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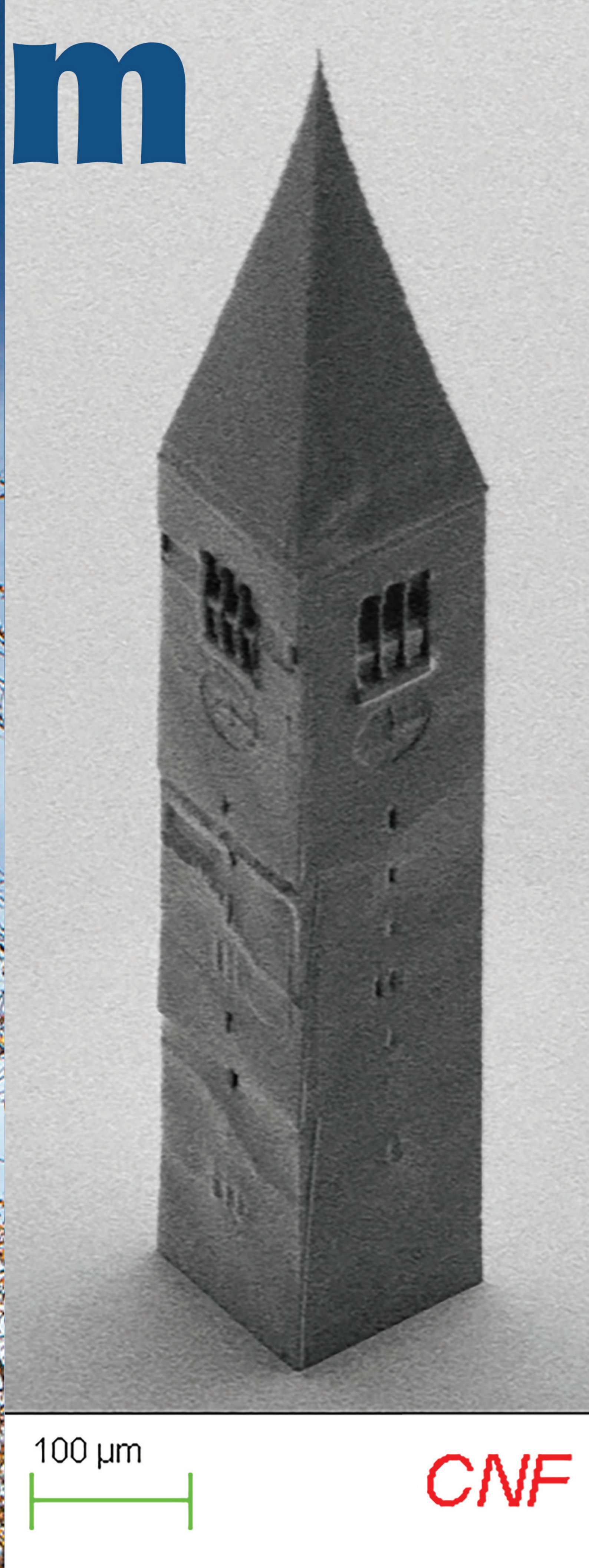

NanoMeter

Spring 2021 Newsletter
Cornell NanoScale Facility
Volume 30 • Issue 1

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Reminder to Submit to the CNF User Wiki

Dear CNF User Community: Please share on the CNF User Wiki any processes and or recipes you have developed at the CNF!

wiki.cnfusers.cornell.edu

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Most photographs in this issue were provided by the author, researcher, or as noted.

The director photographs were taken by University Photography. Screen captures were taken by Melanie-Claire Mallison.

