NanoMeter
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Judy Cha Named Director of Cornell NanoScale Facility

By J. Edward Anthony
August 21, 2023
Cornell Chronicle

Judy Cha, Ph.D. '09, professor of materials science and engineering in the College of Engineering, has been appointed the Lester B. Knight Director of the Cornell NanoScale Science and Technology Facility (CNF), effective August 21, 2023. Cha is an expert in topological and two-dimensional nanomaterials with quantum properties. She becomes the facility's ninth director since its establishment in 1977.

As the director of CNF, Cha will lead one of the premier nanofabrication facilities in the nation. Each year more than 1000 scientists, engineers and technologists from around the world use the facility's state-of-the-art instrumentation with the assistance of CNF's staff of highly trained and creative specialists.

"CNF is a remarkable resource for the national and international scientific community, with a crucial role to play in the advancement of U.S. semiconductor research and development," said Krystyn J. Van Vliet, vice president for research and innovation. "Judy is a leader in nanomaterials research and a longtime member of the community that converges around CNF. As a global expert in nanofabrication techniques and research methods, she knows where the field is going. Judy is well positioned to develop a vision with faculty and CNF's staff and user community, including companies of all sizes, positions and competency needs in the supply network. We know that she will lead an inclusive process to promote access to CNF's crucial infrastructure for innovators in this broad and dynamic field."

In addition to serving a national and international user base, CNF facilitates a wide range of collaborative research at Cornell, providing ready access to nanofabrication and characterization capabilities for individual labs and large-scale research endeavors such as the Center for Research on Programmable Plant Systems (CROPPS) and SUPREME: Superior Energy-efficient Materials and Devices — two centers established at Cornell in the past two years that are coordinating transformational research in the fields of digital agriculture and energy-efficient semiconductors, respectively.

"Advancing our capacity to fabricate novel nanomaterials and harness their unique properties for energy and computing applications is an urgent global and national challenge, as underscored by the passage of the CHIPS and Science Act," Van Vliet said, referring to the 2022 federal law to reinvigorate semiconductor research and manufacturing in the United States.

Continued on page 2

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New Director, continued

"Nanotechnology will play a key role in driving technological development and the U.S. economy. Cornell and CNF are poised to make significant contributions, thanks to the longtime support of the National Science Foundation, the expertise of CNF's leadership and staff, and the talent and dedication of our faculty-led research teams."

"I'm excited and honored to take this directorship," Cha said. "The tools and expertise at CNF have been fundamental to my own work and development as a scientist. So many groups at Cornell and beyond rely on CNF. I look forward to working with Director of Operations Ron Olson, CNF staff and stakeholders to ensure that CNF continually opens the way for new discoveries. I'm especially excited to leverage the unique opportunities created by the CHIPS and Science Act to advance transformative technologies and workforce development."

Cha succeeds Christopher Ober, the Francis Norwood Bard Professor of Materials Engineering in the College of Engineering, who has led CNF since July 2016. Ober oversaw the successful renewal of CNF's position in the National Nanotechnology Coordinated Infrastructure (NNCI) in 2020.

"We owe an incredible debt of gratitude to Chris Ober," Van Vliet said. "His energy, self-effacing expert perspective, and ability to forge connections among scientists and innovators in industry and government have made a lasting impact on Cornell's research ecosystem."

Cha received her Ph.D. in Applied Physics from Cornell in 2009. After conducting postdoctoral research at Stanford University, she joined the faculty of Yale University in 2013. She joined the Cornell faculty in 2022.

In announcing the appointment, Van Vliet also thanked CNF's external advisory board, faculty, staff, and student and postdoctoral researchers who contributed input to the selection process.

CNF was established at Cornell in 1977 with funding from the National Science Foundation. It is the first open-user nanofabrication facility of its kind. CNF is supported by a major grant from the NSF (NNCI-2025233) and receives additional funding from Cornell and New York State.

Directors' Column for the Fall 2023 NanoMeter

"No one who achieves success does so without the help of others. The wise and confident acknowledge this help with gratitude." ~ Alfred North Whitehead, English mathematician and philosopher (1861 — 1947)

Our 45th anniversary last year and these months of 2023 have provided us with time to reflect on many things we are grateful for in life. Personal things such as family, friends, home and good health immediately come to mind when considering gratitude. In relation to professional life, we are thankful for the opportunity to be part of the Cornell community, an outstanding academic institution storied with stellar academics and facilities equipped with state-of-the art equipment and brilliant researchers all committed to serving a diverse population. The users who have placed trust in the CNF to assist them in the successful achievement of their research goals and objectives are what drive us each day. We would like to personally acknowledge and thank all our valued users. Your continued patronage is greatly appreciated. In addition, we are thankful to the companies, groups and people who have supported and contributed to the success of the CNF over the last 45+ years.

The next few pages are dedicated to celebrating our forty-five years as a leading open user research facility for rapid advancements in science, engineering and technology at the nanoscale. We hope you enjoy looking back over the years and forward to the next forty-five years!

Earlier this year, the cleanroom re-opened its doors on February 20th, 2023, after ~ nine weeks of closure due to the "Cleanroom HVAC Rehabilitation Project." The project included the successful rebuild of the Makeup Air Handling Unit (MAU)-1, installation of a heat recovery system to reduce the system-operating cost, and replacement of all the HEPA filters and corroded acid exhaust duct in the cleanroom. We are especially grateful for everyone's patience as we made these critical upgrades.

As we look ahead, several exciting initiatives are in process to help shape the future of the CNF. We are exploring how to further expand the micro-credential program established with Tompkins Cortland Community College (TC3) last year. Planning and partnership efforts will continue with local industry and TC3 as we work collaboratively to solidify New York State and NSF sponsored workforce development initiatives. CNF was also excited to work with Micron's Chip Camp Program over this spring and summer. The program provided 7th, 8th and 9th grade students in the Syracuse region with opportunities to learn about nanotechnology, including an introduction to the CNF cleanroom. Additional education and outreach updates can be found starting on page 21.

CNF is actively participating in two nation-wide semiconductor initiatives — the "American Semiconductor Academy" (ASA) and the American Semiconductor Innovation Coalition (ASIC) — both intended to facilitate long term growth and innovation for the U.S. microelectronics industry. CNF as well as regional universities, community colleges and industries are collaborating on the "Microelectronics Commons" — a CHIPS and Science Act funded program to establish proficiencies to accelerate workforce training and microelectronics technology.

The 2023 NNN Symposium, hosted by CNF and the University of Albany, was held on April 25th. Details and a summary of this symposium can be found on our website at https://www.cnf.cornell.edu/events/nys_nano/2023. Finally, we had another successful Research Experiences for Undergraduates (REU) Program and look forward to seeing how our interns progress in life.

Thank you again for being loyal CNF users and contributing members of our great community.

The CNF staff appreciates your commitment and partnership, and we are grateful for everything you do to aid in our success. Here's to the next forty five years!

Judy Cha, Lester B. Knight Director
Claudia Fischbach-Teschl, Associate Director for Life Sciences
Ron Olson, Director of Operations

CNF 45th Anniversary!

The 2022 CNF Annual Meeting was a celebration of our 45th anniversary (1977-2022) with 174 participants, eleven special invited speakers, a robust discussion of next steps, and a lively poster session. The proceedings, videos, and photo album are available online at https://cnf.cornell.edu/events/past/annual_meetings/2022

2022 CNF 45th Anniversary Best User Poster Award Winners

Melissa Bosch
AEP, Cornell, CNF PI: Gennady Shvets
"Tunable Semiconductor Metasurfaces for Active Lensing"

Brendan McCullian
AEP, Cornell, CNF PI: Gregory Fuchs
"Quantifying NV-Center Spectral Diffusion by Symmetry"

Michael Reynolds
CBE, Cornell, CNF PI: Nicholas L. Abbott
"In-air Electrochemical Polymer Microactuators for Microrobotics"

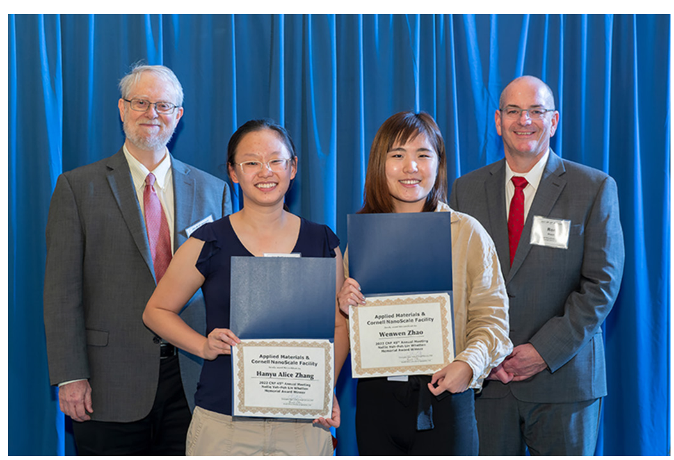
Conrad Smart
LASSP, Cornell, CNF PI: Paul McEuen
"Magnetically Controlled Diffractive Robotics"

Justin Tan
ECE, Cornell, CNF PIs: Jena-Xing
"Electroluminescence Study of Buried Tunnel Junction Laser Diode"

2022 CNF 45th Anniversary Whetten Memorial Award Winners

Hanyu Alice Zhang
AEP, Cornell, CNF PI: Nicholas Abbott
"Investigation of Palladium Strains and Actuation in Gaseous Environments" *(see profile on page 6)*

Wenwen Zhao
AEP, Cornell, CNF PIs: Jena-Xing
"X-band and Ku-band Epitaxial AlN-on-SiC FBARs"
(see profile on page 8)



CNF Annual Meeting & 45th Anniversary Celebration!

The CNF is honored to acknowledge the following CNF 45th Anniversary Corporate Sponsors:

SUPER SPONSOR

(Helped fund the Whetten Awards)

Applied Materials

CORPORATE SPONSOR PLUS

(Helped fund the User Poster Awards)

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2022 Whetten Award Winner: Hanyu Alice Zhang

Hanyu Alice Zhang is one of the two co-recipients of the 2022 CNF Whetten Memorial Awards (with Wenwen Zhao). This award recognizes young women whose work and professional lives exemplify Nellie Yeh-Poh Lin Whetten's commitment to scientific excellence, interdisciplinary collaboration, profes-sional and personal courtesy, and exuberance for life.

Alice received her bachelor's degree in engineering physics from Case Western Reserve University in 2018 and stayed an additional year at Case Western to obtain a master's degree in materials science through their BS/MS program. As a sophomore undergrad, she started her masters work on analyzing the short-range order of metallic glass through XAFS (X-ray absorption fine structure) spectroscopy, and through this work, obtained an award from the physics department at Case Western for the best senior thesis in 2018. During her year as a master's student, she continued to analyze the XAFS spectra of metallic glasses. The project aimed to understand whether XAFS spectroscopy could be used to verify our atomic-level theory in amorphous metal alloys.

In 2019, she joined the applied and engineering physics department at Cornell University as a first-year graduate student and started working with the Atomic Membranes IRG at Cornell to develop microscopic robots and machines.

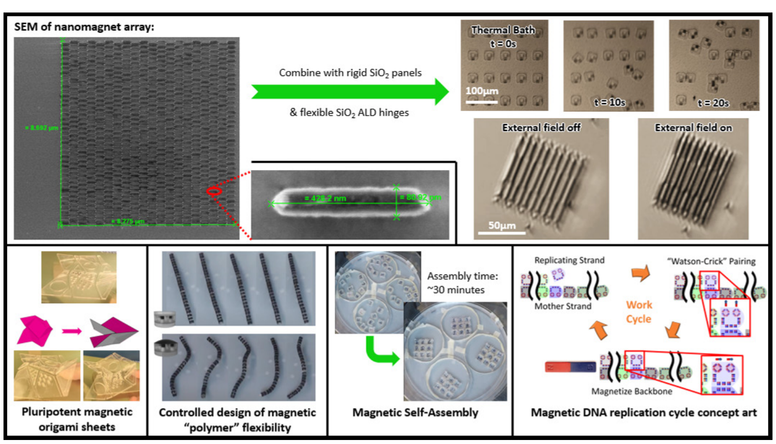


Figure 1: Magnetic devices on the micrometer scale with demonstrations of applications on the centimeter scale.

During her first three years at Cornell, Alice's work focused on developing magnetic systems that self-assemble and fold under the supervision of Itai Cohen and Paul McEuen in the Laboratory of Atomic and Solid-State Physics (LASSP) at Cornell. Along with developing macroscopic realizations as a first pass to validate and verify design concepts for nanofabrication, she learned how to fabricate microscopic magnetic devices at CNF. See Figure 1.

Magnetic handshake machines are magnetic devices that utilize any magnetic interaction to do useful work. Her work in the Cohen group focused on developing three types of magnetic systems: magnetic polymers, magnetic DNA, and magnetic origami. At CNF, she helped develop the recipes to create these devices on the micron scale. By using e-beam lithography, she was able to deposit and lift off magnets that are only a few hundred nanometers long made from evaporated cobalt to embed in a rigid SiO_2 structure.

Over the summer of 2022, Alice transitioned gears to work with Nick Abbott in the Smith School of Chemical and Biomolecular Engineering at Cornell.

Her Abbott group work focuses on developing active microscopic actuators that respond to different chemical stimuli. By making use of different catalytic reactions, the Abbott group aims to create different microscopic machines that respond to chemical stimuli similar to the biological machinery in our bodies.

Alice is currently seeking to understand how to use palladium to build devices that actuate with hydrogen as the chemical stimuli. By fabricating a palladium-titanium bimorph, Alice has been successful in making different hinges in CNF and driving the bimorph actuator. Alice has studied the palladium-hydrogen pressure-composition-temperature phase diagram extensively and has been able to demonstrate actuation of the hinges both under the application of hydrogen and via temperature sweeps. See Figure 2.

To make these devices, an aluminum nitride sacrificial layer is first deposited, protected with ALD aluminum oxide, and both layers are patterned and etched together. The actuator is then deposited.

To make the actuator, palladium is evaporated on top of sputtered titanium. The actuator is then patterned and etched.

Following the etch, an additional layer of titanium to act as an adhesion layer is deposited and lift off, and 500 nm of silicon dioxide is deposited and etched that form rigid panels to control where the hinges are allowed to bend.

Outside of research, Alice loves to take on small engineering build projects, work on different short stories, and fold lots of origami. She is actively working with Erik Demaine, the world expert in computational origami, to develop new theoretical folding ideas. She hopes to make something in CNF one day that is exciting to both the theoretical and experimental communities.

She is also interested in science communication, is on the organization committee for a science communication conference, and helps Veritasium bring his YouTube videos to a Chinese audience.

