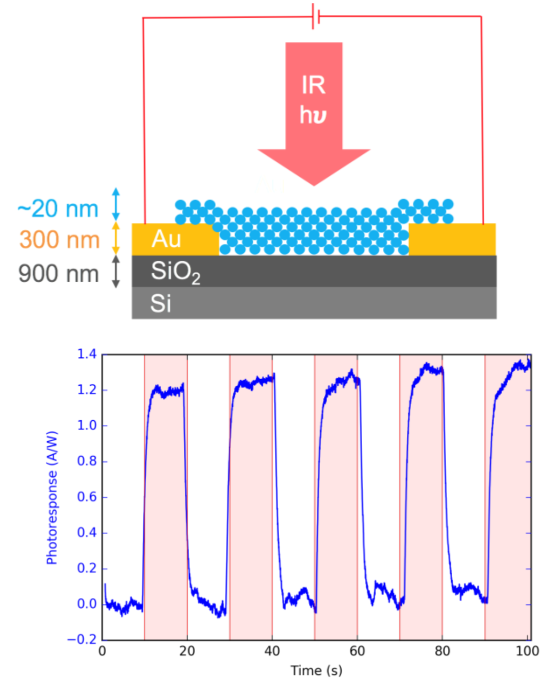


Figure 2: A schematic of a Goto latch RTD series pair created through ohmic contact fabrication.

Plasmonic ITO Nanocrystal Infrared Photodetector

Metal-insulator-metal (MIM) devices, which utilize a rectifying diode together with an infrared (IR) antenna, offer a route to convert infrared photons into electrical current. We seek to advance the design of MIM thermal radiation photodetectors and energy harvesting devices by leveraging the localized surface plasmon resonances (LSPRs) of ITO nanocrystals as deep sub-wavelength IR antennas.

A symmetric test structure was utilized for photoresponse measurements (top). Photoresponse values near 10^{-7} A/W at a bias of 1V were measured (bottom). To our knowledge, this is the first demonstration of photoresponse from infrared LSPRs. Work is on-going to improve the photodetector's design and to also explore energy harvesting devices.

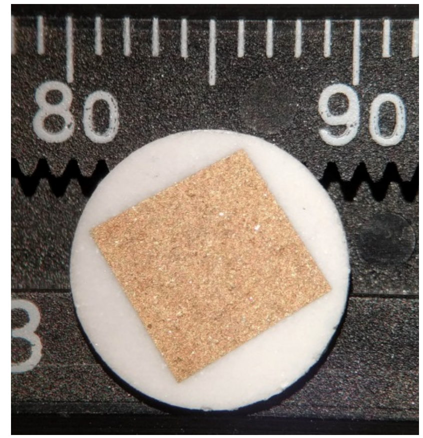


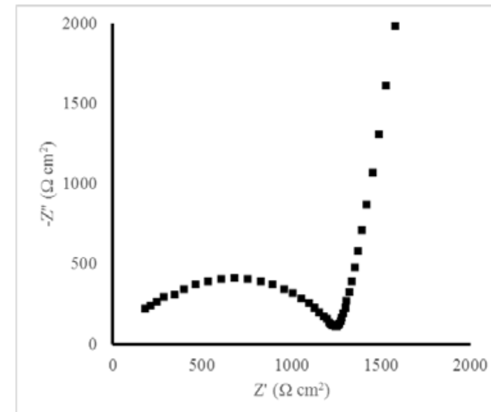
A schematic of an ITO NC film characterization platform and an IR photoresponse measurement as a function of time at bias of 1V across the NC film.

Dmitriy A, Boyuk, Weize Hu and Michael A. Filler, Georgia Institute of Technology
Work performed at Georgia Tech's Institute for Electronics and Nanotechnology (IEN Seed Grant)

Controlling Interfaces in Ceramic Ion Conductors for Next-Generation Lithium Batteries

The goal of this work is to design, synthesize, and test new protection layers for solid-state batteries to enable long term operation of these devices. Solid-state batteries are promising energy storage systems, but instabilities at interfaces between solid electrolytes and electrodes limit performance. Here, we have fabricated different types of solid electrolyte materials, and we have used thin film deposition methods to deposit protection layers at interfaces. This project has set the stage for in situ measurement of interface reactivity and transformation processes that will provide fundamental insight into the stability of these materials.



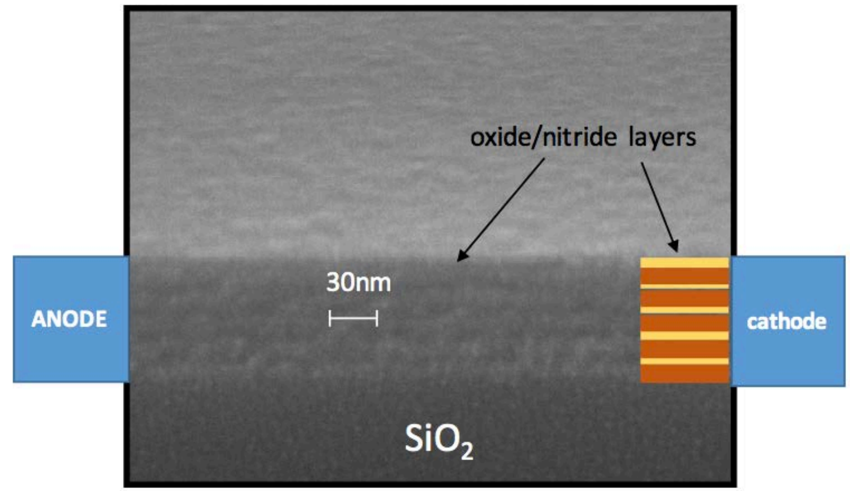


Left: Sintered solid-state electrolyte pellet with gold film as an electrical contact. Right: electrochemical impedance spectroscopy of pellet showing high ionic conductivity.

Prof. Matthew T. McDowell, Francisco Quintero Cortes, David Yeh, Georgia Institute of Technology
Work performed at Georgia Tech's Institute for Electronics and Nanotechnology (IEN Seed Grant)

Dielectric Interfacial Capacitive Energy Storage (DICES) Device Fabrication

This work is focused on optimizing fabrication methods for an experimental planar capacitor that will be used to study the electrical properties of the interfaces between nanolaminate layers of metal oxide materials (see figure). This research derives its motivation from variety of experimental studies of nanoparticle composite materials that have revealed possible anomalous polarization properties at the surface of metal-oxide nanoparticles. This new experimental test structure has been adapted to more readily and directly characterize interfacial polarization than in randomize nanoparticle structures. With thin enough laminates, this structure can possibly achieve a higher energy density than its nanoparticle equivalents.

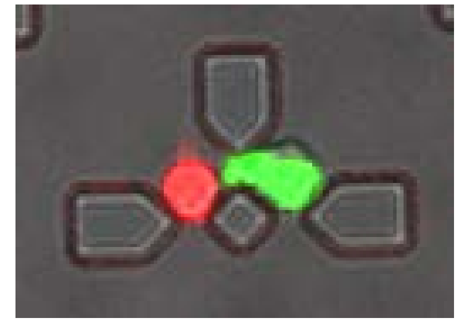


SEM micrograph nanolamanate layers to be used in a planar capacitor structure used to study the interfacial polarization properties between materials.

Blaine Costello, Zeinab Mousavi-Karimi and Jeff Davis, Georgia Institute of Technology
Work performed at Georgia Tech's Institute for Electronics and Nanotechnology (IEN Seed Grant)

Leveraging Microfabricated Systems to Investigate Direct Neutrophil-to-Neutrophil Communication

Neutrophils are a specialized subset of white blood cells crucial to the innate immune response. Upon activation, they migrate to a site of infection, engulf invading microbes, and release soluble factors to activate additional immune cells. Interestingly, recent studies have shown that as neutrophils surround a site of infection, they behave in concert and physically “merge” with each other, and then induce reprogramming in their neighboring adjacent cells, but this process is poorly understood. To study these phenomena, the Lam lab has created a microfluidic device to monitor neutrophils at a single-cell level, exploring both biological and biophysical methods of direct neutrophil-neutrophil communication in real time.