The NanoMeter is formatted by Melanie-Claire Mallison. She welcomes your comments and corrections at mallison@cnf.cornell.edu

CNF Cornell NanoScale Science and Technology Facility
National Nanotechnology Coordinated Infrastructure
Cornell University
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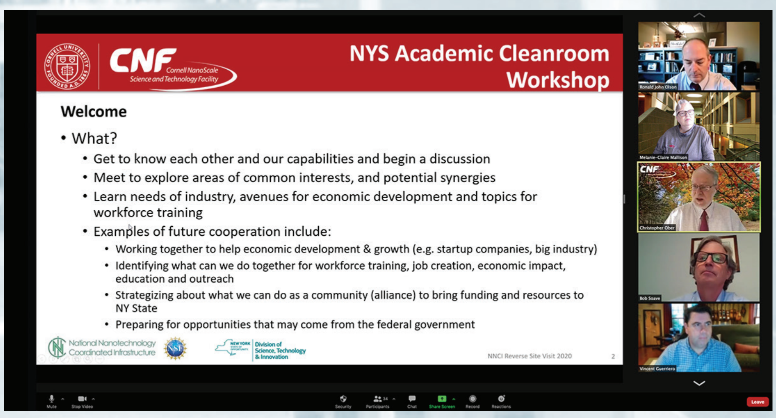
Welcome to the Spring 2021 NanoMeter: Directors' Column

"Spring is here...Welcome all the new beginnings." ~ Unknown

We are happy to welcome Spring and the 2021 edition of the NanoMeter. At the present time the Cornell NanoScale Science and Technology Facility (CNF) is optimistically looking forward to returning to "normal operations". Our emergence from the restrictions of the COVID-19 pandemic marks a new beginning for us as a community; resilient and stronger together. CNF continues to follow the Cornell University and New York State guidelines as reopening plans are evolving. We eagerly anticipate accommodating users from across the United States as New York and Cornell travel restrictions are relaxed. We will have more information to share regarding the full reopening of the CNF. Stay tuned and check out our website for updates!



In October of 2020 the CNF held its first virtual workshop bringing together New York universities and industries in order to generate discussion aimed at understanding possible synergies. Results of this initial workshop led to follow-up activities with smaller, focused groups including:

- A Workforce Training Workshop on March 15, 2021.
- A Startup/Early-Stage Company-Focused Workshop held on February 23, 2021.
- A workshop that explored the framework needed to establish a New York network of nanotechnology facilities held on April 1, 2021.

These initial discussions helped to create a unified NYS front that will make future funding possibilities easier to approve and execute. We also anticipate that a NYS coalition of universities and industries will help address startup and research needs in New York while providing more synergistic opportunities for workforce development.

The CNF has partnered with the Cornell Institute of Biotechnology (Biotech, https://www.biotech.cornell.edu/) to further advance our excellence in the characterization and imaging of micro and nanofabrication tools and make a broader selection of technologies available to users particularly from the life sciences. Through this joint partnership our mission is intended to foster and enhance the convergence of research fields and unify ideas and approaches leading to new solutions inspiring innovation and discovery.

The Cornell Visualization and Imaging Partnership (CVIP) will provide CNF users with access to a broad range of 3-D characterization and imaging tools including a variety of confocal microscopes, super-resolution microscopes, and micro/nano-x-ray-CT scanning.

The CNF and the Cornell Rapid Prototyping Lab (https://cornellrpl.wixsite.com/cornellrpl) have also joined to provide access to additional multiscale 3D printing resources intended to engage, support and advance heterointegration, life sciences, and nano/microfabrication research at Cornell. This new venture referred to as the **Cornell Multiscale 3D Fabrication Partnership (CM3FP)** will provide 3D printing capabilities with a resolution ranging from mm to nm. This partnership will foster and enhance interdisciplinary research and cross-collaboration that will inspire innovation and discovery and drive solutions to scientific challenges. The CM3FP, similar to the CVIP described above, will bring together existing Cornell facilities, expertise and instrumentation/tools with the aim to

National Nanotechnology Coordinated Infrastructure

increase the impact of these resources on research involving life sciences, heterointegration and nano/micro-scale technology and offer a broader range of resources to our user base.