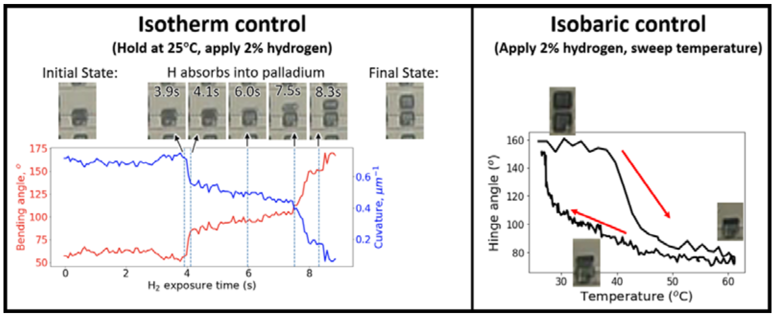
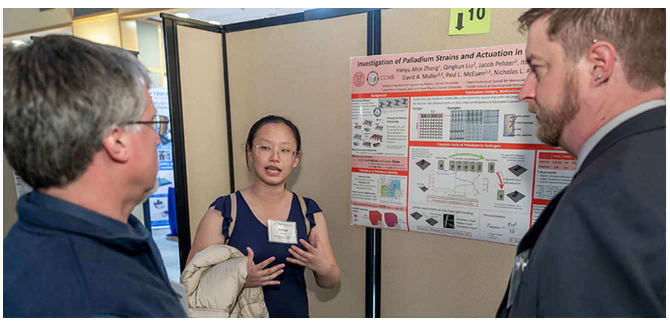


Figure 2: Simple methods to drive hinge actuation in the palladium-hydrogen system.



CNF's Nellie Yeh-Poh Lin Whetten Memorial Award

Photograph provided by Tim Whetten

This award is given in fond memory of Nellie Yeh-Poh Lin Whetten (left) — a CNF staff member from 1984 to 1987 who died on March 24, 1989. In honor of Nellie's spirit, this award recognizes outstanding young women in science and engineering whose research is conducted in the CNF, and whose work and professional lives exemplify Nellie's commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy and exuberance for life.

In the words of her husband, Dr. Timothy Whetten,

"The award should remind us to find out what it is like for people different from us to live and work in the same community. For men, to try to appreciate what it is like to be a woman scientist. For Caucasians, to try to feel what it is to be Asian or Black. For members of racial minorities and women, to try to understand what it is like to be a white male. And finally, the award should stimulate each of us to reach out and encourage women scientists who, like Nellie have the brilliance, stubbornness, and cheerfulness to succeed."

https://cnf.cornell.edu/highlights/whetten — a list of all the CNF Whetten Memorial Award Winners

2022 Whetten Award Winner: Wenwen Zhao

Wenwen Zhao is currently a Ph.D. student at the School of Applied and Engineering Physics at Cornell University. She is one of 2022's co-recipients of the CNF Nellie Yeh-Poh Lin Whetten Memorial Award (together with Hanyu Alice Zhang).

This award recognizes young women whose work and professional lives exemplify Nellie's commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and exuberance for life.

Wenwen received her bachelor's degree in Physics from Harbin Institute of Technology (HIT) in China in 2019. In her second year in college, she won the first prize in 2017 China Undergraduate Physics Tournament together with her collegues. As an undergraduate research assistant, she did fabrication and characterization of Lithium-Oxygen batteries. After joining Cornell University as a Ph.D. student, she started a study on radio frequency (RF) acoustic filters, supervised by Prof. Debdeep Jena, Prof. Grace Xing, and Prof. James Hwang.

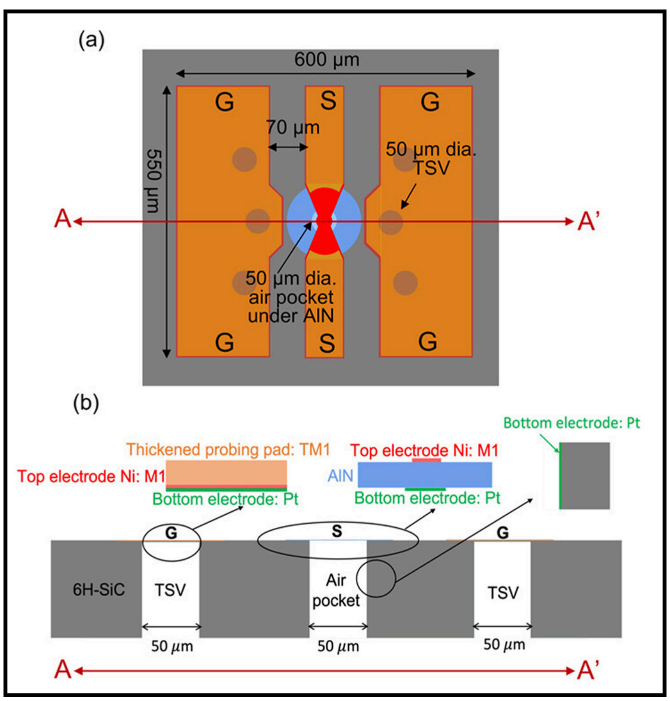


Figure 1: (a) Top view and (b) side view of a two-port epitaxial AlN FBAR on 6H-SiC substrate.

Filters are used to select specific bands of signals. They are widely used in our daily life. Those filters include electronic filters, mechanical filters and optical filters, etc. People are generating lots of revolutionary ideas of the filters for scientific use. For example, for quantum computing, people are exploring pulse filters to uncover the hidden 'noise' that can kill qubits. For electronic filters, people are trying to use advanced materials for super high frequency (3-30 GHz) RF filters.

In a modern smartphone, there are ~ 50 RF filters. These filters take up significant space in a phone. A majority of those components for operations below 2 GHz are Surface Acoustic Wave filters (SAWs). However, due to the degradation in selectivity at higher frequency, the performance of SAW is limited. Bulk Acoustic Wave Filters (BAW) dominate in the range between 1.5 GHz and 6 GHz, which puts filters in the range for the lower 5G bands.

As frequencies increase toward the millimeter wave (mmWave) range, Substrate Integrated Waveguides (SIW) and some other cavity filters dominate.

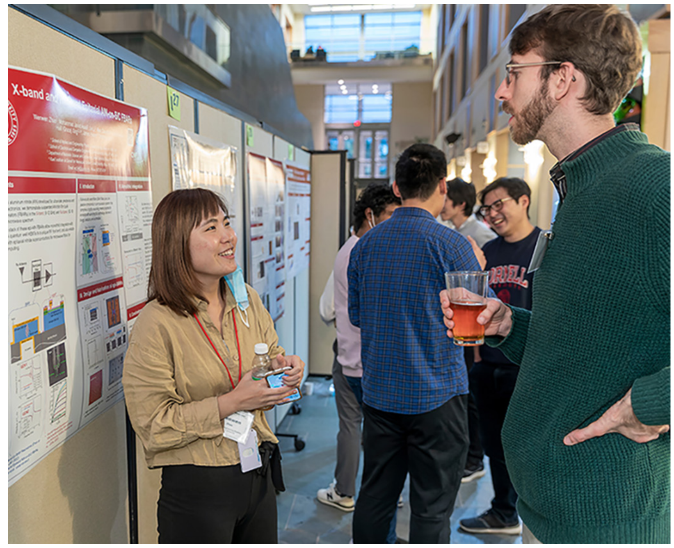
Compared to electromagnetic filters working at the same frequencies, acoustic filters have much smaller size due to lower wave velocity in acoustic domain. Acoustic filters are good candidates for chip miniaturization. People are more and more interested in overcoming the filtering limits and realizing acoustic devices in 10-100 GHz with high quality factors.

Wenwen's research focuses on the thin-film bulk acoustic wave filters (FBARs) utilizing epitaxial piezoelectric films. By utilizing highly crystalline aluminum nitride (AlN) piezoelectric thin films grown by Molecular Beam Epitaxy (MBE) on silicon carbide (SiC) substrate, she and her collegues demonstrated FBARs with a first-order thickness-extensional resonance mode up to 17 GHz with decent quality factor over 400. These epi-AlN FBARs indicate promising potential for immediate scaling to K-band (18-27 GHz) for 5G use.

Those acoustic resonators are important precursors for monolithic integration with active devices such as high-electron-mobility-transistors (HEMTs), and integration with epitaxial nitride superconductors for microwave filters for quantum computing.

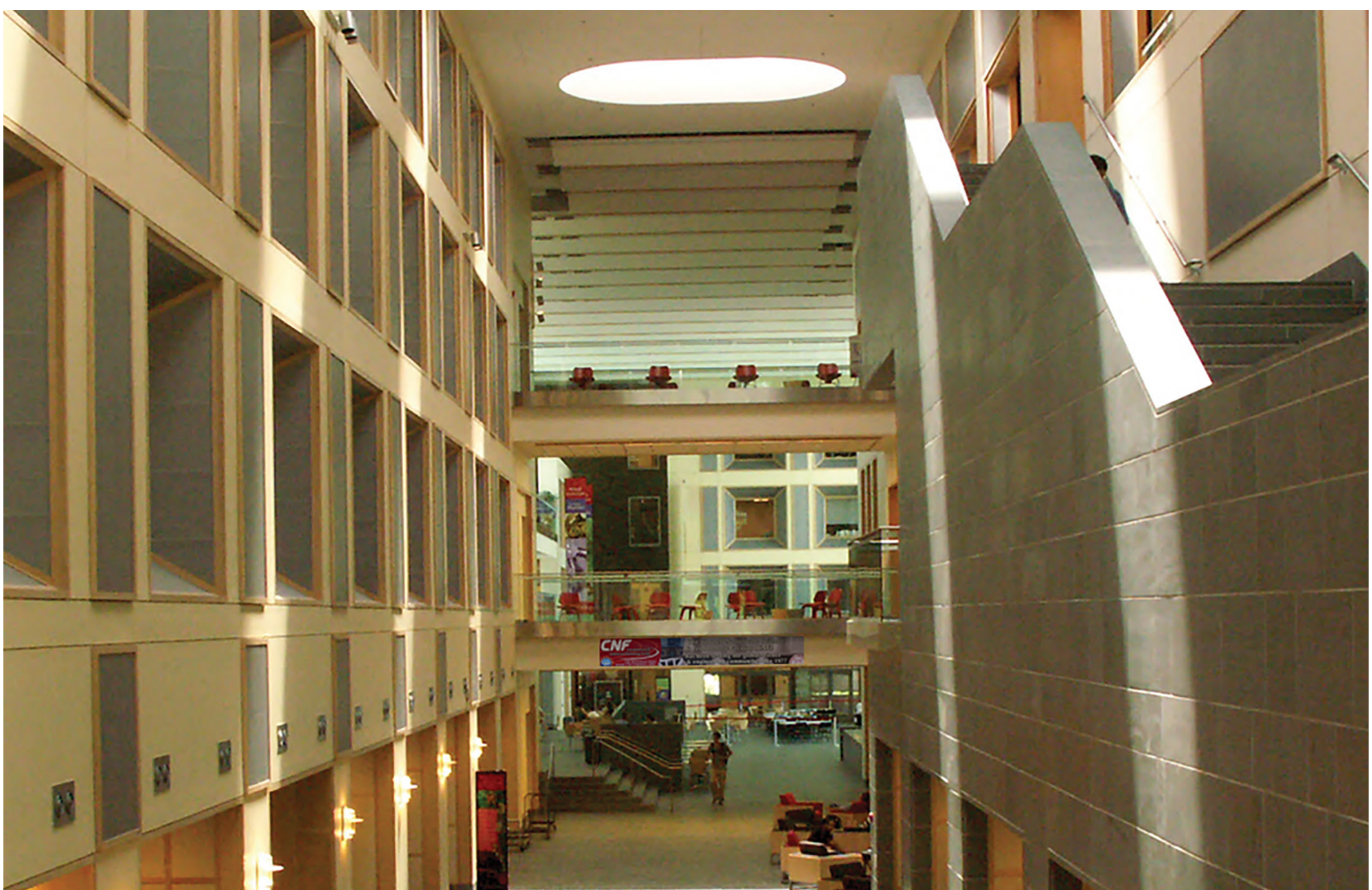
The epi-FBAR work used a double-side wafer process. AlN patterning, evaporation of the top electrode and the probe pads are used for top surface. Deep through-SiC etching and ALD deposition of the bottom electrode are performed on the other side. These epi-AlN FBARs are metal-insulator-metal (M-I-M) structures. As shown in Figure 1(b), the electromechanically vibrating region in the signal line comprises of a 50 nm thick Ni as the top electrode, a 300 ~ 400 nm thick AlN as the piezoelectric layer and a 20 nm thick ALD Pt as the bottom electrode. AlN and Ni (M1) are utilized as the etch stops for the air pockets under the AlN and the TSVs under the ground pads respectively.

The primary tools she uses in CNF include ABM/SUSS MA6 contact aligner, E-beam evaporator, AJA sputter, AJA ion mill, Arradiance ALD, SEM, AFM, PT 770 etcher, Oxford Cobra ICP etcher and Ni electroplating hood. The epitaxial AlN-on-SiC FBAR fabrication is compatible with the AlN-on-SiC HEMTs and SiC-based SIWs for mmWave (~ 140 GHz) frequencies.



Wenwen hopes to broaden her knowledge on the RF acoustic devices and put more effort in the monolithic integration on SiC substrates.

During her spare time, Wenwen likes violin and Chinese classical dancing. She also likes to hang out with her partner and his cat.



Easy Test Can See If Breeding Bulls Have The Right Stuff

By Blaine Friedlander
Cornell Chronicle
March 31, 2022

Forget sending bull semen out for complicated laboratory tests to learn whether the agricultural animal is highly virile. Soon, a quick and easy method — reminiscent of a home pregnancy test — can tell if a breeding bull has the right stuff.

The V-shape of the microfluidic probe allow researchers to count the number of sperm swimming upstream in a simulated reproductive tract. This shows the virility strength for bulls.

By borrowing from nature, Cornell food scientists and chemists have developed a system — they call it RHEOLEX — that can accurately indicate the fertility level of bulls. Their research published March 14 in the journal Lab on a Chip.

"With this new RHEOLEX method, you can conduct better selection and breeding for bulls and cows, which can translate into higher quality and quantity products like improved milk and meat," said Alireza Abbaspourrad, the Youngkeun Joh Assistant Professor of Food Chemistry and Ingredient Technology in the Department of Food Science, College of Agriculture and Life Sciences. "This saves breeders and producers time."