This microfluidic device consists of two paired sets of inlets and outlets surrounding a 0.5 cm by 0.5 cm capture area. Within the capture area, T-shaped traps are designed to study cell signaling. Using the paired inlets and outlets, heterotypic cell types can be placed in close proximity and communication can be monitored.

Meredith E. Fay and Wilbur A. Lam, Georgia Institute of Technology and Emory University
Work performed at Georgia Tech’s Institute for Electronics and Nanotechnology

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.

This work was highlighted in a number of science media, and was featured on the homepage of the National Science Foundation.

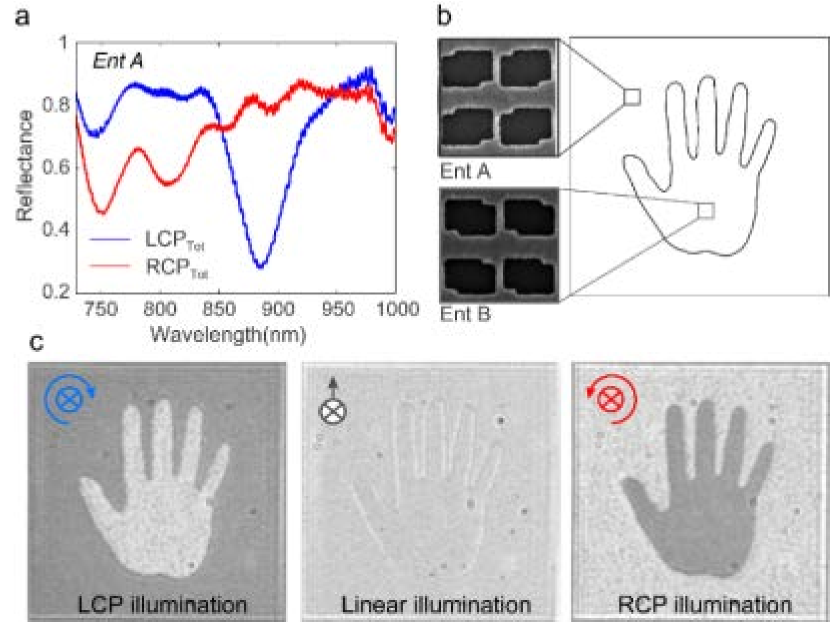


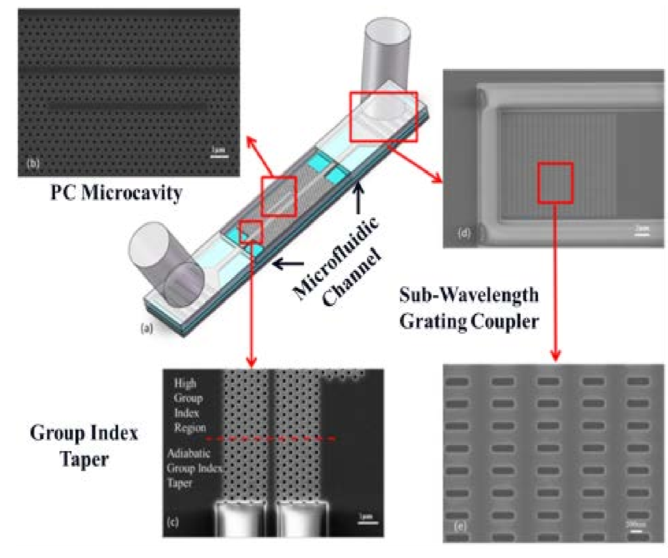
Figure. (a) Measured circular dichroism spectra of a chiral metamaterial. (b) Schematic of enantiomeric placement in the pattern. (c) Imaging of the chiral pattern under linear and circularly polarized lights.

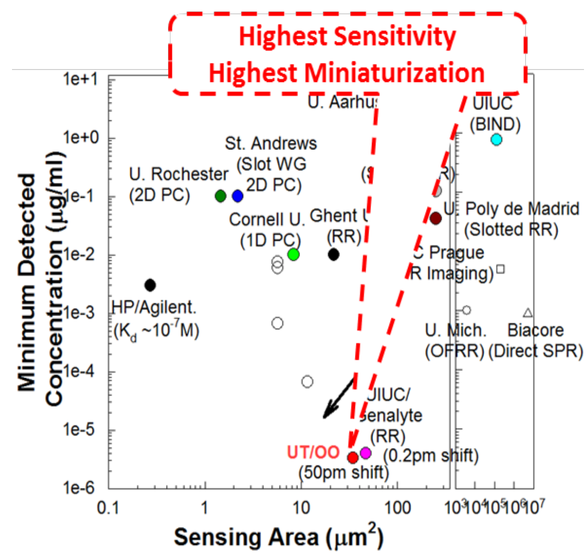
Wenshan Cai, Georgia Institute of Technology
Work performed at Georgia Tech's Institute for Electronics and Nanotechnology

Texas Nanofabrication Facility (TNF)

Silicon Nanophotonic Biosensor Chip for Lung Cancer Detection

With recent advances in optoelectronics and photonics, optical biosensors have flourished in the area of healthcare. Optical biosensors are typically built of three parts: a light source and detector, a photonic crystal substrate, and an analyte flow mechanism made of microfluidic channels. However integrated sensor size have to balance contradictory requirements of resonance quality factor and sensitivity. By simultaneous control of the radiation loss and optical mode volumes, Prof Chen group shown that both requirements can be satisfied simultaneously. Microcavity sensors are designed in which resonances show highest Q ~ 9300 in the bio-ambient phosphate buffered saline as well as highest sensitivity among photonic crystal biosensors. We experimentally demonstrated mass sensitivity 8.8 atto-grams with sensitivity per unit area of 0.8 pg/mm2. Highest sensitivity, irrespective of the dissociation constant K_d, is demonstrated among all existing label-free optical biosensors in silicon at the concentration of 0.1μg/ml





R Chen – University of Texas & Omega Optics,
Work performed at UT Microelectronics Research Center