CNF is pleased to continue its membership in the National Nanotechnology Coordinated Infrastructure (NNCI) with support provided by the National Science Foundation (Grant NNCI-2025233) as well as the NYSTAR/ESD Matching Grant Program from New York State. The CNF recently submitted the Year Six annual report as part of the cooperative agreement with the NNCI. A successful virtual reverse site visit was also held in May.

CNF continues to remain at the forefront of nanotechnology. New and more advanced capabilities are constantly being added in order to continually improve user experiences.

Recently we completed the installation of the Plasma-Therm Atomic Layer Etching (ALE) tool and are in the process of developing processes for this relatively new technology. The system is equipped with a Woollam M2000 *in-situ* spectroscopic ellipsometer and Langmuir probe.

CNF has also received a Veeco Savannah Atomic Layer Deposition (ALD) system. The Savannah will be dedicated to the deposition of metal films, in particular aluminum, platinum, palladium, and ruthenium.

Additionally, a new Bruker DektakXT-A and UHV load-locked thin film evaporator is on order. Delivery of these tools is anticipated in mid-May and June 2021, respectively.

We are pleased to once again offer our three-day short course as a virtual event, so people can participate easily. The **CNF Short Course: Technology & Characterization at the Nanoscale (CNF TCN)** is being offered on Wednesday, June 9th - Friday, June 11th. Details are provided on the next page. **Be sure to register soon!**

It is refreshing to see things at the CNF and across New York and the greater United States starting to return to some semblance of normal. It is imperative we remain diligent in our efforts to support ongoing safety protocols in order to help safeguard the progress we have made as a community.

The directors and staff of the CNF remain thankful for your patience and continued support, and we are looking forward to the future with optimism.

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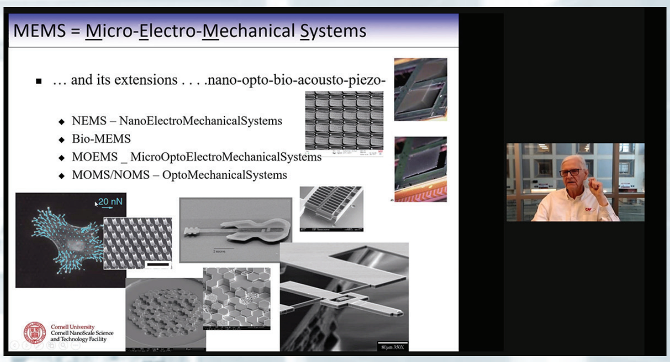
CNF Virtual Short Course: Technology & Characterization at the Nanoscale (CNF TCN)

Wednesday-Friday, June 9-11, 2021

REGISTRATION IS NOW OPEN!

https://cnf.cornell.edu/education/tcn



The CNF TCN is going virtual in June!

The course is being offered at a reduced fee of $60.00 per person to enable a broader audience to attend. Each day offers lectures and laboratory demonstrations designed to impart a broad understanding of the science and technology required to undertake research in nanoscience.

The CNF TCN is an ideal way for faculty, students, post docs and staff members to rapidly come up to speed in many of the technologies that users of the CNF need to employ. Please note the short course augments but does not replace the three-part training required to become a user of our facility.

Primary Topics Include:

- Wednesday: Introduction & Microfluidic Systems
- Thursday: MEMS Cantilever Fabrication
- Friday: Nanoelectrode Fabrication

SAVE THE DATE!

2021 CNF Annual Meeting

Thursday, September 9, 2021

The 2021 CNF Annual Meeting will be a hybrid event with virtual presentations and in-person posters (fingers crossed....).

The CNF Annual Meeting is an excellent opportunity to learn about the exciting research carried out by CNF users over the past year. We are currently planning on hosting the presentations online, so that folks can join us from around the world. **Professor Debdeep Jena** (below) is our keynote speaker. The CNF User presentations will be added online as they confirm their participation.