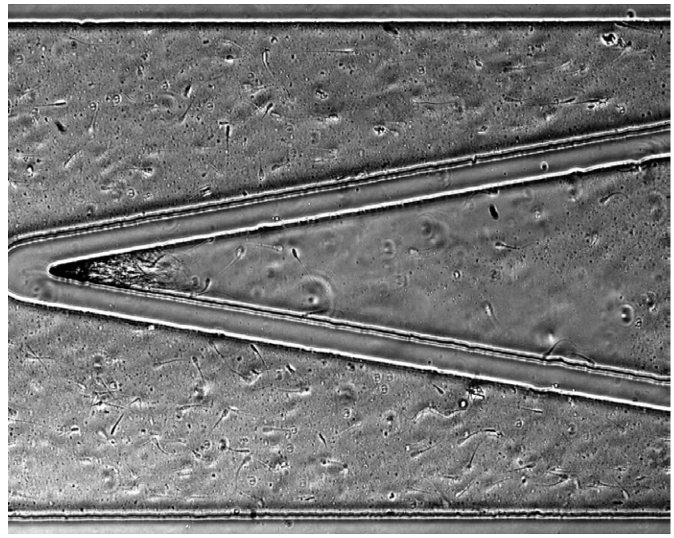
Nature uses a biological process called rheotaxis, in which the bull's sperm swim upstream in the reproductive tract of cows. Traditionally, sperm quality is evaluated using computer-assisted sperm analysis, which measures swimming speed and concentration. However, the computer-assisted analysis ignores rheotaxis, the strenuous process of sperm moving against the female's biological stream.

In this scientific effort led by doctoral student Mohammad "M.J." Yaghoobi, the group mimicked the cow's the female reproductive tract dimensions and hydrodynamic features in a microfluidic model, to quantify the sperm's rheotaxis ability.

Working with the Cornell NanoScale Facility, the scientists fabricated a microfluidic device (with tracts a little larger than human hair) into what looks like a home pregnancy test. The platform measured the number of sperm — during the rheotaxis route — at varied flow rates.

The stronger the rheotaxis power, the better the semen's reproductive quality.

"This combination, along with the motile (fast speed) sperm concentration determination, can quickly predict fertility levels in artificial insemination," Yaghoobi



The V-shape of the microfluidic probe allow researchers to count the number of sperm swimming upstream in a simulated reproductive tract. This shows the virility strength for bulls. Provided.

said. "We can predict the bull's *in vivo* sperm fertility level within five minutes."

Thawed bull semen samples were tested in the device and the results showed a higher rheotaxis quality — indicating a higher fertility level.

Unlike conventional semen quality parameters, which fail to provide statistically significant predictions, the RHEOLEX is an easy biomarker for determining *in vivo* male fertility, Yaghoobi said.

"We are essentially taking rheotaxis results and translating that into signals that tells us the bull fertility level," Abbaspourrad said, "which is great, because it can save companies a lot of money by selecting the best bulls. We are using nature's selection process and that's a huge difference."

In addition to Abbaspourrad and Yaghoobi, other co-authors on the research, "Rheotaxis Quality Index: A New Parameter That Reveals Male Mammalian In Vivo Fertility and Low Sperm DNA Fragmentation," are Morteza Azizi, Ph.D. '20, and doctoral students Amir Mokhtare and Farhad Javi.

The Cornell NanoScale Facility is a member of the National Nanotechnology Coordinated Infrastructure (NNCI), which is supported by the National Science Foundation. Abbaspourrad is a faculty fellow at the Cornell Atkinson Center for Sustainability.

Self-Folding Origami Machines Powered by Chemical Reaction

By David Nutt
Cornell Chronicle
May 2, 2023

A Cornell-led collaboration harnessed chemical reactions to make microscale origami machines self-fold — freeing them from the liquids in which they usually function, so they can operate in dry environments and at room temperature.

The approach could one day lead to the creation of a new fleet of tiny autonomous devices that can rapidly respond to their chemical environment.

The group's paper, "Gas-Phase Microactuation Using Kinetically Controlled Surface States of Ultrathin Catalytic Sheets," published May 1 in Proceedings of the National Academy of Sciences. The paper's co-lead authors are Nanqi Bao, Ph.D. '22, and former postdoctoral researcher Qingkun Liu, Ph.D. '22.

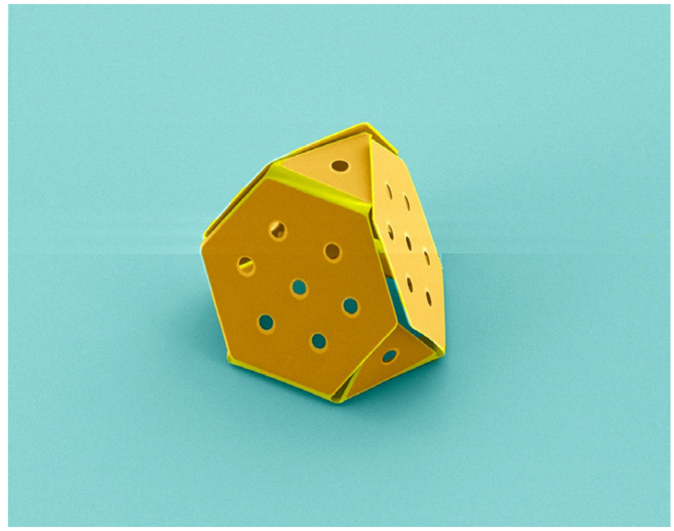
The project was led by senior author Nicholas Abbott, a Tisch University Professor in the Robert F. Smith School of Chemical and Biomolecular Engineering in Cornell Engineering, along with Itai Cohen, professor of physics, and Paul McEuen, the John A. Newman Professor of Physical Science, both in the College of Arts and Sciences; and David Muller, the Samuel B. Eckert Professor of Engineering in Cornell Engineering.

"There are quite good technologies for electrical to mechanical energy transduction, such as the electric motor, and the McEuen and Cohen groups have shown a strategy for doing that on the microscale, with their robots," Abbott said. "But if you look for direct chemical to mechanical transductions, actually there are very few options."

Prior efforts depended on chemical reactions that could only occur in extreme conditions, such as at high temperatures of several 100°C, and the reactions were often tediously slow — sometimes as long as 10 minutes — making the approach impractical for everyday technological applications.

However, Abbott's group found a loophole of sorts while reviewing data from a catalysis experiment: a small section of the chemical reaction pathway contained both slow and fast steps.

"If you look at the response of the chemical actuator, it's not that it goes from one state directly to the other state. It actually goes through an excursion into a bent state, a curvature, which is more extreme than either of the two end states," Abbott said. "If you understand the elementary reaction steps in a catalytic pathway, you can go in and sort of surgically extract out the rapid steps. You can operate your chemical actuator around those rapid steps, and just ignore the rest of it."



An SEM image shows an origami tetrahedra microstructure that self-folded after it was exposed to hydrogen. Provided.

The researchers needed the right material platform to leverage that rapid kinetic moment, so they turned to McEuen and Cohen, who had worked with Muller to develop ultrathin platinum sheets capped with titanium. The group also collaborated with theorists, led by professor Manos Mavrikakis at the University of Wisconsin, Madison, who used electronic structure calculations to dissect the chemical reaction that occurs when hydrogen — adsorbed to the material — is exposed to oxygen.

The researchers were then able to exploit the crucial moment that the oxygen quickly strips the hydrogen, causing the atomically thin material to deform and bend, like a hinge.

The system actuates at 600 milliseconds per cycle and can operate at 20°C — i.e., room temperature — in dry environments.

"The result is quite generalizable," Abbott said. "There are a lot of catalytic reactions which have been developed based on all sorts of species. So carbon monoxide, nitrogen oxides, ammonia: they're all candidates to use as fuels for chemically driven actuators."

The team anticipates applying the technique to other catalytic metals, such as palladium and palladium gold alloys. Eventually this work could lead to autonomous material systems in which the controlling circuitry and onboard computation are handled by the material's response — for example, an autonomous chemical system that regulates flows based on chemical composition.

"We are really excited because this work paves the way to microscale origami machines that work in gaseous environments," Cohen said.

Co-authors include postdoctoral researcher Michael Reynolds, M.S. '17, Ph.D. '21; doctoral student Wei Wang; Michael Cao '14; and researchers at the University of Wisconsin, Madison.

The research was supported by the Cornell Center for Materials Research, which is supported by the National Science Foundation's MRSEC program, the Army Research Office, the NSF, the Air Force Office of Scientific Research and the Kavli Institute at Cornell for Nanoscale Science.

The researchers made use of the Cornell NanoScale Facility, a member of the National Nanotechnology Coordinated Infrastructure, which is supported by the NSF; and National Energy Research Scientific Computing Center (NERSC) resources, which is supported by the U.S. Department of Energy's Office of Science.

The project is part of the Nanoscale Science and Microsystems Engineering (NEXT Nano) program, which is designed to push nanoscale science and microsystems engineering to the next level of design, function and integration.

Molding of Nanowires Spurs Unanticipated Phases

By David Nutt
Cornell Chronicle
April 17, 2023

Sometimes to make big breakthroughs, you have to start very small.

One way that scientists can get the most out of certain quantum materials is by fabricating nanoscale structures that generate new properties at the material's surfaces and edges. Cornell researchers used the relatively straightforward process of thermomechanical nanomolding to create single-crystalline nanowires that can enable metastable phases that would otherwise be difficult to achieve with conventional methods.

"We're really interested in this synthesis method of nanomolding because it allows us to make many different kinds of materials into nanoscale quickly and easily, yet with some of the control that other nanomaterial synthesis methods lack, particularly control over the morphology and the size," said Judy Cha, Ph.D. '09, professor of materials science and engineering in Cornell Engineering, who led the project.

The team's paper, "Nanomolding of Metastable Mo_4P_3," published April 12 in Matter. The paper's lead author is postdoctoral researcher Mehrdad Kiani.

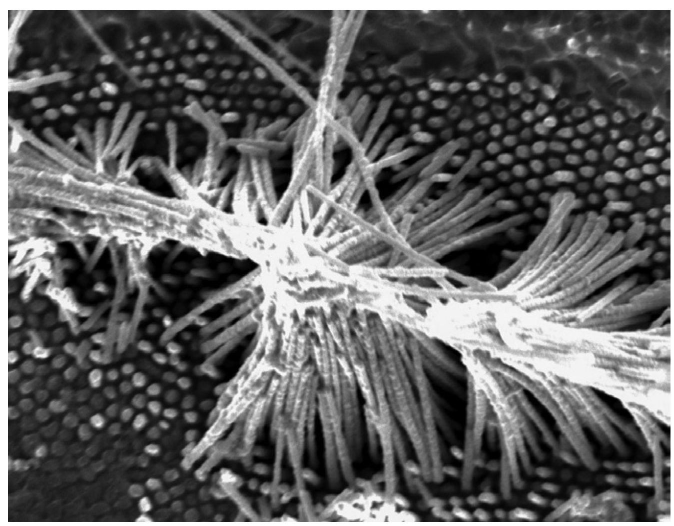


Figure 1: A scanning electron microscope image offers a top-down view of a single-crystalline nanowire of Mo_4P_3 created by thermomechanical nanomolding.

In thermomechanical nanomolding, a material is consolidated into a bulk feedstock, put into a porous mold and pressed at high temperatures for several hours. The resulting structure is then separated from the feedstock — in this case, by ultrasound vibrations, a process known as sonication — and deposited on a silicon wafer or other surface.

The benefit of this process is that nanoscale amounts of solid materials can be molded at temperatures well below their melting point, representing easy processing conditions. This enables a wide range of materials to be leveraged for untapped exotic properties, similar to the way that graphene has revolutionized conduction in electronics. Cha's team has been experimenting with molybdenum monophosphide (MoP), which is a topological compound.

"Topological metals are predicted to have decreasing resistance as you go to smaller sizes, and MoP is not only topological but also has a really high carrier density (electrons per volume), which should further help bring the resistance down," Kiani said.

Cha and her team have previously shown that nanomolding of topological nanowires could accelerate the discovery of new electrical properties for applications such as quantum computing, microelectronics and clean-energy catalysts. These nanowires would be particularly well-suited for being interconnects between the billions of transistors in integrated circuits.

Earlier this year, the group demonstrated that MoP nanowires had such low resistivity, they outperform copper interconnects.

"That was a surprising discovery," Cha said. "But the challenge was, we needed to continue to make MoP smaller and smaller, and the methods that we've been using just weren't getting us there. So, then along came a nanomolding method, and we saw it as a way to make even smaller MoP nanowires to continue to check whether the resistivity is going to be still much lower than copper."

Instead, they found the nanowire molding process converted a crystal structure of MoP into a different composition: Mo_4P_3.

"That was not something we expected. And even more surprising was that this phase Mo_4P_3 is not a stable phase that you normally get," Cha said. "Now we realize that this molding method can potentially get us metastable phases."

The metastable Mo_4P_3's resistivity was about 75% higher than MoP's, so MoP still remains the most promising candidate for interconnects.

"This really broadens our exploration space for new materials. And who knows what the possibilities may be?" Cha said. "When graphene was first discovered, it was not at all clear that we could use it in a golf ball, for example, to think about a mundane application. For now, we want to find the next example of Mo_4P_3, another metastable phase that we can arrest and then make it into nanowires."

Co-authors include doctoral student Quynh Sam; postdoctoral researchers Gangtae Jin and James Hart; former postdoctoral researcher Hyeuk Jin Han; research associate Betül Pamuk; and J.R. Stauff of Yale University.

The research was supported by the National Science Foundation, Semiconductor Research Corporation and the Gordon and Betty Moore Foundation.

The researchers made use of the Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials (PARADIM), Cornell Center for Materials Research, and Cornell NanoScale Facility, all of which are supported by the NSF.

Artificial Cilia Could Someday Power Diagnostic Devices

By David Nutt
Cornell Chronicle
May 25, 2022

Cilia are the body's diligent ushers. These microscopic hairs, which move fluid by rhythmic beating, are responsible for pushing cerebrospinal fluid in your brain, clearing the phlegm and dirt from your lungs, and keeping other organs and tissues clean.

A technical marvel, cilia have proved difficult to reproduce in engineering applications, especially at the microscale.

Cornell researchers have now designed a micro-sized artificial cilial system using platinum-based components that can control the movement of fluids at such a scale. The technology could someday enable low-cost, portable diagnostic devices for testing blood samples, manipulating cells or assisting in microfabrication processes.

The group's paper, "Cilia Metasurfaces for Electronically Programmable Microfluidic Manipulation," published May 25 in Nature. The lead author is doctoral student Wei Wang.

"There are lots of ways to make artificial cilia that respond to light, magnetic or electrostatic forces," Wang said. "But we are the first to use our new nano actuator to demonstrate artificial cilia that are individually controlled."

A typical device contains a "carpet" of about a thousand artificial cilia. As the voltage on each cilium oscillates, its surface oxidizes and reduces periodically, which makes the cilium bend back and forth, allowing it to pump fluid at tens of microns per second.