National Nanotechnology Coordinated Infrastructure

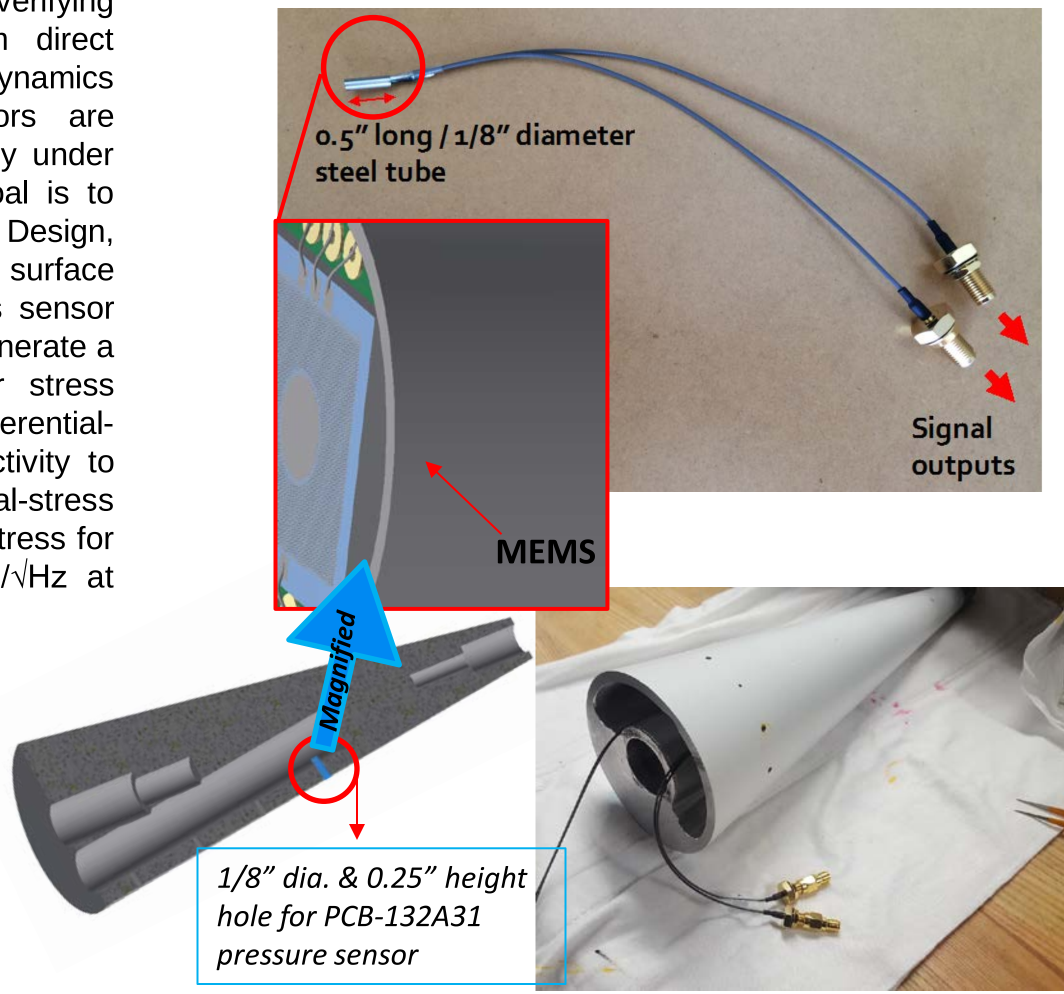
TEXAS The University of Texas at Austin

Sensors for drag measurements at hypersonic speeds

The ability to measure viscous wall shear stress in high-speed flows is important for verifying simulated results typically obtained from direct numerical simulation in the aerodynamics research community, and robust sensors are required to measure wall shear reliably under such high-speed conditions. AFOSR Goal is to design vehicles for Mach 5 – Mach 10. Design, fabrication, and testing of a surface micromachined piezoelectric shear-stress sensor which uses a thin piezoelectric film to generate a voltage proportional to an applied shear stress without moving parts are developed. A differential-cell architecture is used to enhance selectivity to shear stress while canceling normal-stress sensitivity. The minimum detectable shear stress for the sensor is estimated to be 52.9 mPa/√Hz at 1.5kHz.

N Hall– University of Texas & Silicon Audio, Work performed at UT Microelectronics Research Center

Rendering (left) and real Mach-6 testing setup of a complete package (right) for field testing at UT, Purdue, and U of Arizona.



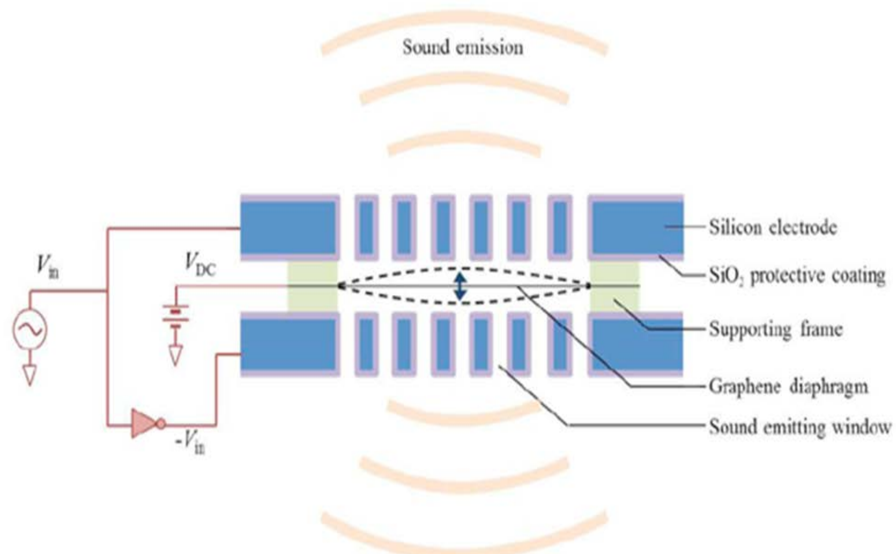
National Nanotechnology Coordinated Infrastructure

TEXAS
The University of Texas at Austin

Graphene Enabled Acoustics

GraphAudio is a California-based company taking technology from research lab to market. GraphAudio is developing a new generation of graphene based micro audio componentry that will outperform the current generation and open new realms of capabilities. Graphene enabled acoustic devices with no distortion are running on much lower power and having much better form factors than current technology. In production, GraphAudio graphene transducers can be economically produced in high volume utilizing high technology foundries for micro-speakers, mobile devices, earbuds and headphones in the next three to five years. GraphAudio's patent pending graphene based transducer delivers an electrostatic micro speaker and enhancements through digital manipulation that is the solution to unlock a revolution in micro audio componentry. UT MRC team are coordinating goals with researchers at UC Berkeley and UN Lincoln.

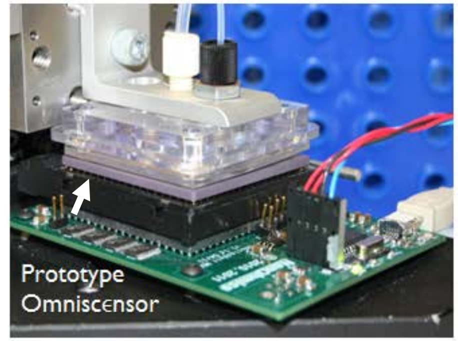
Burt Fowler and Harry Chou for GraphAudio, Synthesis, characterization, and fabrication performed at UT Microelectronics Research Center



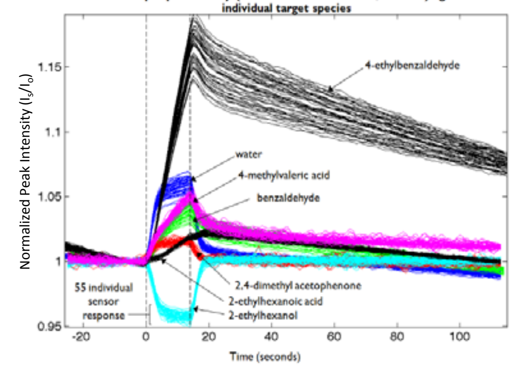
Transducer design functions as speaker or microphone, or both.
Graphene diaphragm is thinner, stronger and more responsive.
Air dampening improves response and energy efficiency.
New range of acoustic capabilities individually or in arrays

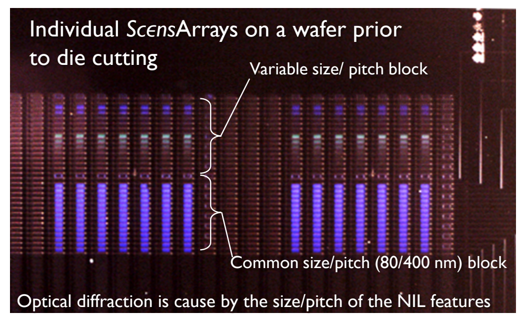
Multiplexed Metal-Oxide Gas and Fluid Sensor Arrays

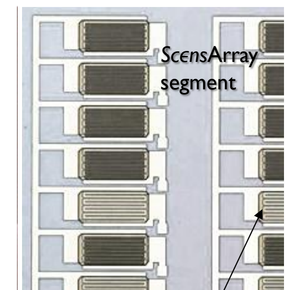
Bioassays employed to evaluate the diverse range of biomarkers associated with organ injury are time-consuming, costly and require multiple instruments/testing formats to reach a diagnosis (i.e. fluorescence-based capture, ELISAs, PCR, etc.). Individually, these platforms are incapable of predicting the onset of irreversible organ tissue injury (e.g. kidney, liver, heart and lung). One barrier to transitioning microarray technology into multiplex medicinal diagnostics has been the limitations imposed by fluorescence/optical-based labeling and endpoint detection. To overcome these limitations, Nanohmics Inc., developed the SnO_2 nanowire chemiresistive sensor array. The diverse surface derivitizations across array elements allows for incident gas/ion species identification. The platforms are room temperature operable and provide fast response in gas applications. Integration efforts are underway with commercial ROIC (DHP Phase II SBIR Program and NIH Phase I SBIR Program)