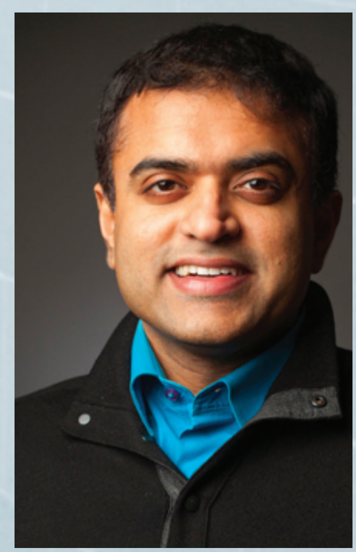
We would like to follow up the presentations by hosting an in-person **Poster Session & Corporate Soiree** — if state and university pandemic guidelines allow! But in-person or online, CNF Users will present posters on their CNF-related research, while sponsoring companies will have display space in order to meet participants and discuss employment opportunities and tool capabilities. Please join us!

"Novel Materials and Devices for Quantum Computation and Communication"

Keynote Speaker

Prof. Debdeep Jena

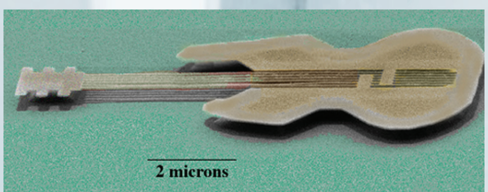
ECE and MSE Departments, Cornell University



https://cnf.cornell.edu/events/annual_meeting

CNF's Nano-Sized McGraw Tower Features 161 Steps, Chimes

By Tom Fleischman
Cornell Chronicle
May 10, 2021



Twenty-four years ago, physics professor Harold Craighead and then-doctoral student Dustin Carr, Ph.D. '00, created the world's smallest guitar using cutting-edge technology available in what was then the Cornell Nanofabrication Facility.

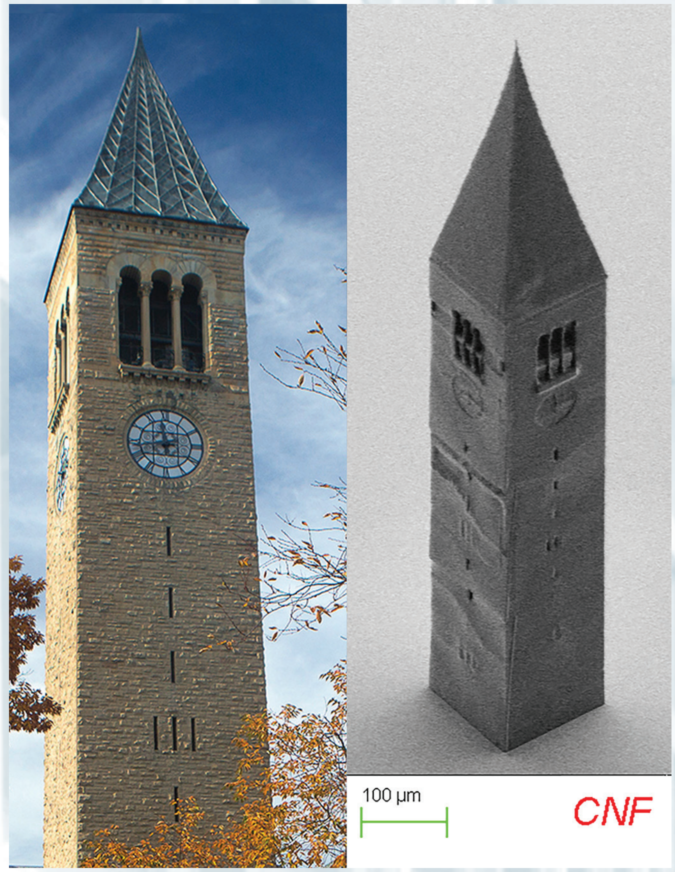
They're at it again at the center — now known as the Cornell NanoScale Science and Technology Facility (CNF). A team led by staff photolithographer Edward Camacho has created what is thought to be the world's smallest rendition of Cornell's iconic McGraw Tower — complete with its 161 interior steps, two sets of stairs and 21 bells.