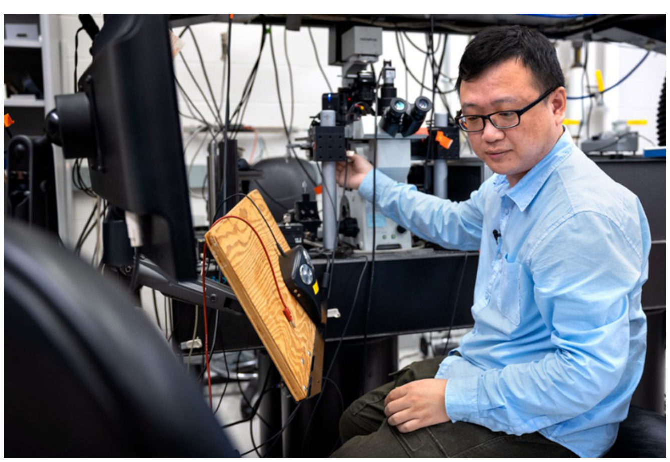


Figure 1: Doctoral student Wei Wang of the Itai Cohen Group helped design an artificial cilial system using platinum-based components that can control the movement of fluids at the microscale. Credit: Ryan Young/Cornell University.

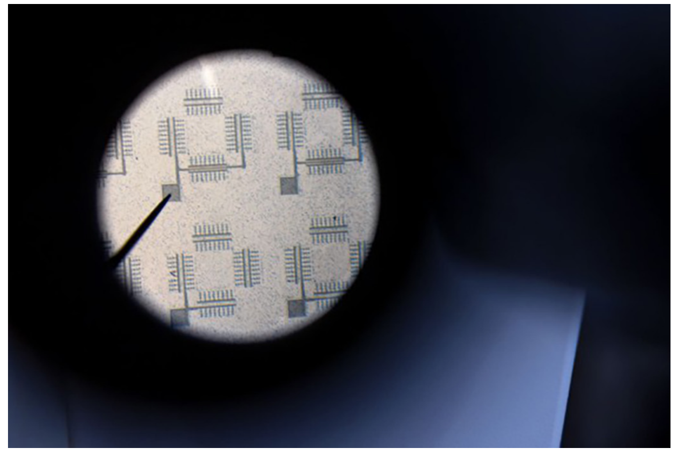


Figure 2: Microscope view of cilia. Credit: Ryan Young/Cornell

The project, led by the paper's senior author, Itai Cohen, professor of physics in the College of Arts and Sciences, builds off a platinum-based, electrically-powered actuator — the part of the device that moves — his group previously created to enable microscopic robots to walk. The mechanics of those bending bot legs is similar, but the cilia system's function and applications are different, and quite flexible.

"What we're showing here," Cohen said, "is that once you can individually address these cilia, you can manipulate the flows in any way you want. You can create multiple separate trajectories, you can create circular flow, you can create transport, or flows that split up into two paths and then recombine. You can get flow lines in three dimensions. Anything is possible."

"It's been very hard to use existing platforms to create cilia that are small, work in water, are electrically addressable and can be integrated with interesting electronics," Cohen said. "This system solves these problems. And with this kind of platform, we're hoping to develop the next wave of microfluid manipulation devices."

A typical device consists of a chip that contains sixteen square units with eight cilia arrays per unit, and eight cilia per array, with each cilium about 50 μm long, resulting in a "carpet" of about a thousand artificial cilia. As the voltage on each cilium oscillates, its surface oxidizes and reduces periodically, which makes the cilium bend back and forth, allowing it to pump fluid at tens of microns per second. Different arrays can be activated independently, therefore creating an endless

combination of flow patterns mimicing the flexibility observed in their biological counterparts.

As a bonus, the team created a cilia device that is equipped with a complementary metal-oxide-semiconductor (CMOS) clock circuit — essentially an electronic "brain" that allows the cilia to operate without being tethered to a conventional computer system. That opens the door to developing a host of low-cost diagnostic tests that could be performed in the field.

"You can imagine in the future, people taking this tiny centimeter-by-centimeter device, putting a drop of blood on it and conducting all the assays," Cohen said. "You wouldn't have to have a fancy pump, you wouldn't have to have any equipment, you would just literally put it under sunlight and it would work. It could cost on the order of $1 to $10."

Co-authors include postdoctoral researchers Qingkun Liu and Michael Reynolds; former postdoctoral researchers Alejandro Cortese, Ph.D. '19 and Marc Miskin; Michael Cao '14 , Ph.D. '20; David Muller, the Samuel B. Eckert Professor of Engineering; Alyosha Molnar, associate professor of electrical and computer engineering; Paul McEuen, the John A. Newman Professor of Physical Science; and Ivan Tanasijevic and Eric Lauga of the University of Cambridge.

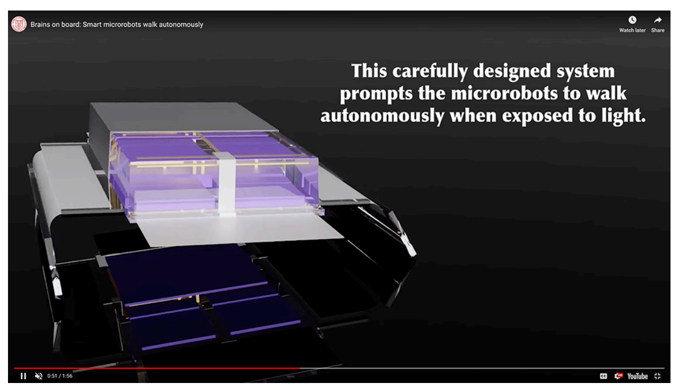
The research was primarily supported by the Army Research Office, the National Science Foundation, the Cornell Center for Materials Research, which is supported by the NSF's MRSEC program, the Air Force Office of Scientific Research and the Kavli Institute at Cornell for Nanoscale Science.

The work was performed in part at the Cornell NanoScale Science and Technology Facility, a member of the National Nanotechnology Coordinated Infrastructure (NNCI), which is supported by the National Science Foundation (Grant NNCI-2025233).

Brains On Board: Smart Microrobots Walk Autonomously

By David Nutt
Cornell Chronicle
September 21, 2022

A collaborative effort has installed electronic "brains" on solar-powered robots that are 100 to 250 μm in size — smaller than an ant's head — so that they can walk autonomously without being externally controlled.



While Cornell researchers and others have previously developed microscopic machines that can crawl, swim, walk and fold themselves up, there were always "strings" attached; to generate motion, wires were used to provide electrical current or laser beams had to be focused directly onto specific locations on the robots.

"Before, we literally had to manipulate these 'strings' in order to get any kind of response from the robot," said Itai Cohen, professor of physics in the College of Arts and Sciences. "But now that we have these brains on board, it's like taking the strings off the marionette. It's like when Pinocchio gains consciousness."

The innovation sets the stage for a new generation of microscopic devices that can track bacteria, sniff out chemicals, destroy pollutants, conduct microsurgery and scrub the plaque out of arteries.

The team's paper, "Microscopic Robots with Onboard Digital Control," published Sept. 21 in Science Robotics. The lead author is postdoctoral researcher Michael Reynolds, M.S. '17, Ph.D. '21.

The project brought together researchers from the labs of Cohen, Alyosha Molnar, associate professor of electrical and computer engineering in Cornell Engineering; and Paul McEuen, the John A. Newman Professor of Physical Science (A&S), all co-senior authors on the paper.

The "brain" in the new robots is a complementary metal-oxide-semiconductor (CMOS) clock circuit that contains a thousand transistors, plus an array of diodes, resistors and capacitors. The integrated CMOS circuit generates a signal that produces a series of phase-shifted square wave frequencies that in turn set the gait of the robot. The robot legs are platinum-based actuators. Both the circuit and the legs are powered by photovoltaics.

"In some sense, the electronics are very basic. This clock circuit is not a leap forward in the ability of circuits," Cohen said. "But all of the electronics have to be designed to be very low power, so that we didn't have to put humungous photovoltaics to power the circuit."

The low-power electronics were made possible by the Molnar Group's research. Former postdoctoral researcher Alejandro Cortese, Ph.D. '19, worked with Reynolds and designed the CMOS brain, which was then built by a commercial foundry, XFAB.

Alejandro Cortese, Ph.D. '19 displays a silicon-on-insulator wafer that contains finished CMOS "brains." Credit: Provided.

The finished circuits arrived on 8-inch silicon-on-insulator wafers. At 15 μm tall, each robot brain — essentially also the robot's body — was a "mountain" compared to the electronics that normally fit on a flat wafer, Reynolds said. He worked with the Cornell NanoScale Facility (CNF) to develop an intricate process using 13 layers of photolithography to etch the brains loose into an aqueous solution and pattern the actuators to make the legs.

"One of the key parts that enables this is that we're using microscale actuators that can be controlled by low voltages and currents," said Cortese, who is CEO of OWiC Technologies, a company he founded with McEuen and Molnar to commercialize optical wireless integrated circuits for microsensors. "This is really the first time that we showed that yes, you can integrate that directly into a CMOS process and have all of those legs be directly controlled by effectively one circuit."

The team created three robots to demonstrate the CMOS integration: a two-legged Purcell bot, named in tribute to physicist Edward Purcell, who proposed a similarly simple model to explain the swimming motions of microorganisms; a more complicated six-legged antbot, which walks with an alternating tripod gait, like that of an insect; and a four-legged dogbot that can vary the speed with which it walks thanks to a modified circuit that receives commands via laser pulse.

"Eventually, the ability to communicate a command will allow us to give the robot instructions, and the internal brain will figure out how to carry them out," Cohen said. "Then we're having a conversation with the robot. The robot might tell us something about its environment, and then we might react by telling it, 'OK, go over there and try to suss out what's happening.'"

The new robots are ~ 10,000 times smaller than macroscale robots that feature onboard CMOS electronics, and they can walk at speeds faster than 10 μm per second. The fabrication process that Reynolds designed, basically customizing foundry-built electronics, has resulted in a platform that can enable other researchers to outfit microscopic robots with their own apps — from chemical detectors to photovoltaic "eyes" that help robots navigate by sensing changes in light.

"What this lets you imagine is really complex, highly functional microscopic robots that have a high degree of programmability, integrated with not only actuators, but also sensors," Reynolds said. "We're excited about the applications in medicine — something that could move around in tissue and identify good cells and kill bad cells — and in environmental remediation, like if you had a robot that knew how to break down pollutants or sense a dangerous chemical and get rid of it."

In May, the team integrated their CMOS clock circuits into artificial cilia that were also built with platinum-based, electrically-powered actuators, to manipulate the movement of fluids.

"The real fun part is, just like we never really knew what the iPhone was going to be about until we sent it out into the world, what we're hoping is that now that we've shown the recipe for linking CMOS electronics to robotic actuating limbs, we can unleash this and have people design low-power microchips that can do all sorts of things," Cohen said. "That's the idea of sending it out into the ether and letting people's imaginations run wild."

Co-authors include former postdoctoral researcher Marc Miskin; postdoctoral researchers Qingkun Liu and Sunwoo Lee; doctoral students Wei Wang, Samantha Norris; and Zhangqi (Jackie) Zheng '24.

The research was supported by the Cornell Center for Materials Research, which is supported by the NSF's MRSEC program; the National Science Foundation; the Air Force Office of Scientific Research; the Army Research Office; and the Kavli Institute at Cornell for Nanoscale Science.

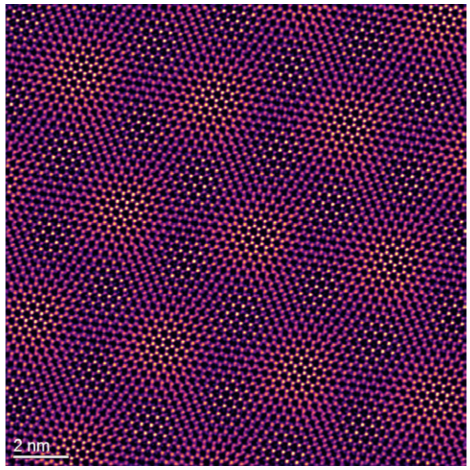
Semiconductor Lattice Marries Electrons and Magnetic Moments

By David Nutt
Cornell Chronicle
March 21, 2023

A model system created by stacking a pair of monolayer semiconductors is giving physicists a simpler way to study confounding quantum behavior, from heavy fermions to exotic quantum phase transitions.

The group's paper, "Gate-Tunable Heavy Fermions in a Moiré Kondo Lattice," published March 15 in Nature. The lead author is postdoctoral fellow Wenjin Zhao in the Kavli Institute at Cornell.

The project was led by Kin Fai Mak, professor of physics in the College of Arts and Sciences, and Jie Shan, professor of applied and engineering physics in Cornell Engineering and in A&S, the paper's co-senior authors. Both researchers are members of the Kavli Institute; they came to Cornell through the provost's Nanoscale Science and Microsystems Engineering (NEXT Nano) initiative.



A transmission electron microscope image shows the moiré lattice of molybdenum ditelluride and tungsten diselenide. Yu-Tsun Shao and David Muller/Provided.

The team set out to address what is known as the Kondo effect, named after Japanese theoretical physicist Jun Kondo. About six decades ago, experimental physicists discovered that by taking a metal and substituting even a small number of atoms with magnetic impurities, they could scatter the material's conduction electrons and radically alter its resistivity.

That phenomenon puzzled physicists, but Kondo explained it with a model that showed how conduction electrons can "screen" the magnetic impurities, such that the electron spin pairs with the spin of a magnetic impurity in opposite directions, forming a singlet.

While the Kondo impurity problem is now well understood, the Kondo lattice problem — one with a regular lattice of magnetic moments instead of random magnetic impurities — is much more complicated and continues to stump physicists. Experimental studies of the Kondo lattice problem usually involve intermetallic compounds of rare earth elements, but these materials have their own limitations.

"When you move all the way down to the bottom of the Periodic Table, you end up with something like 70 electrons in an atom," Mak said. "The electronic structure of the material becomes so complicated. It is very difficult to describe what's going on even without Kondo interactions."

The researchers simulated the Kondo lattice by stacking ultrathin monolayers of two semiconductors: molybdenum ditelluride, tuned to a Mott insulating state, and tungsten diselenide, which was doped with itinerant conduction electrons. These materials are much simpler than bulky intermetallic compounds, and they are stacked with a clever twist. By rotating the layers at a 180° angle, their overlap results in a moiré lattice pattern that traps individual electrons in tiny slots, similar to eggs in an egg carton.

This configuration avoids the complication of dozens of electrons jumbling together in the rare earth elements. And instead of requiring chemistry to prepare the regular array of magnetic moments in the intermetallic compounds, the simplified Kondo lattice only needs a battery. When a voltage is applied just right, the material is ordered into forming a lattice of spins, and when one dials to a different voltage, the spins are quenched, producing a continuously tunable system.

"Everything becomes much simpler and much more controllable," Mak said.