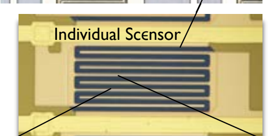


64 Channel vapor profile array (56 sensors- underivatized, 8 blanks) against seven individual target species

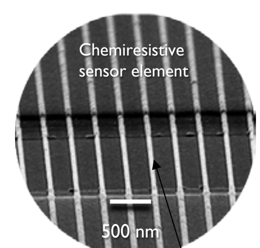


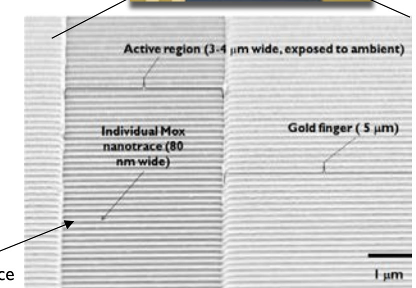






Imprinted SnO_x transducers



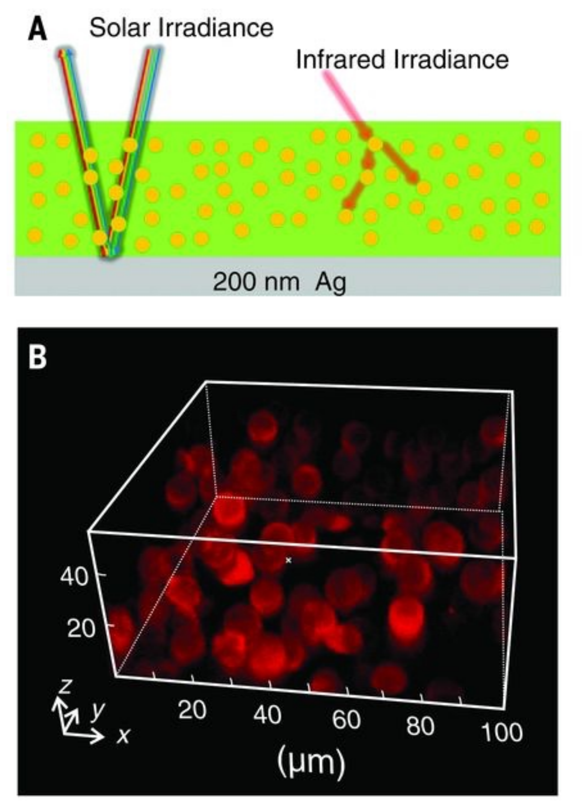


Individual 80 nm SnO_2 nanotrace

Nanohmics work is performed in part at UT Microelectronics Research Center using JEOl EBL, Trion Etcher, Oxford RIE, Imprio 100, SussMicrotec MA6, Zeiss Neon 40 SEM and ADT dicing saw.

Fabrication of metamaterials for efficient passive cooling

Passive radiative cooling draws heat from surfaces and radiates it into space as infrared radiation to which the atmosphere is transparent. However, the energy density mismatch between solar irradiance and the low infrared radiation flux from a near-ambient-temperature surface requires materials that strongly emit thermal energy and barely absorb sunlight. We embedded resonant polar dielectric microspheres randomly in a polymeric matrix, resulting in a metamaterial that is fully transparent to the solar spectrum while having an infrared emissivity greater than 0.93 across the atmospheric window. When backed with a silver coating, the metamaterial shows a noontime radiative cooling power of 93 watts per square meter under direct sunshine. More critically, we demonstrated high-throughput, economical roll-to-roll manufacturing of the metamaterial, which is vital for promoting radiative cooling as a viable energy technology.
Heat in emit IR radiation Materials: no absorbance and high thermal emittance. Material: polymer matrix and glass beads backed with metal coating cooling by
10-15C below ambient (Zhai et al., Science 355, 1062 - 2017).
Instruments used: e-beam evaporator, optical microscope, UV-VIS/NIR spectroscopy.



*Spectroscopic response of the hybrid metamaterial. (**A**) Schematic of the hybrid metamaterial backed with a thin silver film. The silver film diffusively reflects most of the incident solar irradiance, whereas the hybrid material absorbs all incident infrared irradiance and is highly infrared emissive. (**B**) Three-dimensional confocal microscope image of the hybrid metamaterial. The microspheres are visible because of the autofluorescence of SiO_2.*

Prof. A Heltzel – University of Texas & PC Krause and Associates,
Work performed at Texas Materials Institute

National Nanotechnology Coordinated Infrastructure

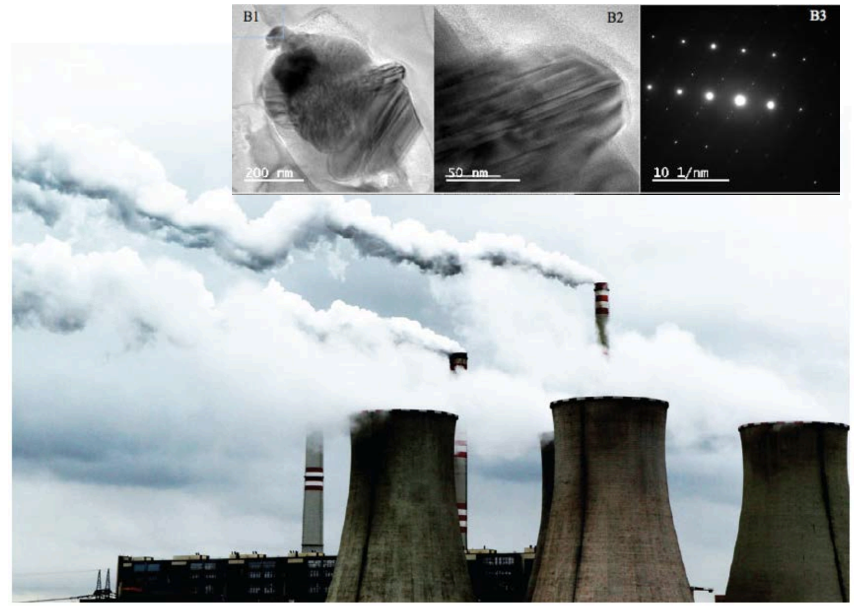
TEXAS The University of Texas at Austin

Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth)

Discovery of incidental Magnéli phase generation and release from industrial coal-burning

This work shows for the first time that burning coal produces large quantities of otherwise rare Magnéli phase nanoparticles (Ti_xO_{2x-1} with $4 \le x \le 9$) from TiO_2 minerals naturally present in coal. This provides a new tracer for tracking solid-state emissions worldwide from industrial coal-burning. In its first toxicity testing, we have shown that nano-Magnéli phases have potential toxicity pathways that are not photoactive like TiO_2 phases, but instead seem to be biologically active without photostimulation. In laboratory mice lung exposure in vivo, several biochemical markers indicate damage and/or death to vital cells.

Published in *Nature Communications* (2017), doi: 10.1038/s41467-017-00276-2. This paper was reported in many major press outlets internationally.



TEM images and an electron diffraction pattern of Magneli phases (titanium suboxides) produced from titanium oxide minerals found in coal. Also shown is a Chinese coal-burning power plant where Magneli phases are released to the atmosphere. From here, they are distributed regionally and globally.

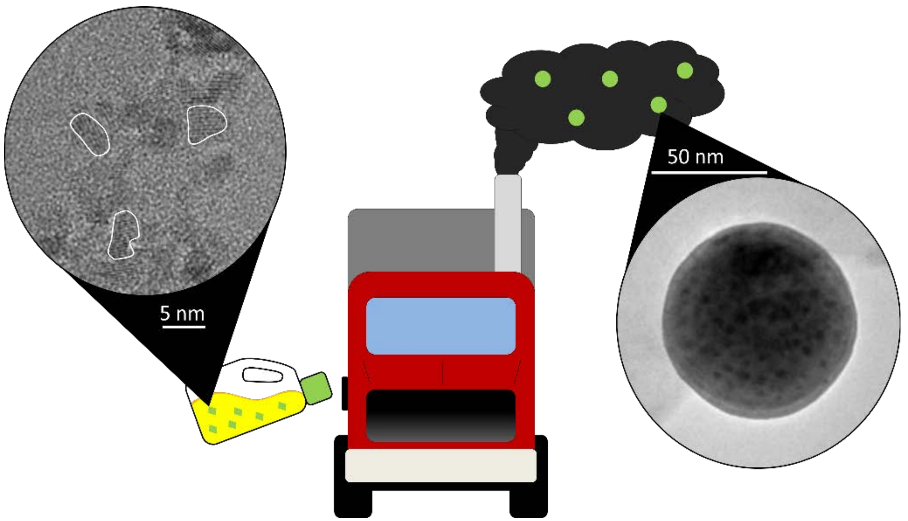
Yi Yang (East China Normal University), Michael Hochella (Virginia Tech), Jim Hower (University of Kentucky), Michael Schindler (Laurentian University, Canada).