How small, you ask? It is tiny indeed: Constructed to scale, it is 160 µm wide, 150 µm deep and 1 mm tall. Another way to picture it: A penny is approximately 1.5 millimeters thick, so the nano-McGraw would be dwarfed standing next to the coin.

Camacho's tiny achievement of epic proportions was accomplished using one of CNF's newest tools: the NanoScribe GT2 Laser Lithography System, a two-photon polymerization volumetric 3D printer.

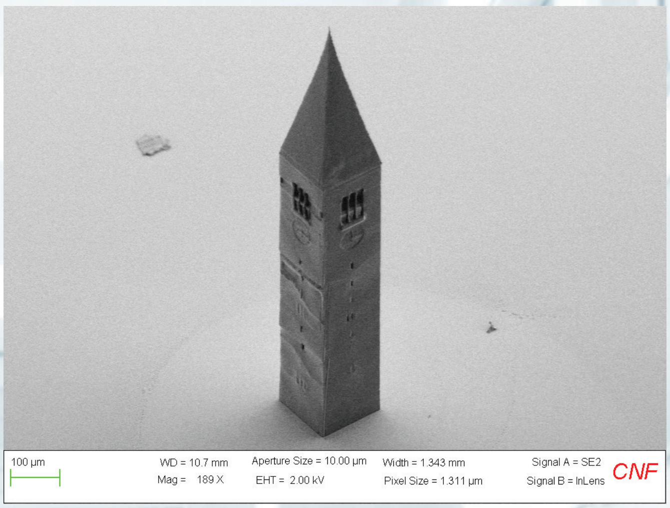
One of nine photolithography tools at CNF, the tool — funded by a grant from the NSF — was acquired in late 2019, and installed in January 2020. The state-of-the-art NanoScribe GT2 can create 3D nanostructures using a near infrared, femtosecond laser via direct-write onto a photosensitive resin.

The laser sets a focal light cone where a concentration of the light intensity defines the exposure focal spot volume, or "3D pixel." Using this technique, a 3D CAD (computer-aided design) layout can be broken into an X-Y-Z coordinate system to define the structure pixel by pixel, layer by layer.



Models for printing can be designed using the stand-alone software DeScribe — which comes with the tool — or any CAD software capable of outputting file formats DXF or STL. And you don't need to be a photolithography specialist to use the technology.

"This is a commercial device," said Chris Ober, Lester B. Knight Director of CNF. "Fifteen years ago, only a specialist could do this with very specialized equipment," he said. "Today, with this tool, researchers in the life sciences can make cell scaffolds or microfluidic devices; researchers in photonics can draw 3D waveguides; researchers in robotics can make very small, soft structures for soft robotics — all at this tiny length scale."



Left; The nano McGraw Tower that Ed Camacho created — a scale replica of Cornell's iconic McGraw Tower. The model, just one millimeter tall, contains the tower's 161 steps and chimes. Right; Detail of tower window and clock. Edward Camacho/Provided.

The CNF chose perhaps the most iconic Cornell symbol to demonstrate the advanced capabilities of the NanoScribe GT2. Camacho said that during the pandemic lockdown, he spent a lot of time researching the history behind McGraw Tower.

"I did not find a detailed 3D CAD model of the structure, so I created my own," he said. "Pictures from the Cornell [library] online archive and the building's website were used as a reference. My main specifications and assumptions: 173 feet (53 meters) tall, 161 steps, 21 bells, identical sides, two different staircases, two floors at the top, a pyramidoid roof and a Romanesque Revival architecture style."