The researchers were able to continuously tune the electron mass and density of the spins, which cannot be done in a conventional material, and in the process they observed that the electrons dressed with the spin lattice can become 10 to 20 times heavier than the "bare" electrons, depending on the voltage applied.

The tunability can also induce quantum phase transitions whereby heavy electrons turn into light electrons with, in between, the possible emergence of a "strange" metal phase, in which electrical resistance increases linearly with temperature. The realization of this type of transition could be particularly useful for understanding the high-temperature superconducting phenomenology in copper oxides.

"Our results could provide a laboratory benchmark for theorists," Mak said. "In condensed matter physics, theorists are trying to deal with the complicated problem of a trillion interacting electrons. It would be great if they don't have to worry about other complications, such as chemistry and material science, in real materials. So they often study these materials with a 'spherical cow' Kondo lattice model. In the real world you cannot create a spherical cow, but in our material now we've created one for the Kondo lattice."

Co-authors include doctoral students Bowen Shen and Zui Tao; postdoctoral researchers Kaifei Kang and Zhongdong Han; and researchers from the National Institute for Materials Science in Tsukuba, Japan.

The research was primarily supported by the Air Force Office of Scientific Research, the National Science Foundation, the U.S. Department of Energy and the Gordon and Betty Moore Foundation. This research was performed in part at the Cornell NanoScale Science & Technology Facility (CNF).

Soft Robot Detects Damage and Heals Itself

By David Nutt
Cornell Chronicle
December 7, 2022

If robots are going to venture into remote environments that humans can't reach, such as deep underwater or distant outer space, they won't only require power and a means to get there. They'll also need to take good care of themselves.

To that end, a team led by Rob Shepherd, associate professor of mechanical and aerospace engineering in Cornell Engineering, combined optical sensors with a composite material to create a soft robot that can detect when and where it was damaged — and then heal itself on the spot.

Their paper, "Autonomous Self-Healing Optical Sensors for Damage Intelligent Soft-Bodied Systems," published Dec. 7 in Science Advances. The lead author is doctoral student Hedan Bai.

"Our lab is always trying to make robots more enduring and agile, so they operate longer with more capabilities," Shepherd said. "The thing is, if you make robots operate for a long time, they're going to accumulate damage. And so — how can we allow them to repair or deal with that damage?"

The first step for such a repair to occur is that the robot must be able to identify that there is, in fact, something that needs to be fixed.

For years, Shepherd's Organic Robotics Lab has used stretchable fiber-optic sensors to make soft robots and related components — from skin to wearable technology — as nimble and practical as possible.

Researchers installed SHeaLDS — self-healing light guides for dynamic sensing — in a soft robot resembling a four-legged starfish and equipped with feedback control. After the researchers punctured one of its legs, the robot was able to detect the damage and self-heal the cuts. Provided.

In fiber-optic sensors, light from a LED is sent through an optical waveguide, and a photodiode detects changes in the beam's intensity to determine when the material is being deformed. One of the virtues of the technology is that waveguides are still able to propagate light if they are punctured or cut.

The researchers combined the sensors with a polyurethane urea elastomer that incorporated hydrogen bonds, for rapid healing, and disulfide exchanges, for strength.

The resulting SHeaLDS — self-healing light guides for dynamic sensing — provide reliable dynamic sensing, are damage-resistant, and can self-heal from cuts at room temperature without any external intervention.

To demonstrate the technology, the researchers installed the SHeaLDS in a soft robot resembling a four-legged starfish and equipped with feedback control. After the researchers punctured one of its legs a total of six times, the robot was able to detect the damage and self-heal each cut in about a minute. The robot could also autonomously adapt its gait based on the damage it sensed.

While the material is sturdy, it is not indestructible.

"They have similar properties to human flesh," Shepherd said. "You don't heal well from burning, or from things with acid or heat, because that will change the chemical properties. But we can do a good job of healing from cuts."

Shepherd plans to integrate the SHeaLDS with machine learning algorithms that recognize tactile events to eventually create "a very enduring robot that has a self-healing skin, but uses the same skin to feel its environment to be able to do more tasks."

Doctoral student Young Seong Kim co-authored the paper.

The research was supported by the Air Force Office of Scientific Research, the NASA Innovative and Advanced Concepts program, and the National Science Foundation EFRI program.

The researchers made use of the Cornell NanoScale Facility, a member of the National Nanotechnology Coordinated Infrastructure, which is supported by the NSF; the Cornell Center for Materials Research, which is supported by the NSF's MRSEC program; and the Cornell Energy Systems Institute.

Cornell to Lead New Semiconductor Research Center

By David Nutt
Cornell Chronicle
January 5, 2023

Cornell is leading a new $34 million research center that will accelerate the creation of energy-efficient semiconductor materials and technologies, and develop revolutionary new approaches for microelectronics systems.

The SUPeRior Energy-efficient Materials and dEvices (SUPREME) Center will bring together leading researchers from 14 higher education institutions, in collaboration with the center's sponsor, Semiconductor Research Corporation (SRC). SUPREME is one of seven centers funded by SRC's JUMP 2.0 consortium. The center will be funded by SRC and its 14 partner universities; Cornell's investment in the five-year project will be $7 million.

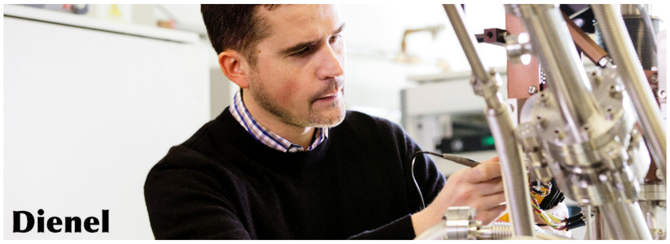

Xing

Partners include: Cornell; Massachusetts Institute of Technology (MIT); Boise State University; Georgia Institute of Technology; North Carolina State University; Northwestern University; Rensselaer Polytechnic Institute; Rochester Institute of Technology; Stanford University; Yale University; the University of Colorado, Boulder; the University of Texas, Austin; the University of California, Santa Barbara; and the University of Notre Dame.

Huili Grace Xing, the William L. Quackenbush Professor of Engineering in materials science and engineering, and in electrical and computer engineering, at Cornell Engineering, will serve as the center's director. Tomás Palacios, director of Microsystems Technology Laboratories and a professor in the electrical engineering and computer science at MIT, will serve as the center's associate director. The center's managing director will be Thomas Dienel, a condensed matter physicist who has been running the user program at Cornell's Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials (PARADIM).

"Our center will focus on the material science, the new device architectures and how they interplay with each other," said Xing, whose own pioneering research has included materials that support unipolar or bipolar transport, such as 2D materials, ultra-wide bandgap semiconductors, and devices with record performance that reveal fundamental limits.

"We're not engineering a particular approach," she said. "We're actually going down to the material genome level. If we go down to the building blocks and make a connection, then we can serve a very broad



application space in logic, memory, computing, sensing and communication with the desired energy efficiency.

Researchers at the center will explore both fundamental new science and novel engineering technologies, with the aim of driving the semiconductor industry in the next 3-15 years, while also training the next generation of scientists and engineers to work across disciplines.

The center's four primary goals are to:

- assemble interdisciplinary teams of materials scientists, device engineers, chemists and physicists to develop new materials, technologies and devices that can bring at least 10-fold system-level performance improvements to key applications;
- accelerate the pace of discovery and "lab-to-fab" transition in microelectronics, creating prototype devices at nanofabrication facilities at Cornell and partner institutions;
- maintain a close collaboration with six other centers that are part of the latest iteration of the Joint University Microelectronics Program (JUMP) — a consortium of industry research participants and the U.S. Defense Advanced Research Projects Agency (DARPA), which is administered by SRC — with SUPREME developing and demonstrating new materials and technologies that can be used for prototype chips and systems built by other centers in JUMP 2.0; and
- ensure diverse and broad workforce development.

"We've known for some time that Cornell Engineering faculty are pursuing research at the forefront of semiconductor materials science and engineering," said Lynden Archer, the Joseph Silbert Dean of Engineering. "With this new multi-institutional research center, we look to the future and to providing leadership that translates to national impact in multiple areas, including autonomous systems and robotics, energy systems, medicine, and space exploration — all fields which require advances in semiconductor materials and new device architectures that consume less energy."

SUPREME is organized around four interdisciplinary sub-themes, or thrusts: digital and analog; memory and applications; interconnects and metrology; and materials discovery and processing.

The first thrust aims to harness the unique properties of two-dimensional materials, wide and ultra-wide bandgap semiconductors, advanced ferroelectrics, spin and molecular materials to develop a new generation of digital and analog devices.

The second thrust will present new approaches for embedded and neuromorphic memory and storage technologies — such as ferroelectric, spintronic and electrochemical devices — that will support the computational workloads of the future.

The third thrust will focus on new physics of electron transport and new materials — such as anisotropic conductors and topological semimetals — to engineer better interconnects from devices to devices, and dies to dies. This thrust will also develop advanced metrology to characterize new materials and accelerate material discovery by high throughput experimentation.

The fourth thrust will develop the new materials and processing technologies required by the first three device-focused thrusts, with an emphasis on several broad classes of materials: 2D and wide bandgap materials for logic and analog computing; metal-oxide-semiconductors for low-power complementary architecture; ferroelectrics and electrochemical materials for new memory/computing architectures, and strongly nonlinear optical materials for interconnects.

There are seven Cornell faculty among the center's 25 principal investigators (PIs), including: Xing; Debdeep Jena, the David E. Burr Professor of Engineering in the School of Electrical and Computer Engineering and in the Department of Materials Science and Engineering; James Hwang, M.S. '76, Ph.D. '78, a research professor of materials science and engineering; Dan Ralph, Ph.D. '93, the F.R. Newman Professor of Physics in the College of Arts and Sciences; Farhan Rana, the Joseph P. Ripley Professor of Engineering in electrical and computer engineering; Judy Cha, Ph.D. '09, professor of materials science and engineering; and Darrell Schlom, the Herbert Fisk Johnson Professor of Industrial Chemistry in materials science and engineering.

The PIs will also work in close collaboration with industry leaders to maximize the impact and relevance of their work, which will not only lead to more energy-efficiency technologies, but also ultimately boost equality, according to Xing.

"We want technology that can use as little energy as possible but provide as much function as possible. That is essential if we want to propagate equality," Xing said. "If we're able to lower the energy consumption for all of those essential means we want to have in modern life, we can lower the barrier for everybody to have access to information, to have access for education, and to have access to opportunities."

CNF Education and Outreach Coordinator's Column — 2023

By Tom Pennell

The Cornell NanoScale Facility recently celebrated our 45th anniversary and had no shortage of education and outreach opportunities this year! We oversaw the return of the nano exhibit to the Ithaca ScienCenter (see photo below) and made some special additions to the exhibit. These additions include a Nanooze magazine rack, full color posters, and an interactive plasma globe display.

The outreach program hosted several hundred students in 2022. Many of these were repeat visitors to the facility including the TST BOCES New Visions Engineering program, 4-H Career Explorations, and the Sharpsteen Science Group from Onondaga Central School District in Syracuse, NY. These are great groups of students to work with and we look forward to hosting their visits to CNF every year!

After a brief hiatus due to COVID, we have restarted the CNF Ambassadors program. We currently have a group of 10 new CNF ambassadors who will be participating in our various youth outreach events throughout the coming year. This is a great opportunity for graduate students to increase exposure to their research, by interacting with a public audience in a fun and immersive environment.

We continue to host our Technology & Characterization at the Nanoscale (TCN) short course twice a year. The June TCN course was held in person with hands-on demonstrations in the cleanroom. We offered a virtual TCN during the pandemic and it was so well received that we are continuing with this format every January, enabling us to reach a much wider audience.

Here are other great outreach opportunities this year.

FIRST® LEGO® EXPO at CNF: For the first time in three years, CNF hosted a First Lego League competition in Duffield Hall on February 18th. This was a fantastic event that brought a large crowd of 8-10-year-olds to campus to show off their creations. This year's focus was "Super Powered" — inspiring youth to investigate the energy that powers the world around us. (See photos on page 24.)

Math Kangaroo: The CNF has established a public Math Kangaroo center in the Central New York area. For a quarter of a century, Math Kangaroo has been hosting an annual global mathematical tournament for students from 1st to 12th grades. The aim of Math Kangaroo is to enhance students' math abilities, introduce new techniques for tackling word and logic puzzles, foster critical thinking skills, and boost their confidence in the classroom. The competition took place in person in March, with a prize ceremony in June. For information about the next LEGO Event or the Math Kangaroo event, please contact CNF staff member Xinwei Wu at wu@cnf.cornell.edu.

4-H Career Explorations: This event is held annually in June on the Cornell Campus and gives junior high students the opportunity to learn about the various facilities on campus. CNF is one of the favorite sites that students visit and we typically host small groups totalling around 120 students during the event.

CNF ATLAS Program Launch: With the recent passing of the CHIPS Act and the announcement of the largest semiconductor cleanroom in the United States being built by Micron Inc., CNF recognized the need for a workforce development program. The "Accelerated Training for Labor Advancement in Semiconductors" (ATLAS) program is intended to provide students the advanced training they need to enter this highly technical field. Read more about this program in the coming pages of this NanoMeter issue.

New Partnerships: Continuing with the theme of workforce development, CNF is working on several new endeavors that will expand our educational audience. This includes a nanofabrication micro-credential program at Tompkins Cortland Community College (TC3). We are also developing several new events in cooperation with Onondaga County Community College (OCC) and Micron Inc. These large "chip camp" events will bring junior high and high school students from the Central New York region to CNF to learn about nanotechnology.

It's been a very exciting year so far at CNF and I can't wait to work with the next batch of students! For information about our education and outreach programs, contact me at pennell@cnf.cornell.edu.

Tom Pennell, CNF Education and Outreach Coordinator

Hunter and Freya Pennell explore the new plasma exhibit provided by CNF, at the Ithaca ScienCenter.

Cornell NanoScale Launches ATLAS:
A Semiconductor Workforce Development Program

By Tom Pennell

In the fall of 2022, the Cornell NanoScale Facility (CNF) held its kickoff meeting of the Accelerated Training for Labor Advancement in Semiconductors (ATLAS) program. Over the course of the spring 2023 semester, high school seniors from the Tompkins-Seneca-Tioga BOCES New Visions Engineering program visited the CNF multiple times and learned about all aspects of micro and nanoscale device fabrication.

Under the instruction of David Syracuse, the Tompkins-Seneca-Tioga BOCES New Visions Engineering program has flourished on Cornell University's Ithaca campus. This program provides high school seniors from the surrounding area with the unique opportunity to visit state of the art research facilities on the Cornell campus and to learn key skills in a variety of engineering disciplines.