National Nanotechnology Coordinated Infrastructure

NanoEarth

Transformation of CeO_2 nanoparticles in diesel engine fuel and exhaust, and plant toxicity

Nanoscale cerium oxide (CeO_2) is used as a diesel fuel additive to reduce particulate matter emissions and increase fuel economy, but its fate in the environment has not been established. We determined that the combustion process induces significant changes in the size and morphology of the particles; ~15 nm aggregates consisting of 5 to 7 nm faceted crystals in the fuel additive became 50 to 300 nm, near-spherical, single crystals in the exhaust. The results of this study suggests that pristine, laboratory-produced, nanoscale cerium oxide is not a good substitute for the cerium oxide released from fuel borne catalyst applications. Exhausted ceria particles added to laboratory soils in environmentally realistic concentrations did not affect *Brassica napus,* a well studied broadleaf plant.



Cerium oxide released as a result of the combustion of diesel fuel containing the additive Envirox™, which utilizes suspended 5-7 nm cerium oxide to reduce particulate matter emissions and increase fuel economy (left image), was captured from the exhaust stream of a diesel engine and was characterized using a combination of bulk analytical techniques and high resolution TEM (right image).

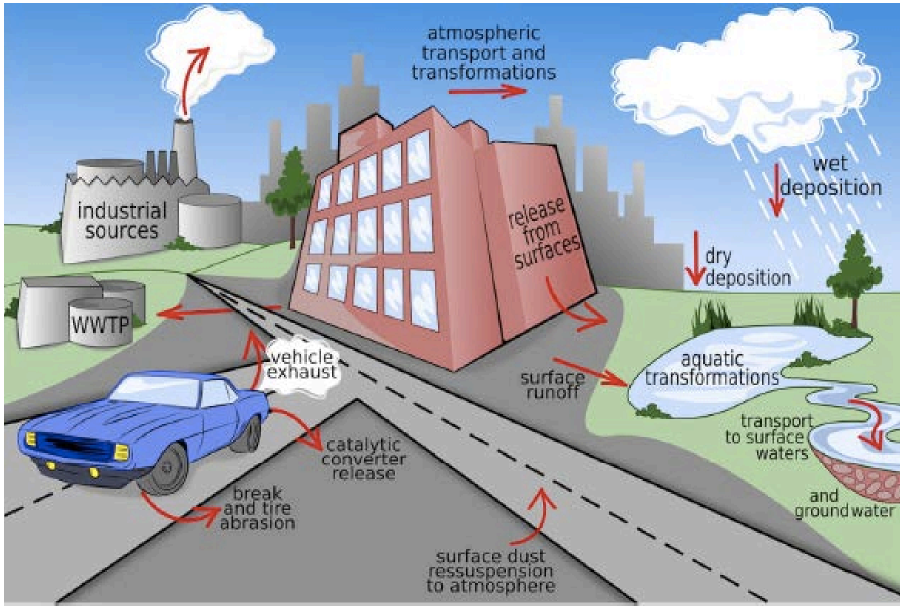
James Dale, Steve Cox, Marina Vance, Linsey Marr, and Michael Hochella (Virginia Tech). *Environmental Science and Technology*, 2017 (published) and 2018 (submitted).

National Nanotechnology Coordinated Infrastructure

NanoEarth

Outdoor urban nanomaterials: The emergence of a new, integrated, and critical field of study

Engineered nanomaterials (ENMs) are currently widely incorporated in the outdoor urban environmental fabric and numerous new applications and products containing ENMs are expected in the future. As has been shown repeatedly, products containing ENMs have the potential, at some point in their lifetime, to release ENMs into their surrounding environment. However, the expanding body in environmental nanomaterial research has not yet shifted toward ENMs in the context of the complex outdoor urban environment. This is especially surprising because the world's human populations are on a steady march toward more and more urbanization and technological development, accompanied with increased applications for ENMs in the outdoor urban environment.

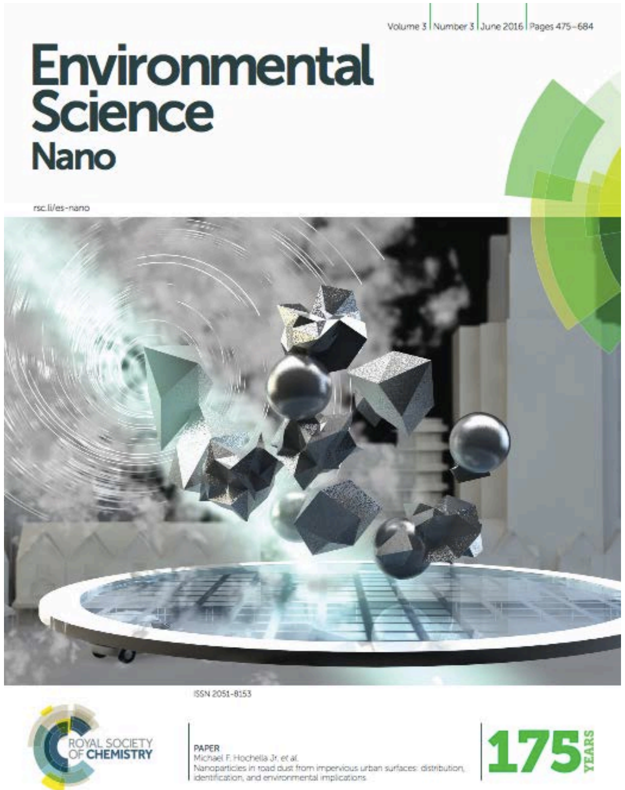


Baalousha et al. (2016) is the first compilation, review, and case study in the literature devoted to outdoor urban nanomaterials in the environment. Engineered and incidental nanomaterials are included in this study. Published in Science of the Total Environment.

M. *Baalousha (Univ. South Carolina); Y. Yang (East China Normal Univ.); M. Vance (Univ. Colorado); B. Colman (Univ. Montana); E. Bernhardt (Duke Univ.); M. Hochella (Virginia Tech).*

Nanoparticles in road dust from impervious urban surfaces: identification, environmental implications

Nanoparticles (NPs) resulting from urban road dust resuspension are an understudied class of pollutants in urban environments with strong potential for health hazards. The objective of this study was to investigate the heavy metal and nanoparticle content of PM2.5 generated in the laboratory using novel aerosolization of 66 road dust samples collected throughout the mega-city of Shanghai (China). Results show that metals were generally enriched in aerosolized samples relative to the bulk dust. Elevated concentrations of metals were found mostly in downtown areas with intense traffic. For example, dangerous Pb sulfide and sulfate NPs likely have an incidental origin and are also sometimes associated with Sn; we believe that these materials originated from an e-waste plant. Size distributions of most aerosolized samples presented a peak in the ultrafine range (<100 nm). Yang et al. (2016) ES Nano: DOI: 10.1039/C6EN00056H



Cover of the journal Environmental Science: Nano (published by the Royal Society of Chemistry), based on the article described on this slide.