The level of detail Camacho was able to achieve is striking: It includes a complete reconstruction of the tower, from the individual external bricks to the dual internal stairways and bells.

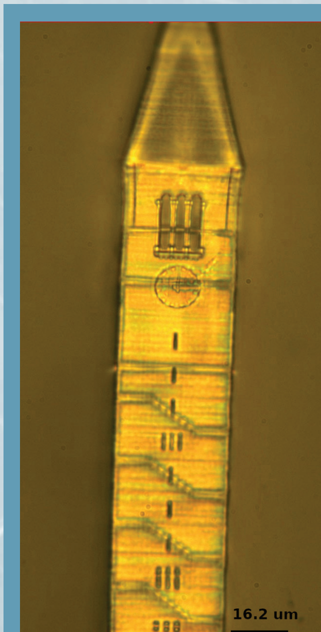
"The reason we purchased this tool was because it solves many of the limitations in speed and capacity of the current generation of 2-photon 3D nano-printers," Camacho said. "Cornell's McGraw Clock Tower is unique and has the right combination of complexity to display 3D printing at the nanoscale for this flagship tool."

No, there's no pumpkin adorning the spire of this tower, but it's still a monumental achievement.

"Ed's creation is a tour de force effort, with sentimental value for any Cornellian," Ober said. "It's something we can share with K-12 students, proving the reality of nanoscience, and at the same time it's a wonderful demonstration of what this tool can do, creating the tower in such detail."

CNF encourages the public to follow its news on advancements via Twitter, Instagram, Facebook, and or LinkedIn.

https://cnf.cornell.edu/highlights/socialmedia



The McGraw Tower Gets Even Smaller!

Camacho has pushed the envelope of the NanoScribe GT2 even further — creating a smaller, higher-resolution print with even more of the McGraw Tower's fine detail.

Left; a 200-micron-tall clock tower — one-fifth the size of the 1 mm nano-tower!

Edward Camacho/Provided.

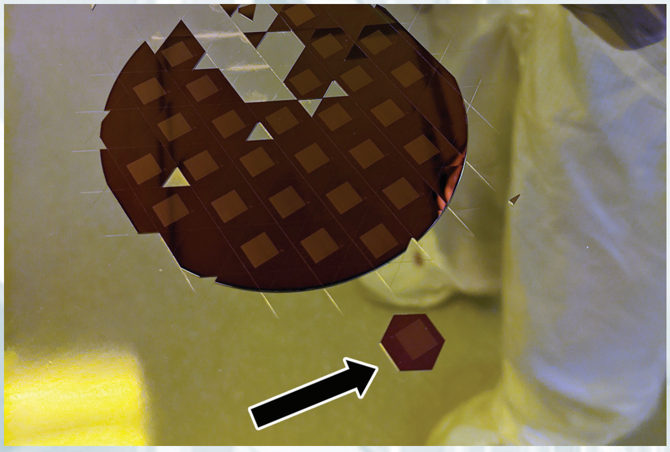
More than 27,000 Civil Air Patrol Names Headed to the Moon on a CNF Chip!

Pittsburgh, PA – Ithaca, NY – Richmond, VA – FOR IMMEDIATE RELEASE, Thursday, February 25, 2021

On Saturday, Major James Mathews of Civil Air Patrol (CAP) drove more than 300 miles to deliver a special microchip to space robotics company Astrobotic. This microchip, carrying 27,285 names, messages, and images, is set to be carried to the Moon later this year aboard Astrobotic's Peregrine lunar lander.

The US Air Force Auxiliary, CAP partnered with the Cornell NanoScale Science and Technology Facility to etch more than 27,000 CAP member names, 270 Air Force Association (AFA) StellarXplorers names, an 80th anniversary CAP logo, and messages from CAP and AFA leadership onto a microchip the size of a postage stamp. To achieve this, Cornell's lab employed deep ultraviolet (DUV) lithography, along with other nanofabrication processes, to create the 0.5" hexagonal chip.