"It's been my absolute pleasure and honor to be able to work with students in this program," says Syracuse. "They are getting an amazing experience that will allow them to become the transformative engineers that our world will need in the coming years. Programs like ATLAS are a critical part of our course that really sets the students up for success."

With the recent passing of the CHIPS Act and the announcement of Micron Incorporated installing one of the largest semiconductor facilities in the United States in the Central New York area, the CNF recognized the need for a workforce development program in the local area to support this expanding industry. The CNF is no stranger to educating students in this space. The facility just celebrated its 45th anniversary of providing expertise in good laboratory practice, tool operation, and the critical aspects of device fabrication.

The ATLAS program was developed by CNF technical staff member and Education and Outreach Coordinator Tom Pennell. "The New Visions program has been visiting CNF for six years to learn about nanotechnology as part of their curriculum and are always a fantastic group of students to interact with. We are excited to welcome them back to CNF for this experience." Pennell said. "We designed the ATLAS program using some of the educational opportunities we already have in place and added new content so the program will meet the needs of industry. This comprehensive program will give these students a real leg up in this industry in a fun and immersive environment."

Over the course of several visits to CNF, the ATLAS program students learned about nanotechnology and its impact on society, toured the cleanroom along with the building infrastructure required to keep it operating, and received instruction on plasma tool operation, repair and maintenance. They also attended CNF's Technology and Characterization at the Nanoscale (TCN) three day short course. The program culminated with the students engaging in hands on device fabrication in CNF's cleanroom facility and a meeting with the collective CNF staff to answer any remaining questions. All of this happened under the education and direction of the facility's expert staff.

"CNF is excited to add the ATLAS program to our long list of education and outreach activities and looks forward to expanding this program. Our award-winning staff are the absolute best at educating people of all skill levels in this unique and important area of expertise." CNF Director of Operations Ron Olson stated. "A program of this caliber would not be possible without CNF's expert staff."

For more information:

- Tompkins County New Visions Engineering Program: https://www.tstnv.org/engineering.html
- Cornell Nanoscale Facility: www.cnf.cornell.edu
- CNF TCN Short Course: https://www.cnf.cornell.edu/education/tcn
- Outreach and Educational Visits to CNF: email Tom Pennell at pennell@cnf.cornell.edu

Cornell, Micron Bring Nanoscience to Middle Schoolers

By Laura Gallup
Cornell Chronicle
April 10, 2023

Nearly 120 Syracuse-area middle schoolers descended upon the Duffield Hall atrium on April 5th for a hands-on program designed to get kids excited about STEM.

The three-day Chip Camp was the result of a partnership between Liverpool, New York, Central School District (LCSD) and Micron, a computer memory chip manufacturer. The company plans to begin construction in 2024 on a semiconductor manufacturing facility in Clay, New York, potentially bringing tens of thousands of jobs to the region.

"Everything is connected back to technology in some way, and everything keeps changing and developing and becoming more effective and efficient," said Kasey Dolson, the LCSD assistant superintendent for curriculum, instruction and assessment.

"And we want our students to not only be consumers, but creators, of technology and be involved in any kind of career or field in STEM," Dolson said at the event.

LCSD middle schools hosted the first and third days of Chip Camp.

For Day Two, Chip Camp came to the university to visit the Cornell NanoScale Science and Technology Facility (CNF) for a crash course in the science of the very small. CNF, a world-class facility for micro and nanofabrication, operates as an open-user facility, allowing people from all over the world access to its cutting edge tools and machines.

The day started off with a presentation on items made at the nanoscale, such as chips for batteries, biomedical devices, computers, cell phones and cars, led by Tom Pennell, CNF Education and Outreach Coordinator.

"If we don't do this, we don't have the next generation of scientists and kids who are inspired to pursue a career in this field," Pennell said. "It's incredibly important. So that's the goal: to have fun and also to inspire and teach at the same time."

Tom Pennell, CNF education and outreach coordinator. shows a student from Liverpool Central School District how to use a microscope at Chip Camp on April 5, 2023. Ron Olson, CNF director of operations, looks on. Credit: Charissa King-O'Brien/Cornell Engineering

He finished the session by carrying an iPad into the CNF cleanroom to broadcast himself to the auditorium getting suited up and walking through the facility.

After Pennell's presentation, the students broke into three groups for activities.

At the first station, they used different types of microscopes to look at slides of tiny things such as horsehair, sardine scales and butterfly wings. At the second, kids drew on plastic and then printed their designs onto light sensitive paper using a UV light; they also made bracelets using beads that change color in sunlight.

"At every one of these events, I end up hearing my favorite quote, at least once." Pennell said. "And that is, 'That's so cool.' When you hear somebody say that, you know you've done a good job, you've inspired somebody. The look on their face sometimes is just wonderful — this awe that comes over them, like — 'I just did that.'"

Micron

At the last station, students dress up in cleanroom gear including suits, hairnets, boot covers and hoods to pose for selfies.

"Dressing up in the costumes and the selfie area was fun, to experience how to put everything on, and just the feeling in the suit," said Michael Esposito, an 8th grader from Chestnut Hill Middle School.

Martin Sarkodee, a 7th grader from Morgan Road Middle School, had heard about Micron on television many times before the event, but didn't know much about them, he said.

"This whole Chip Camp thing, it's helped us understand what Micron does, and their mission, their goal," Sarkodee said. "It's helped us understand technology better, and how to better use it to help our future."

The first and third days of Chip Camp gave students the opportunity to launch rockets, learn to code, and build robots. Dolson said that district teachers took Micron processes and turned them into activities that the students would understand. The whole experience, free for students, was made possible by a $40,000 grant from the Micron Foundation.

"I want all of our students to be excited about opportunities in STEM and have these experiences to do something different and unique, but also something cutting edge and new," Dolson said. "I hope that by engaging our middle school students, them will have a better idea of what pathway they would like to take into high school and beyond our school walls."

The company has been running Chip Camps near their other facilities for more than 20 years, and was excited to launch the first one in central New York, said Robert Simmons III, the Micron Foundation's head of social impact and STEM programs.

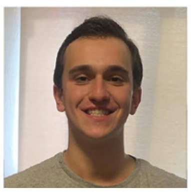
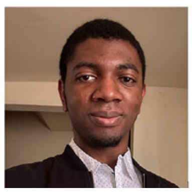
"The success of this program is due in large part to the participation of partners like Cornell, who not only help provide programming to get young people excited about STEM," Simmons said, "but also expose them to the vast array of opportunities that exist to pursue their dreams and passions."

The CNF hosted two more Micron Chip Camps over the summer.

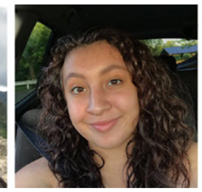
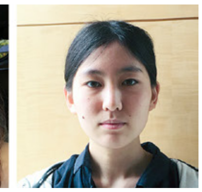
Scenes from the Super Powered FIRST® LEGO® EXPO at CNF

The 2023 CNF REU Program

This past summer, we were pleased to host seven undergraduate students as part of the 2023 Cornell NanoScale Facility Research Experiences for Undergraduates (CNF REU) Program. We also welcomed a graduate student from Hokkaido University as part of our international program (CNF iREG) collaborating with the National Institute for Materials Science (NIMS) in Tsukuba, Ibaraki, Japan.



SAMANTHA AVERITT
Mechanical Engineering, UC Berkeley
CNF REU Staff Mentors: Roberto Ricardo Panepucci, Giovanni Sartorello
CNF REU Project: NanoScribe Advanced Patterning Techniques for Two-Photon 2D and 3D Structures

PAUL BLOOM
Optical Engineering, University of Rochester
CNF REU PI: Prof. Hari P. Nair
CNF REU Project: Electrical Interconnects Based on Delafossite Thin Films

ASTRID DZOTCHA KENGNE
Electrical Engineering, Morgan State University
CNF REU PI: Prof. Judy Cha
CNF REU Project: Nanomolding of Topological Materials

DANIEL HARRISON
Electrical Engineering, Morgan State University
CNF REU PI: Prof. Debdeep Jena
CNF REU Project: A Systematic Study of How Different Phases of Niobium Nitride (NbXN) React to Xenon Difluoride (XeF2) Undercut Etch

BRYAN KIM
Chemistry, UC Berkeley
CNF REU Principal Investigator:
Nicholas Lawrence Abbott
CNF REU Project: Investigation of Pd-Au Alloys for Sensing and Actuation

NAOMI NARANJO
Engineering, Cornell University
CNF REU PI: Itai Cohen
CNF REU PROJECT: Wafer-Scale Fabrication of Single-Domain Magnetic Nanostructures

AMARA TADDEO
Chemistry, Allegheny College
CNF REU Staff Mentors: Roberto Ricardo Panepucci, Xinwei Wu
CNF REU Project: Nanoimprint Process Optimization for Overlay and Fidelity

TOKO OGATA
Graduate Student, Hokkaido University, Sapporo Japan
CNF iREG Staff Mentors: Jeremy Clark, Phil Infante, Aaron Windsor
CNF iREG PROJECT: Electrical Characterization of Dielectric Films

Look for their final reports and NNCI REU Convocation presentations online at
https://www.cnfusers.cornell.edu/reu

New Staff at the Cornell NanoScale Facility

James Crawford is one of the newest additions to the tech staff at CNF, in late 2021. Growing up in the lonely hills of upstate NY, James would take apart anything with a fastener in a quest to find how things work. A non-traditional path took James through studies in electronics, computer information systems and mechanical engineering technology. His passion for fabrication, radio control modeling and automotive shenanigans, have built skills that keep the lab at CNF running.

Roberto Panepucci has 32 years of experience in nanofabrication and related techniques, starting with graduate work at UIUC, and other academic work in the US and Brazil. He enjoys research in nano and microdevice fabrication, and has done in-depth work in photonics. At the cellular level, he contributed 50% of DNA and provided growth environment to three wonderful humans.

Giovanni Sartorello obtained his MSc from the University of Padua in Italy and his PhD from King's College, London in the UK. He came to Cornell as an AEP postdoc in 2019, and worked on nonlinear optical metasurfaces. He has been at CNF since 2022, specializing in lithography.

Check out the Latest Nanooze!!

Issue 18 of our youth newsletter, Nanooze, is now available and this one focusses on "ORGANIC LIGHT-EMITTING DIODES" with articles like; What are OLEDS?, OLEDS in your life, Carbon; A most useful atom, and Q&A with Nancy Stoffel, Flexible Hybrid Electronics Engineer!

Please visit our website for more information, past issues to download, and the form for subscribing to receive Nanooze for your classroom!

https://www.nanooze.org/

New CNF Tools or Capabilities

Direct Write Laser Lithography — Heidelberg DWL66

One of CNF´s key lithography workhorse is the DWL2000 mask making system, where you start all your photolithography! Its little brother, the DWL66, has seen little use as it is not as fast as the DWL. In the Fall of 2022, a set of new procedures for using the DWL66 for direct wafer lithography have been put in place. It is now possible to do automated cross detection for global marks and die to die alignment using this tool. Full 4"-6" wafers can be exposed with or without alignment with a 10 mm or 4 mm write head. The feature sizes can be as small as 0.6 μm with the 4 mm head.

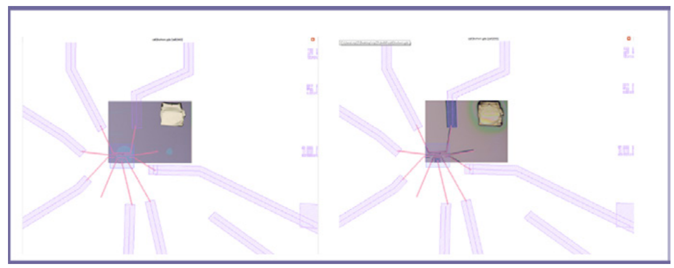
Another exciting feature of the system is the capability to do backside alignment with this tool, using the dedicated stages.

Finally, a very simple procedure for uploading an image of your sample to KLayout so you can visually choose where to expose your GDS file has been setup!

No prior alignment marks needed! Small pieces are exposed in 15-30min. Please note that write times can be quite long for full wafers.

Check with Garry Bordonaro and or Roberto Ricardo Panepucci to learn more about this very flexible tool. (*bordonaro@cnf.cornell.edu, panepucci@cnf.cornell.edu*)

The figure below shows a set of electrodes written directly onto a flake of graphene (picture on left) on a 10mm square silicon die in 5min.



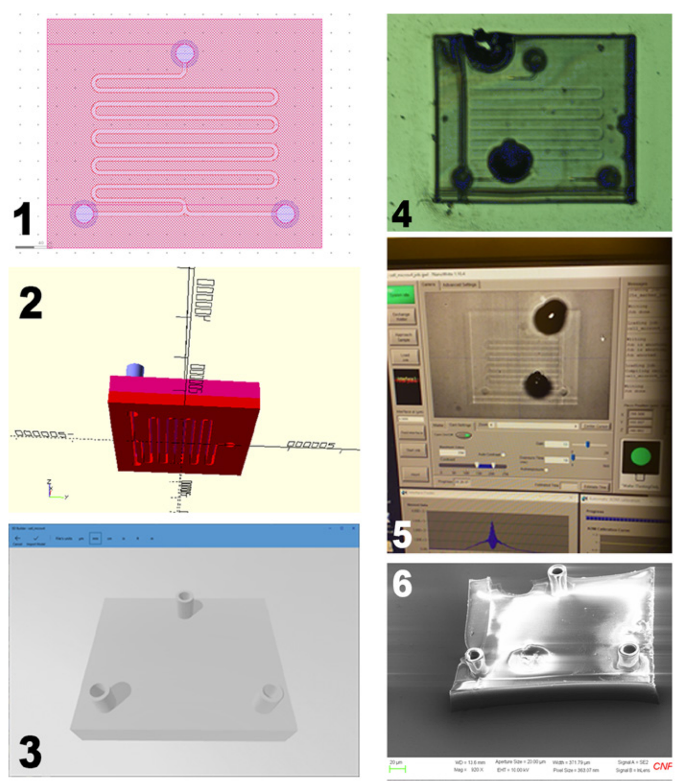
Nanoscribe — 3D Printing Down to the Nanoscale

CNF´s Nanoscribe GT2 two-photon 3D lithography system has been in the spotlight before as a Halloween sculpting tool! This system is capable of advanced 3D printing with objectives of 10x, 25x and 63x magnification enabling features as small as 200 nm and perhaps even less!

To leverage this potential, Roberto Ricardo Panepucci and Giovanni Sartorello, with the help of CNF Fellow Giancarlo D'Orazio, have worked on process developments that can serve the needs of a wider variety of users. Figure 1 shows an image of the generation — using an open-source tool — of 3D STL files converted from 2D GDS files. You can find more information about this online: https://confluence.cornell.edu/display/CNF/GDS3XTRUDE+for+KLayout

There, you will find detailed instructions on running KLayout and the gds3xtrude macro to convert GDS to STL. Moreover, to facilitate user experimentation, a simplified flow that operates "in air" has been set up, with SU-8 spun and baked on a hotplate. This should allow direct write of 3D or 2D patterns easily. Another important capability we added is a 4" wafer holder fixture that allows users to explore lithography directly on their wafers. Finally, an alignment procedure for overlay using existing alignment marks on the wafer has been tested and documented.