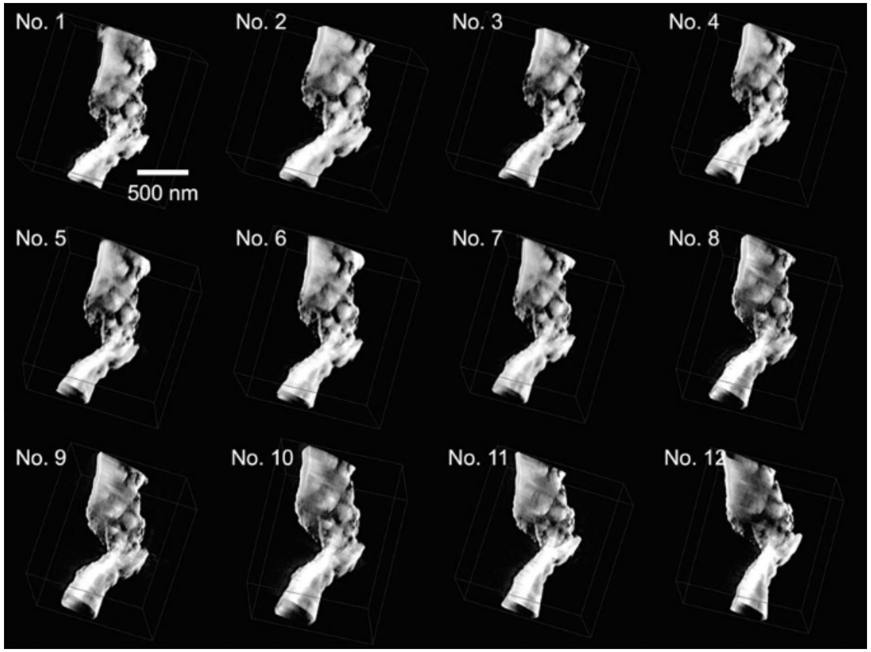
Yi Yang (East China Normal Univ.), M.Vance, A. Tiwari, M. Hochella (Virginia Tech)

National Nanotechnology Coordinated Infrastructure

NanoEarth

Developing a new in-situ 3D TEM imaging system for probing nanoscale deformation behavior

This project was sponsored by a Japanese government fund, "Development of advanced measurement and analysis systems", focused on transforming scientific ideas into marketable products based on academic – industry collaborative team efforts. The paper (see Figure caption for reference) summarizes the functionality of a new in-situ three-dimensional (3D) imaging system for observing plastic deformation behavior in a TEM. The authors designed an integrated system using a uniquely developed sample holder and image-acquisition software suite for in-situ deformation and time-resolved electron tomography data acquisition. They achieved time-resolved 3D visualization of nanometer-scale plastic deformation behavior in a Pb−Sn solder alloy sample, thus demonstrating the capability of this system for new applications. It also demonstrates an inter-network collaboration between NNCI (NanoEarth) and Japan's Nanotechnology Platform (Kyushu University node).



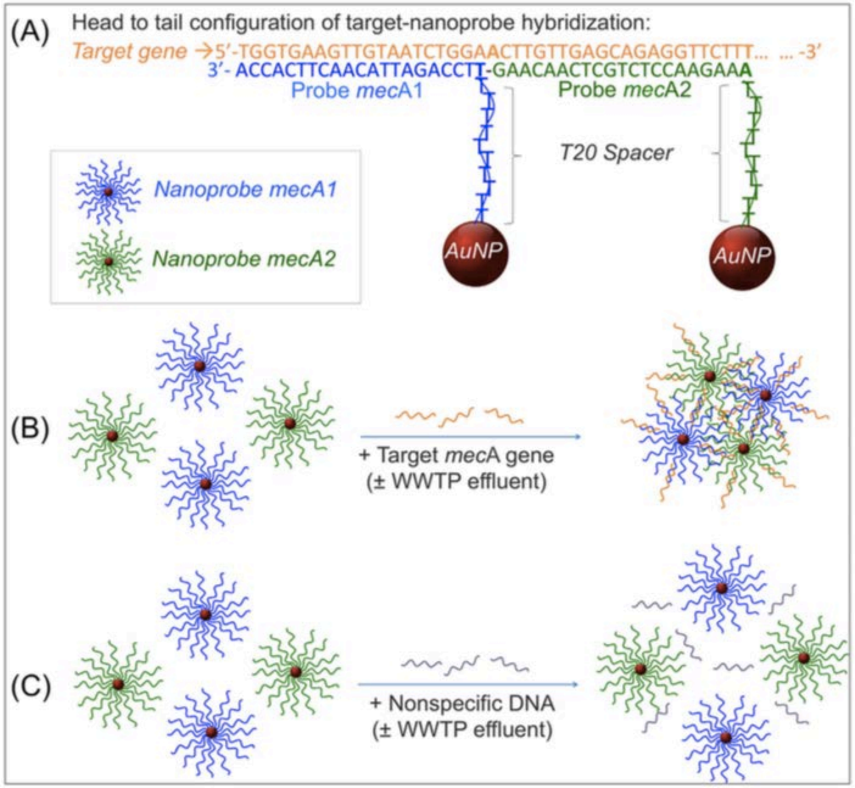
3D volumes reconstructed from 12 tilt-series data sets from a Pb-Sn solder alloy sample using state-of-the-art TEM 3D imaging system described in the journal Miscroscopy (2016) doi: 10.1093/jmicro/dfw109

S. Hata (Kyushu U., Japan); S. Miyazaki, T. Gondo, H. Miyazaki (FEI Company Japan, and Mel-Build Co., Japan); K. Kawamoto, N. Horii, H. Furukawa (System in Frontier, Inc., Japan), H. Kudo (U. Tsukuba, Japan); M. Murayama (Virginia Tech)

Stable oligonucleotide-functionalized gold nanosensors for enviro-biocontaminant monitoring

The global propagation of environmental biocontaminants such as antibiotic resistant pathogens and their antibiotic resistance genes (ARGs) is a public health concern that highlights the need for improved monitoring strategies. This group demonstrated the environmental stability and applicability of an oligonucleotide-functionalized gold nanosensor. The mecA ARG was targeted as model biocontaminant due to its presence in clinically-relevant pathogens and to its emergence as an environmental contaminant. mecA-specific nanosensors were tested for antibiotic resistance gene (ARG) detection in ARG-spiked effluent from four wastewater treatment plants (WWTPs).

This contribution supports the environmental applicability of a new line of cost-effective, field-deployable tools needed for wide-scale biocontaminant monitoring.



Schematic of nanoprobe-DNA interactions using surface enhanced Raman spectroscopy as a nano-detector: A&B = sensing target genes; C = sensing failure, as designed. Journal of Environmental Sciences (http://dx.doi.org/10.1016/j.jes.2017.08.005)

M. Riquelme, W. Leng, A. Pruden and P. Vikesland (Dept. of Civil and Environmental Engineering, Virginia Tech); M. Carzolio (Dept. of Statistics, Virginia Tech)

National Nanotechnology Coordinated Infrastructure

NanoEarth

Education and Outreach

CNF Ambassadors - Users Sharing Science with Youth

CNF's youth outreach aims to empower students for careers in the STEM fields. The activities are designed to exert high impact and promote diversity by targeting students who are at a crossroads for embracing STEM. The demand from school districts, 4-H and other organizations exceeds what can be covered by CNF staff alone, so the CNF has enlisted facility users (typically Cornell graduate students) to be outreach volunteers. They're called the CNF Ambassadors. This is a beneficial arrangement for everyone. The Ambassadors gain valuable experience in science communication. The youth relate well with enthusiastic science role models. And the CNF has extra help to reach greater numbers. The CNF ambassador program finished its second year in 2017 with 10 Ambassadors helping in 14 youth outreach events.

CNF User Brian Schafer (in red), volunteers as a CNF Ambassador to show high school students from NYC about photolithography. The group designed copper LED circuits and learned how to test the conductivity of their chips.

Beth Rhoades, Cornell NanoScale Facility
Outreach conducted at the Cornell NanoScale Facility

Video Tours of Cleanrooms- Exposing Youth to Nanotechnology

CNF's youth outreach program aims to empower students for careers in the STEM fields. Activities are designed to have high impact and promote diversity by targeting youth who are at a crossroads for embracing STEM. One challenge is to provide stimulating, memorable experiences for those who are too young to enter the clean room or those who want to visit remotely. To address this need the CNF offers interactive Facetime tours. Students may ask questions of users in the facility to learn how scientists use nanotechnology. During longer visits, students draw their own photolithography masks and watch as a staff person patterns their chips. Afterwards, they learn how to test conductivity and assemble LED chips. They take the chips home as a nanotechnology memento. The video tours and lessons are popular for 4-H groups and others who are exploring careers in nanotechnology.

CNF staff, Tom Pennell (on screen), explains how the UV exposure tool works to transfer the patterns from photomasks that 4-Her's drew during a Career Explorations event on Cornell's campus. The students were too young to go into the cleanroom, but they had the opportunity to see the process and to ask questions in real time.