"Among these names are more than 4,000 CAP high school cadets," says Lt. Paul Douglas, Burke Composite Squadron's Aerospace Education officer. "My personal hope is that our young cadets will stand in their back yards, look up at the Moon, and dream big. They'll know if they can make it to the Moon, they can do anything."



The processed wafer with an arrow pointing to the final microchip. Photograph provided by CNF staff member C. Alpha.

Astrobotic's Peregrine lander is poised to be the first American spacecraft to land on the Moon since the Apollo program around 50 years ago. Peregrine will fly aboard ULA's new Vulcan Centaur rocket later this year carrying CAP's microchip and a diverse suite of other payloads from seven different countries, dozens of science teams, and hundreds of individuals.

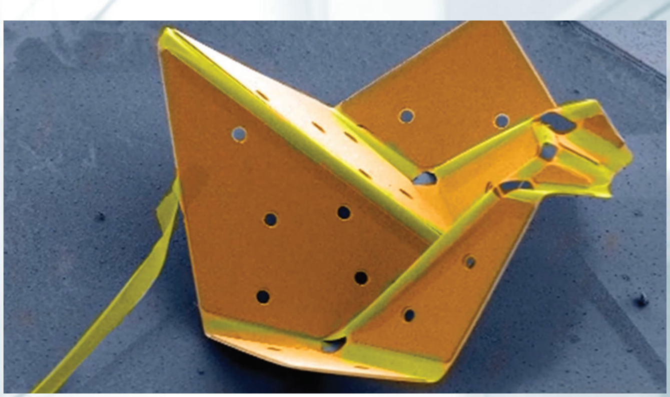
"Working together, we can inspire and make changes for the good. Together, we can improve our nation, our planet, and even our universe," says Major General Mark Smith, National Commander and CEO of CAP.

Full Press Release, https://vawg.cap.gov/cap-goes-to-the-moon/information-timeline

Left: 80th anniversary CAP logo. Middle: Chris Alpha delivers the completed chip to Major James Mathews of CAP. Right: Major Mathews hands over the encased microchip to Alivia Chapla, Astrobotic's Senior Marketing and Communications Specialist.

Self-Folding Nanotech Creates World's Smallest Origami Bird

By David Nutt
Cornell Chronicle
March 17, 2021



If you want to build a fully functional nanosized robot, you need to incorporate a host of capabilities, from complicated electronic circuits and photovoltaics to sensors and antennas.

But just as importantly, if you want your robot to move, you need it to be able to bend.

Cornell researchers have created micron-sized shape memory actuators that enable atomically thin two-dimensional materials to fold themselves into 3D configurations. All they require is a quick jolt of voltage. And once the material is bent, it holds its shape — even after the voltage is removed.

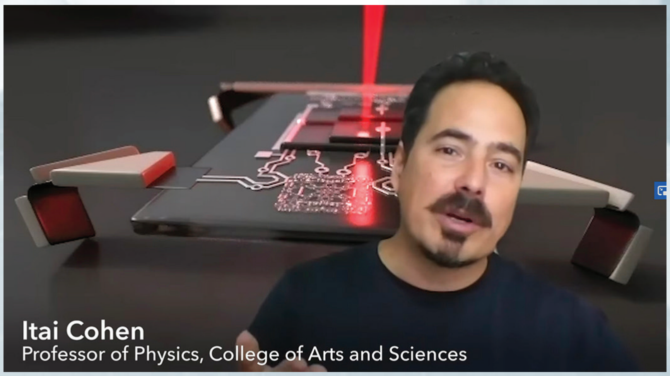
As a demonstration, the team created what is potentially the world's smallest self-folding origami bird. And it's not a lark.

The group's paper, "Micrometer-Sized Electrically Programmable Shape Memory Actuators for Low-Power Microrobotics," published 3/17 in Science Robotics and was featured on the cover. The paper's lead author is PostDoc researcher Qingkun Liu.