Check with the staff for details and for training schedules.



CNF Community News

CNF Community News from Abbaspourrad's Lab

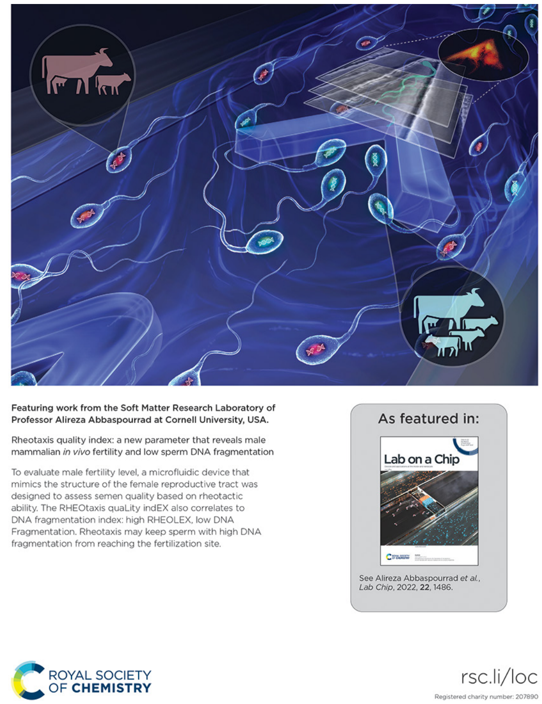
Hi Melanie,

Last year (March 2022) one of our research papers went on the cover of the lab-on-a-chip journal. Here is the link to the cover and a short description.

The work from the soft matter research laboratory of Prof. Abbaspourrad at Cornell was featured on the cover of the Lab On a Chip. The microfluidics platform designed in their lab (manufactured in CNF) showed that the ability of mammalian sperm to swim against the current is associated with the male fertility potential and DNA intactness. (Editor Notes: See page 10 in this newsletter, also!)

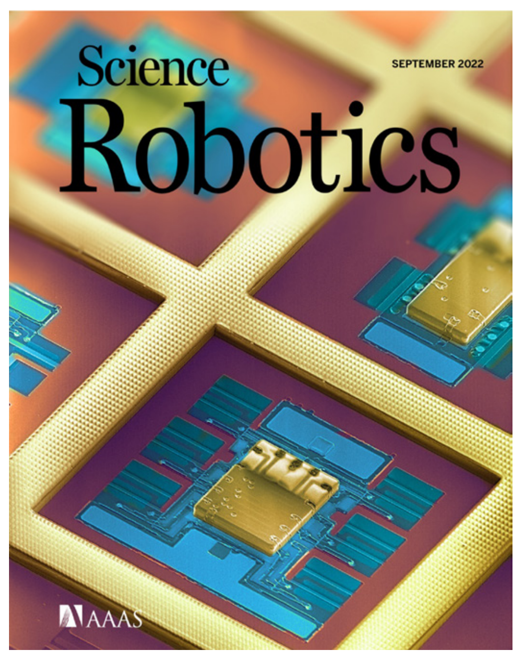
https://pubs.rsc.org/en/content/articlepdf/2022/lc/d2lc90035a

Best, Mohammad Yaghoobi



Itai Cohen's Research Group Scored Two Covers

"Cilia metasurfaces for electronically programmable microfluidic manipulation"; Wang, Wei, et al, Nature 605.7911 (2022): 681-686.



"Microscopic robots with onboard digital control"; Reynolds, Michael F., et al., Science Robotics 7.70 (2022): eabq2296.

CNF Community News: Harry Peng

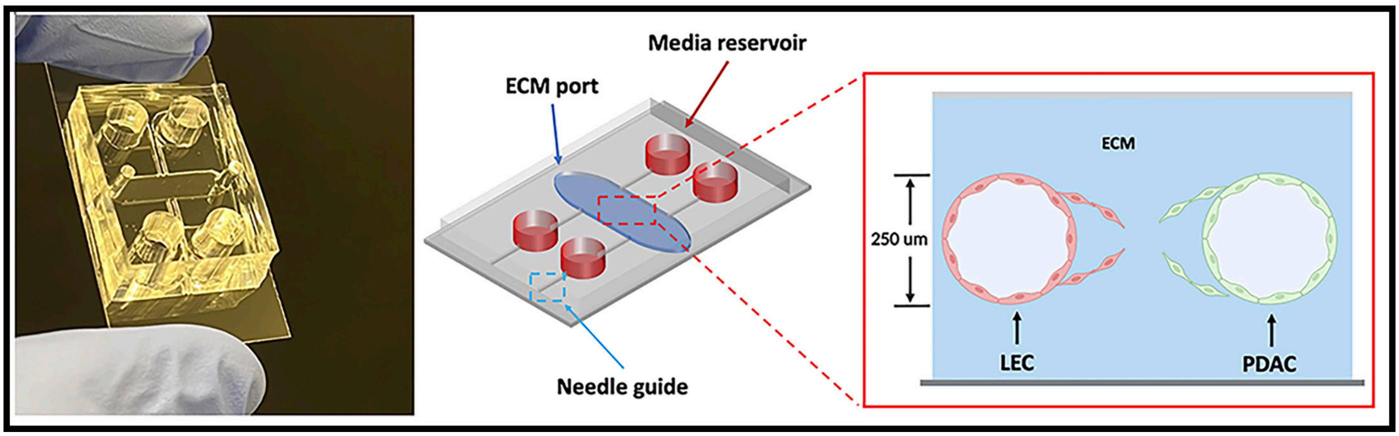
Dear Melanie-Claire,

I recently received the IFER graduate fellowship!

My research titled "A tissue-engineered pancreatic cancer model for dissecting the roles of lymphatic vessels in tumor immunity" was awarded the 2022-23 graduate fellowship of the International Foundation for Ethical Research. We combine multiple techniques in tissue engineering and microfabrication and create a 3D vascularized pancreatic cancer model to study the role of lymphatic vessels in regulating tumor interstitial fluid pressure, immune cell infiltration, and cancer drug delivery. We hope that this study can provide a promising alternative to avoid ethical issues related to animal use and live up to the guiding 3R principles (i.e. replacement, reduction, and refinement).

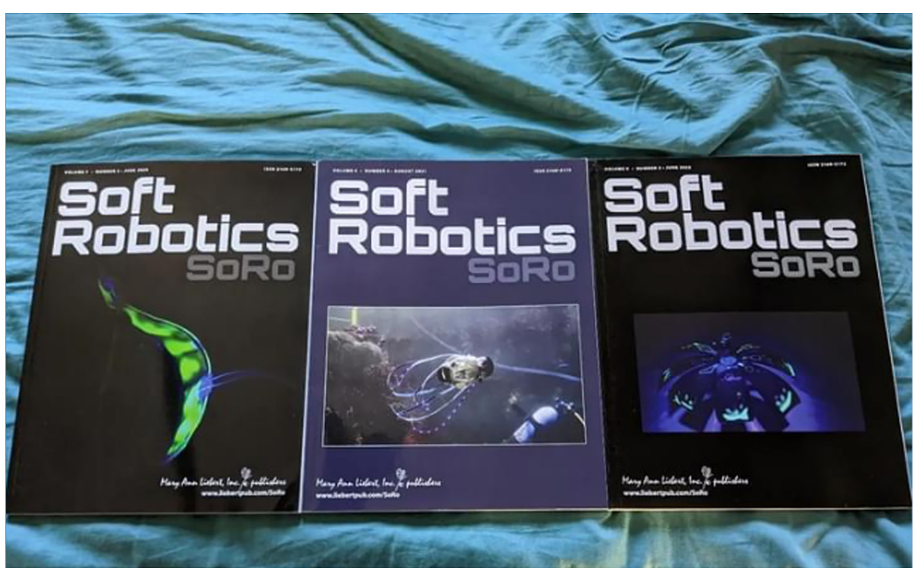
https://www.ifer.org/graduate-fellowships/current-recipients

Best, Yansong (Harry) Peng



Caleb Christianson Scored Three Soft Robotics Covers!

Caleb was a 2013 CNF REU intern with Derek Stewart...



Two Awards for CNF Associate Director Claudia Fischbach

2023 CMBE (Cellular and Molecular Bioengineering) Momentum Award

Congratulations to professor Claudia Fischbach-Teschl, winner of the 2023 CMBE (Cellular and Molecular Bioengineering) Momentum Award, recognizing a BMES (Biomedical Engineering Society)-CMBE SIG member who is at the mid-career stage and has made a substantial impact on their field that is related to cellular and molecular bioengineering.

Dr. Fischbach gave an award talk during the 2023 BMES-CMBE Conference.

https://www.bme.cornell.edu/news/claudia-fischbach-teschl-wins-2023-cmbe-momentum-award

ALSO!

First RFSR MPZPM Awardee

The first awardee of the Rosalind Franklin Scientist-in-Residence (RFSR) Program of the Max-Planck-Zentrum für Physik und Medizin (MPZPM), Claudia Fischbach-Teschl, has started her seven month-sabbatical in Erlangen.

https://tinyurl.com/Fischbach-RFSR-MPZPM

CNF Community News: James Hart

Hi Melanie-Claire,

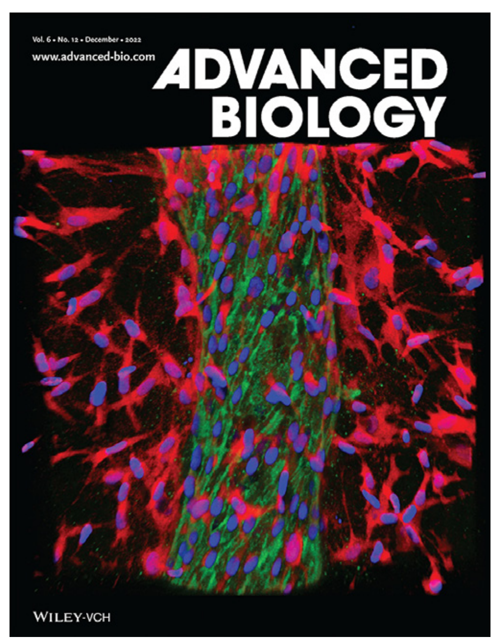
Here is a news blurb on an award I won, based on research done in the CNF:

> James Hart presented at the Materials Research Society conference in Boston, December 2022, and won the "Best Contributed Speaker Award" in the symposium Frontiers of Imaging and Spectroscopy in Transmission Electron Microscopy. James is a post-doc in Judy Cha's lab, and his research focuses on understanding structure-property coupling in quantum materials. His work depends on the e-beam lithography and thin film deposition capabilities of the CNF.

Thanks, Jamie

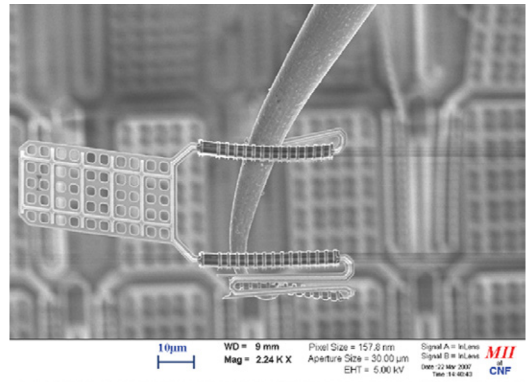
Esak Lee's Research Group Scored a Cover

Dr. Esak Lee's research "A microfluidic model of AQP4 polarization and fluid transport in the healthy and inflamed brain: the first step towards glymphatics-on-a-chip", made the cover of Advanced Biology. 2022 Aug 4; doi: adbi.202200027.



Gregory Simelgor Passes at 51

August 26, 1970 ~ July 3, 2022 (age 51) • Long Time CNF User



"Very sad to hear this news. Gregory was really good man who also served on the CNF user committee. He lobbied long and hard to get the water fountain in the togging room. I often thought it should have a plaque with his name on it. I am attaching a photo from the 2007 CNF picnic (above left). Thank you for including me in your remembrances."

- Don Tennant (CNF Director of Operations, 2007-2019)

Left image: Greg at one of the many CNF picnics he attended.

Right image: The device image is an SEM of one of Greg's MEMs devices taken using the Ultra with new nanoprobes.

Meredith G. Metzler

April 30, 1975 - July 21, 2023 • CNF Staff: 2002-2015

It is with heartfelt sadness that the Metzler family announces the death of Meredith G. Metzler, 48, of Columbus, Ohio. Meredith passed away on July 21, 2023 after a courageous battle with cancer.

Meredith studied mathematics and physics at Kalamazoo College (where he met his wife, Kelly) and Cornell University. Then worked in a variety of positions including the Cornell NanoScale Facility (CNF), the Quattrone Nanofabrication-Singh Center for Nanotechnology (QNF), and the National Institute of Standards and Technology (NIST). He also participated in many working groups and planning teams in his scientific interest areas.

Meredith enjoyed his time volunteering with Scouting and his son's robotics team. He was a car enthusiast, and delighted in fixing cars, spectating at amateur rally racing, and attending professional races. Meredith's other hobbies included cycling (proudly completing two charity century races), tackling house projects, taking his sons to concerts, and spending time with friends.

He is survived by his loving parents, Patricia and Eric Metzler; wife, Kelly Metzler; children, Riley and Kieran Metzler; and many caring aunts, uncles, and cousins.

Meredith's co-worker Gerald Lopez said: This image is from our early training days as the inaugural management team of the QNF. (L2R: Noah Clay, Eric Johnston, Metz, Gerald Lopez)

Ober, Materials Scientist, Elected to National Academy of Engineering

By Reeve Hamilton
Cornell Engineering
February 9, 2023

Christopher K. Ober, professor of materials science and engineering, has been elected to the National Academy of Engineering, among the highest professional distinctions for an engineer.

The Department of Materials Science and Engineering was well-represented in the academy's new class, which also includes adjunct professor Kelin J. Kuhn and alumni Peter F. Green, Ph.D. '85, and Jie Xue, Ph.D. '92.

Election to the academy honors those who have made outstanding contributions to "engineering research, practice or education… or developing/implementing innovative approaches to engineering education," according to a February 7 announcement by the academy. The election of Ober and Kuhn brings the current total of NAE members in Cornell Engineering to 26.