Beth Rhoades, Cornell NanoScale Facility
Outreach conducted at the Cornell NanoScale Facility

CNF's Youth Outreach Program - Targeting Youth at the Crossroads for STEM

CNF's youth outreach program aims to empower students for careers in the STEM fields. The outreach activities are designed to exert high impact and promote diversity by targeting students who are at a crossroads for embracing STEM. Although all are welcome, the CNF prioritizes outreach to middle school-aged students, especially girls, as well as under-represented minorities and economically disadvantaged youth. One way that the CNF has tackled this goal is by participating in career exploration events organized by 4-H, school districts, Expanding Your Horizons, the Center for Excellence in Youth Education, and the American Association of University Women. Outreach through these organizations alone reached 535 youth, which was 46% of the youth who participated in 2017.

A student in a summer course on nanotechnology cleans the copper circuit chip that she designed as part of a visit to the CNF. 2017 was the second year that students visited. The course was organized by the Center for Excellence in Youth Education which serves underrepresented minorities and economically disadvantage students from New York City.

Beth Rhoades, Cornell NanoScale Facility
Outreach conducted at the Cornell NanoScale Facility

Developing Globally Aware Scientists: International Research Experience for Students

Since 2008, CNF has coordinated an advanced undergraduate international research program. Started under NNIN, it continues in cooperation with NNCI with separate funding under the IRES program from NSF.

Each year, 6 outstanding students from the NNCI REU program are selected for a 2nd summer research experience at the National Institute for Materials Science in Tsukuba, Japan. In addition to gaining advance research experience in nanotechnology, participants experience how science is done and communicated in another culture and gain valuable experience as a globally aware scientist.

2017 participants at the National Institute for Materials Science.

Lynn Rathbun, Cornell NanoScale Facility

Nanooze- A Science Magazine for Kids

Nanooze is a science magazine for children published and distributed by the Cornell Nanoscale Facility. It features themed content related to nanotechnology with engaging graphics. It is distributed free, on request, in packs of 30 or more to classrooms throughout the United States. Well over 1 million copies have been distributed.

The current issue, #15, focuses on the Environment. Issues in the back catalog cover topics such as The Five Senses, Nanomedicine, Space, and a variety of issues on atoms and molecules. Content is also available on-line at www.nanooze.org .

Some of the back issues of Nanooze. Copies of issues from the back catalog are distributed regularly on request

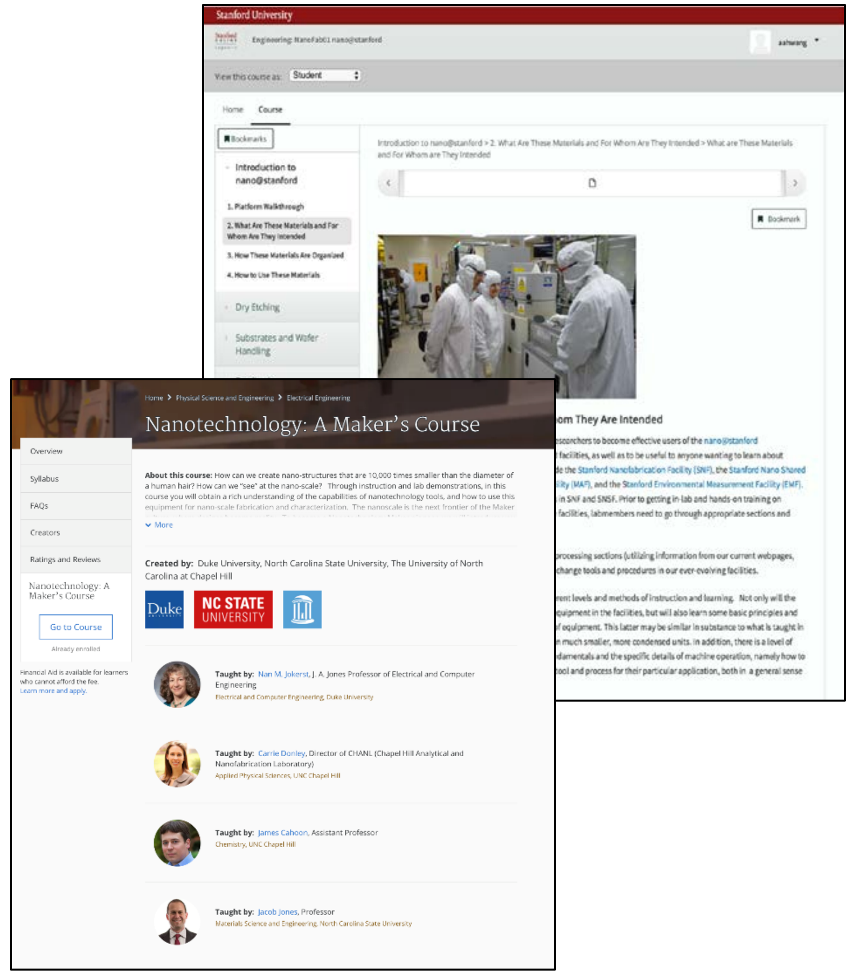
Lynn Rathbun, Cornell NanoScale Facility; Prof. Carl Batt, Cornell University

Technical Content Development

We have seen a universal issue of users with varied educational backgrounds. We hope to normalize the foundational knowledge of users to prepare for hands on training and to optimize staff time.

Stanford has developed pilot modules on an edX-based platform, Lagunita. Meanwhile RTNN has developed a Coursera course “Nanotechnology: A Maker’s Course”.

We have established a working group to connect NNCI network to show we are ‘greater than the sum of our parts’. Currently gathering training content throughout the network to better understand our resources and how to utilize them.



Top: *Stanford’s open EdX-based online course, “Nanofabrication 101”*
Bottom: *RTNN’s Coursera Course, “Nanotechnology: A Maker’s Course”.*

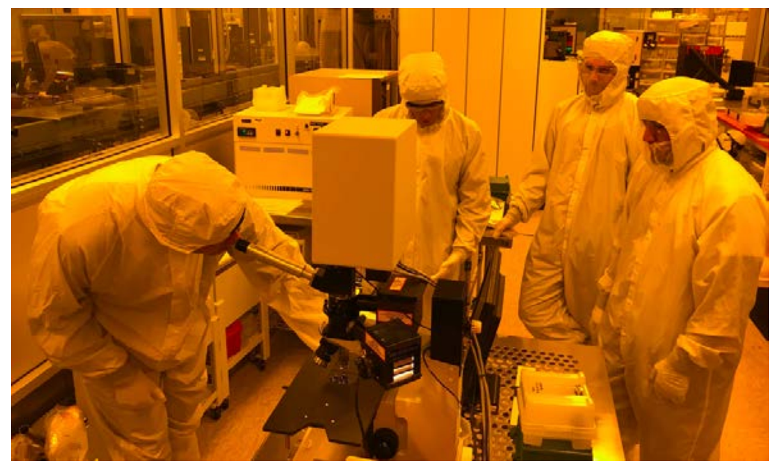
National Nanotechnology Coordinated Infrastructure

nano@stanford

Academic Partnership: Cal State East Bay & Stanford

Over the course of 2 years, we have grown our partnership with Cal State East Bay:

- **Fall 2015:** Prof. Ryan Smith joins proposal for NNCI, CSUEB's first field trip to nanofacilities
- **Fall 2016:** Prof. James Tandon visits with computer science class
- **Spring 2017:** Prof. Smith brings class to perform fabrication & characterization methods in SNF that would would not be possible at their own facilities. Highlighted in the Stanford Report
- **Summer 2017:** Prof. Smith prepares & submits educational journal article with Stanford to American Journal of Physics
- **Currently:** Prof. Smith is given a seed fund to onboard as a user and utilize more instruments for research

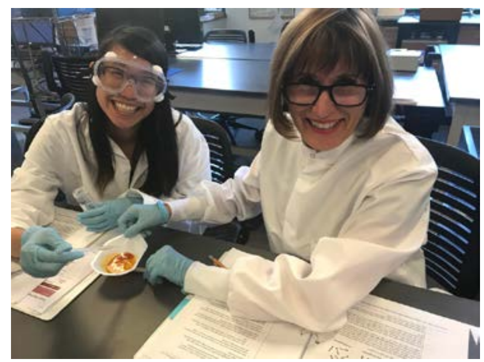


Top: *CSUEB students observe an oxide etch for part of their photovoltaic cell project.* ***Bottom:*** *Students measure the thickness of their thin films on their wafers using the nanospec.*

NanoSIMST Program

Nanoscience Summer Institute for Middle School Teachers (NanoSIMST) had been a legacy program (2005-2014) from Center for Probing the Nanoscale, NSF-funded (NSEC). We have updated the program for 2017 to include more hands-on experiments and continued engagement.

- Updated program is a 3 day workshop with fall follow up
- Currently improving program in response to feedback and extending program through RETs
- Assessment showed significant improvement of understanding of the nanoscience vocabulary and/or relationships of words
- To date, 5 out of 12 total teachers have implemented a nanoscience lesson in the classroom



***Top left:** Annual group photo of teachers in front of Memorial Church. **Top right:** Postdoc from Prof. Bao's lab shows a prototype. **Bottom left:** Bianca and Doe are excited to make some ferrofluid! **Bottom left:** Teachers gowned up in bunny suits.*

Nebraska Nanoscale Facility
Traveling Nano Exhibit

In 2017 the 400-sq.-ft. hands-on exhibit Nano Exhibit was viewed in three Nebraska museums by over 50,000 people. The three museums which were located throughout the state reached thousands of underserved populations in Nebraska with the Nano mini-exhibit, including both rural populations and the growing number of ethnic minorities in those communities.

Nano was created by the Nanoscale Informal Science Education Network (NISE Network) with support from the National Science Foundation. The Nano Exhibit includes interactive stations—interesting and informative for all ages—that invite exploration of nano phenomena and real world applications and implications.

Nano is an interactive exhibition that engages family audiences in nanoscale science, engineering, and technology.

National Nanotechnology Day

<u>National Nanotechnology Day</u> – In October 2017 NNI hosted our first annual National Nanotechnology Day in partnership with the Pacific Science Center, an independent, non-profit science center located in downtown Seattle. Working with the Pacific Science Center's staff to regionally advertise the event, dozens of NNI faculty and students hosted 2,057 guests (K-gray) throughout the day with over a dozen hands-on demonstrations of nanotechnology in action.

In October 2017, NNI partnered with the Pacific Science Center to host over 2,000 guests in a hands-on nanotechnology fair, including demonstrations of some of the latest technology to come out of NNI investigator laboratories.

Introduce a Girl to Nano

<u>Introduce a Girl to Nano</u> – NNI-associated students from Chemical Engineering launched the inaugural 2017 'Introduce a Girl to Nano' event, hosted on the University of Washington Campus in the Student Union Building on Saturday, October 14, 2017. 277 K-12 students attended the event, experiencing hands-on demonstrations in nanotechnology, including modules in drug delivery, colloidal nanoparticles, and the role of nanotechnology in every day life. Surveys were collected from participating organizations to help build upon the experience for future years. Event organizers coordinated with NNI staff and the National Nanotechnology Coordination Office to advertise the event and distribute educational materials for teachers and students to bring back to the classroom.

NNI students hosted the first annual Introduce a Girl to Nano event on the UW campus, introducing nanotechnology to 277 girls from across the region.

Nanotechnology: A Maker's Course

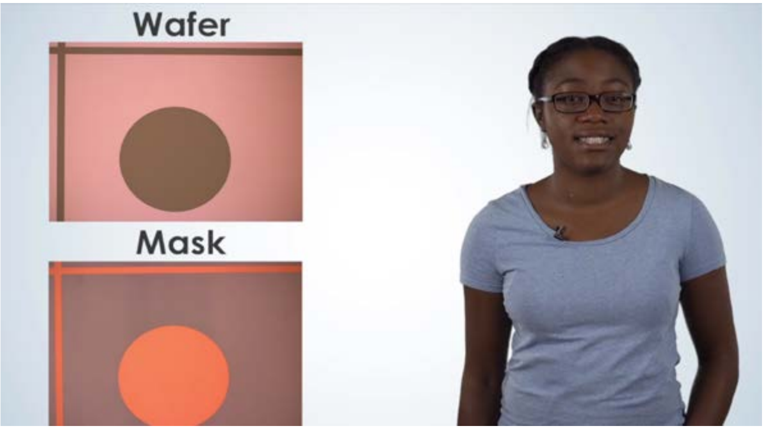
Easy-to-understand explanations and demos of nanofabrication and nanocharacterization tools and techniques

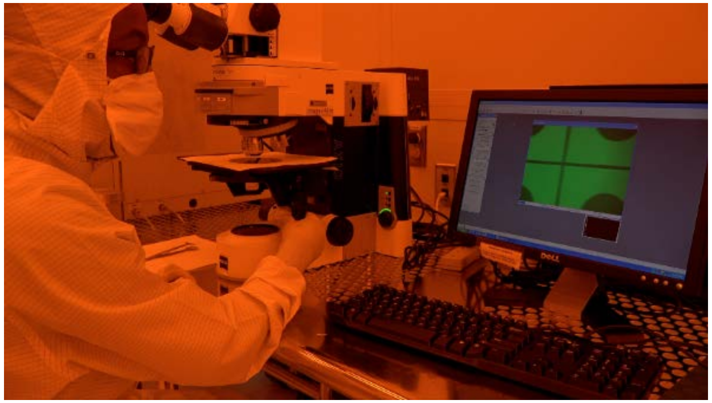
Recorded in laboratories by diverse individuals

Launched September 2017, to date:

- >5,400 course views
- >2,000 enrolled learners

Assessment tool developed and implemented





https://www.coursera.org/learn/nanotechnology

National Nanotechnology Coordinated Infrastructure

RTNN

Workshop for Community College Educators

Providing nanotechnology teaching materials to educators

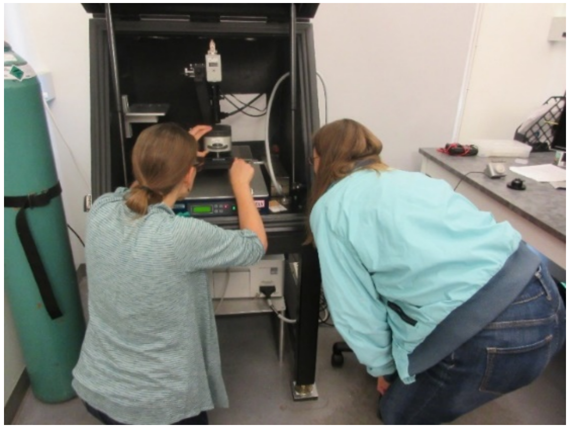
Hands-on learning experiences

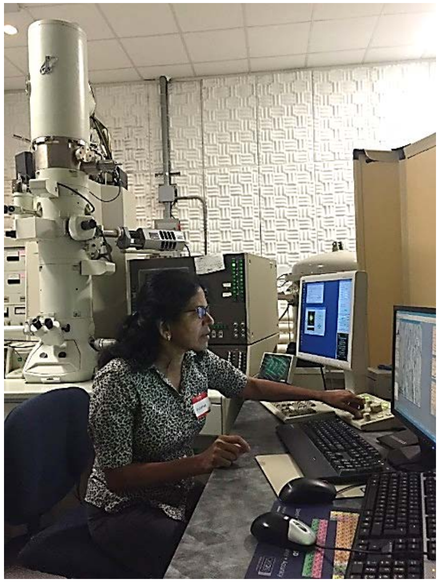
Lesson plan development

Rotating locations

- Year 1: NC State
  - 10 participants from 6 community colleges
- Year 2: UNC
  - 10 participants from 6 community colleges/small colleges

"…gave me a better understanding so that I can expose [my] students to nanotech."





National Nanotechnology Coordinated Infrastructure

RTNN

Encouraging URM's in STEM

SENIC at Georgia Tech has developed a partnership with Atlanta Public Schools' Gifted and Talented Program to encourage underrepresented students to consider STEM for education and career choices. Primarily, we place 11th and 12th grade students in faculty labs with graduate student mentors to undertake research. APS is a minority serving district (82% black; 11% white; 3% Hispanic). We host approximately four students each spring and in late April they present talks on their research experience during a capstone event at APS and also at Georgia Tech. In addition we host the APS Pipeline event for 9th and 10th grade students who APS is encouraging to participate in for their Gifted and Talented Program.

APS interns with mentors

APS Pipeline Event

National Nanotechnology Coordinated Infrastructure

SENIC Southeastern Nanotechnology Infrastructure Corridor