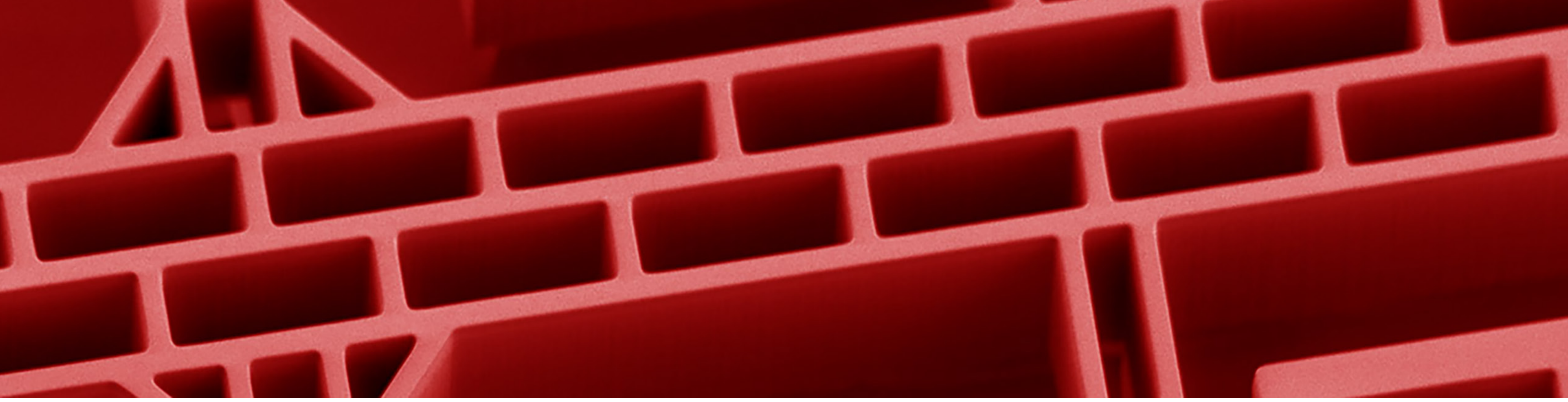
Ober, the Francis Norwood Bard Professor of Metallurgical Engineering, was elected for "the invention of new photoresist families enabling high-resolution lithography in microelectronics manufacturing." His research focuses on fine-tuning the thermal, optical and electrical properties of polymers through precise changes to molecular structure. He has co-authored more than 500 scientific publications and shares more than 50 patents. Formerly chair of his department and interim dean of Cornell Engineering, Ober served as the Lester B. Knight Director of the Cornell NanoScale Science and Technology Facility from 2016 until August 2023. CNF is one of the nation's premier nanofabrication sites.

"Chris is known internationally for his clever use of organic polymer chemistry to design macromolecules capable of spontaneously assembling to create patterns at resolutions set entirely by the microscopic molecular dimensions, stiffness, and thermodynamics," said Lynden Archer, the Joseph Silbert Dean of Engineering.

"Used in concert with macroscopic processing methods such as photolithography, his work has transformed how we think about high-resolution patterning of materials for next-generation microelectronics devices."

"Chris is an integral part of our department, a wonderful mentor to his students, a caring adviser and a respected leader who has served as a role model to me and many others in all aspects of being a successful professor," said Lara Estroff, professor of materials science and engineering and chair of the department. "We are also thrilled for Kelin, Peter and Jie, and congratulate them on their well-deserved recognitions. The multiple connections to our department in this year's NAE class is a testament to the strength and impact of our research community."

The newly elected class will be formally inducted during the NAE's annual meeting on Oct. 1.



This banner is a MEMs device created by Pete Hartwell when he was working on his Ph.D. with Noel MacDonald.

Noel Charles MacDonald

1940-2022

CNF Director, 1995-1997

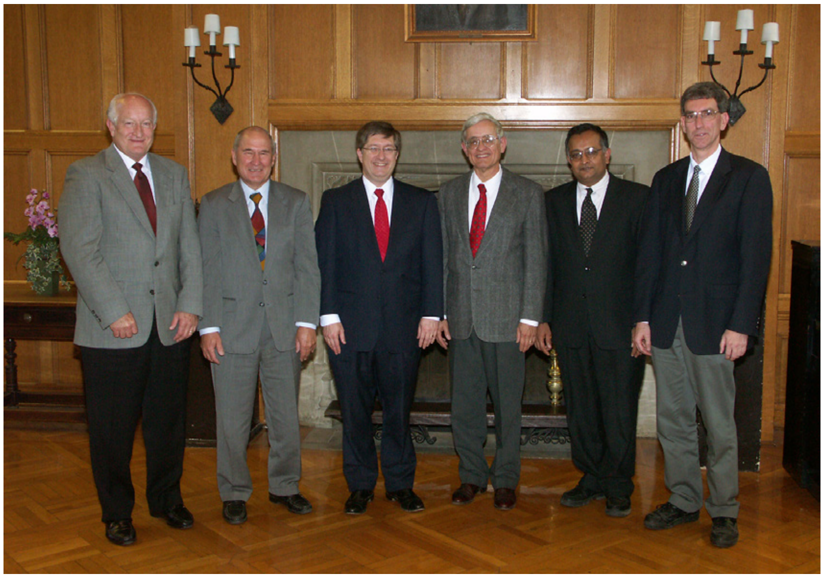
Noel Charles MacDonald passed away at age 81 on May 18, 2022, in Boynton Beach, Florida. He was born December 31, 1940, to Daniel Stuart and Rose Marie MacDonald in San Francisco California. He is survived by his wife Karen and his four children, Gina, Heather, Tyler, and Sara, his two grandchildren Rose and Conor, his two sisters Dolores Bagshaw and Patricia MacDonald, and his many loving nieces, nephews, and extended family.

Noel received his Bachelor of Science, Masters of Science, and Doctor of Philosophy from UC Berkley. Noel worked at Rockwell International Science Center then joined Physical Electronics. He attended Harvard Business School's program for Management Development, and then worked at Perkin Elmer. Noel was a professor of Electrical Engineering at Cornell University from 1984-2000. While at Cornell he served as Chairman of the department and as the Lester B. Knight director of the Cornell Nanofabrication Facility. After leaving Cornell, Noel spent two years in the Electronic Technology Office at DARPA, and then moved to UC Santa Barbara where he served as both Chair and as a Professor of Materials until retiring in 2008.

Noel authored over 100 publications and book chapters and he holds over 60 patents. He received several awards and helped start multiple companies. Noel was elected into the National Academy of Engineering in 2000 for his contributions to the development of the Scanning Auger Microprobe and micromachined micro-instruments.

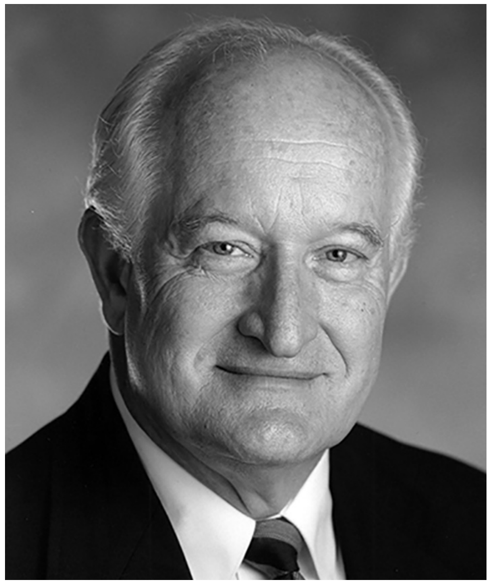
Noel always lived out the saying "choose a job you love and never work a day in your life." His legacy lives on through his children, and his students and postdocs he mentored, and the CNF staff — we benefitted greatly from his expertise.

The twinkle in Noel's eyes and his resounding laugh — that could easily be heard in the next room — will always be fondly remembered by his family, friends and colleagues.



Edward Wolf, First Cornell NanoScale Facility Director, Dies at 87

By Tom Fleischman
Cornell Chronicle
March 27, 2023



Edward Dean Wolf, a pioneer in nanofabrication who joined Cornell University in 1978 as the first director of what would become the Cornell NanoScale Science and Technology Facility (CNF), died March 11 in Ithaca. He was 87.

An emeritus professor of electrical and computer engineering at Cornell, Wolf is credited with coining the term "biolistic" (biological ballistics), a method for the delivery of nucleic acid to plant cells by high-speed particle bombardment. He also helped invent the biolistic particle delivery system, known as the "gene gun."

According to current CNF director Christopher Ober, the Francis Norwood Bard Professor of Metallurgical Engineering at Cornell, Wolf "helped to establish the user-focused culture that remains at the core of CNF's present operations, and was copied by subsequent user facilities supported by the National Science Foundation."

"In addition to his tremendous academic accomplishments, Ed was a wonderful human being," said Greg Galvin, M.S. '82, Ph.D. '84, MBA '93, CEO of Ithaca-based Rheonix and CNF's associate director from 1984-1989. "Ed had friendships with scientists worldwide that endured for decades. It was privilege to have been one of them."

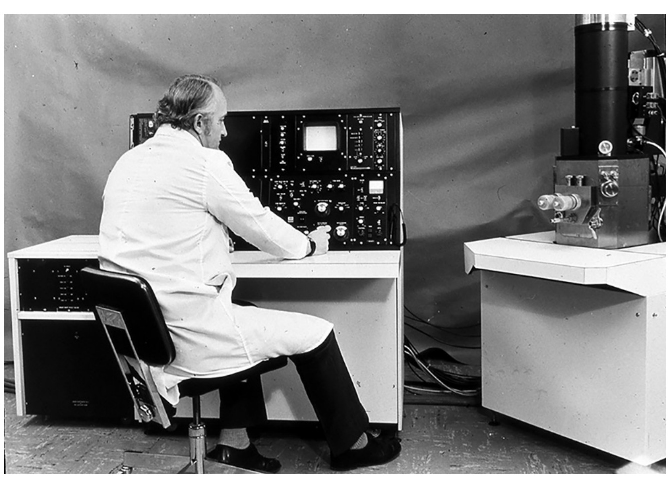
Born May 30, 1935, near Quinter, KS, Wolf received a bachelor's in chemistry in 1957 from McPherson College, Ph.D. in physical chemistry in 1961 from Iowa State University, and did his postdoctoral studies at Princeton University and UC Berkeley.

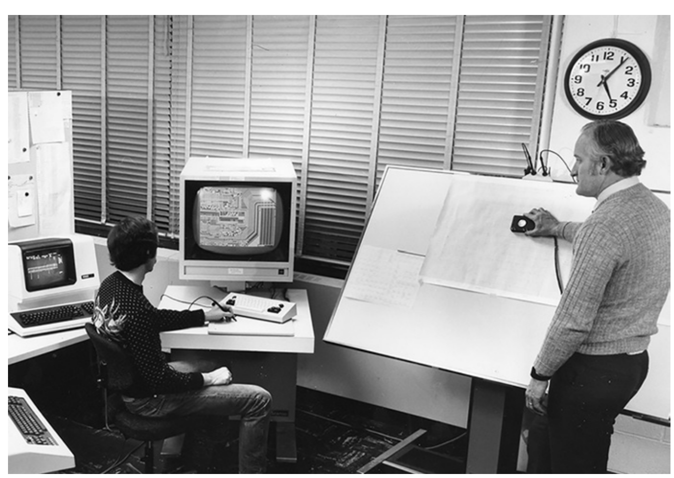
From 1965-78, Wolf worked as a senior scientist at the Hughes Research Laboratories in Malibu, California, where he led a pioneering research and development group in scanning electron beam surface physics. During that time, he was made a fellow of the Institute of Electrical and Electronic Engineers.

Wolf joined Cornell in 1978 as a tenured professor in the School of Electrical and Computer Engineering, and as the inaugural director of the National Research and Resource Facility for Submicron Structures (NRRFSS), which became the CNF. He oversaw the facility for ten years, and was responsible for the design and staffing of Knight Laboratory, the NRRFSS state-of-the-art cleanroom.

"During the first two years, he jumped into the design and construction of Knight Lab in a very hands-on way, effectively acting as project manager," said Dr. Lynn Rathbun, CNF laboratory manager, who was hired in February 1979, about seven months after Wolf. "He ran around the construction site with an ohmmeter to check that the contractors had properly isolated the rebar, to prevent ground loops. As a result, Knight Lab served us well for 20 years."

At Cornell, Wolf's research focused on chemically assisted ion beam etching and on electron and ion





beam lithography. In 1983-84, Wolf teamed with plant geneticist John Sanford and engineering lab machinist Nelson Allen as co-inventors of the biolistics gene gun, for genetic transformation using genetically coated, high-velocity micro-scopic metal particles.

Working on principles similar to a BB gun, the gene gun would blast cells with microprojectiles covered in DNA. Wolf had Allen modify a standard air pistol so that it could accelerate extremely small particles of tungsten into whole onions. According to an account by the National Museum of American History, "Sanford, Wolf, and Allen spent Christmas break 1983 trying out the gun and splattering themselves with exploded onion parts."

A second and more successful prototype led Wolf and Allen to form Biolistics Inc. in 1986; three years later, they sold the business to DuPont. In 2015, Wolf was inducted as a fellow into the National Academy of Inventors.

During a sabbatical in 1986-87, Wolf was a visiting fellow commoner at Trinity College, and a visiting professor in the Department of Engineering at Cambridge University. He was also a guest professor at Vienna University of Technology in Austria, and visiting scientist at Ion Microfabrication Systems, also in Vienna. He gave numerous guest lectures in Europe, sharing his experiences with others looking to establish nanotechnology centers.

A staunch promoter of entrepreneurship, Wolf retired in 1991 but returned in 1995 to serve for two years as founding director of the Cornell Office for Technology Access and Business Assistance, in the Office of the Vice President for Research.

An avid collector of historical telescopes, Wolf sold his collection — 111 telescopes from 65 makers in eight countries, spanning four centuries — to the Beijing Planetarium in 2016. That same year, he self-published a full-color, 365-page telescope collection book.

"I vividly recall when he invited me into his workshop to see his telescopes," Rathbun said. "I was expecting to see one or two: Instead, I was greeted by about 50 meticulously restored historical telescopes — polished brass tubes and mahogany tripods from wall to wall, each documented in detail as to its provenance. It was quite impressive."

A beloved teacher and mentor, Wolf would often invite graduate students to holiday dinners when they were unable to travel home. And his "Club Ed" home on the west shore of Cayuga Lake, which featured nationally recognized dwarf conifer gardens, was a gathering spot for family and friends.

"Ed remained interested in CNF, regularly attending our annual meetings and other events, most recently in Fall 2022, and was quite proud of us and our accomplishments," Rathbun said. "And likewise, we greatly respect his contributions that made us successful from the start."

Ed is survived by his wife of 67 years, Marlene Kay (Simpson) Wolf (left) as well as his three daughters Julie (Carter) Saline, LeAnn (Dean) Shea, and Shelly (Larry) Muray, nine grandchildren, and four great-grandchildren.

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