The project is led by Itai Cohen, professor of physics, and Paul McEuen, the John A. Newman Professor of Physical Science, both in the College of Arts and Sciences.

"We humans, our defining characteristic is we've learned how to build complex systems and machines at human scales, and at enormous scales as well," said McEuen. "But what we haven't learned how to do is build machines at tiny scales. And this is a step in that basic, fundamental evolution in what humans can do, of learning how to construct machines that are as small as cells."

McEuen and Cohen's ongoing collaboration has so far generated a throng of nanoscale machines and



Video screen captures: Cornell researchers have created micron-sized shape memory actuators that enable atomically thin two-dimensional materials to fold themselves into 3D configurations. View the full video online at https://news.cornell.edu/stories/2021/03/self-folding-nanotech-creates-worlds-smallest-origami-bird components, each seemingly faster, smarter and more elegant than the last.

"We want to have robots that are microscopic but have brains on board. So that means you need to have appendages that are driven by complementary metal-oxide-semiconductor (CMOS) transistors, basically a computer chip on a robot that's 100 µm on a side," Cohen said. Imagine a million fabricated microscopic robots releasing from a wafer that fold themselves into shape, crawl free and go about their tasks, even assembling into more complicated structures. That's the vision.

"The hard part is making the materials that respond to the CMOS circuits," Cohen said. "And this is what Qingkun and his colleagues have done with this shape memory actuator that you can drive with voltage and make it hold a bent shape."

These actuators can bend with a radius of curvature smaller than a micron — the highest curvatures of any voltage-driven actuator by an order of magnitude. This flexibility is important because one of the bedrock principles of microscopic robot manufacturing is that the robot size is determined by how small the various appendages can be made to fold. The tighter the bends, the smaller the folds, and the tinier the footprint for each machine. It's also important that these bends can be held by the robot, which minimizes the power consumption, a feature especially advantageous for microscopic robots and machines. Cohen and McEuen credit Liu's background in chemistry with giving the project an extra jolt, to nail down the science behind the electrochemical reaction that enables the material to fold and maintain its shape.

RADICAL COLLABORATION

"At this small scale, it's not like traditional mechanical engineering, but rather chemistry, material science and mechanical engineering all mixed together," Liu said.

The devices consist of a nanometer-thin layer of platinum capped with a titanium or titanium dioxide film. Several rigid panels of silicon dioxide glass sit atop those layers. When a positive voltage is applied to the actuators, oxygen atoms are driven into the platinum and swap places with platinum atoms. This process, called oxidation, causes the platinum to expand on one side in the seams between the inert glass panels, which bends the structure into its predesignated shape. The machines can hold that shape even after the voltage is removed because the embedded oxygen atoms bunch up to form a barrier, which prevents them from diffusing out.

By applying a negative voltage to the device, the researchers can remove the oxygen atoms and quickly restore the platinum to its pristine state. And by varying the pattern of the glass panels, and whether the platinum is exposed on the top or bottom, they can create a range of origami structures actuated by mountain and valley folds.

"One thing that's quite remarkable is that these little tiny layers are only about 30 atoms thick, compared to a sheet of paper, which might be 100,000 atoms thick. So it's an enormous engineering challenge to figure out how to make something like that have the kind of functionalities we want," said McEuen, who co-chairs the Nanoscale Science and Microsystems Engineering (NEXT Nano) Task Force, part of the provost's Radical Collaboration initiative, and directs the Kavli Institute at Cornell for Nanoscale Science.

The machines fold themselves fast, within 100 milliseconds. They can also flatten and refold themselves thousands of times. And they only need a single volt to be powered to life. "These are major advances over current state-of-the-art devices," Cohen said. "We're really in a class of our own."

The team has already been recognized by Guinness World Records for creating the smallest walking robot. Now, they hope to capture another record with a self-folding origami bird that is only 60 µm.

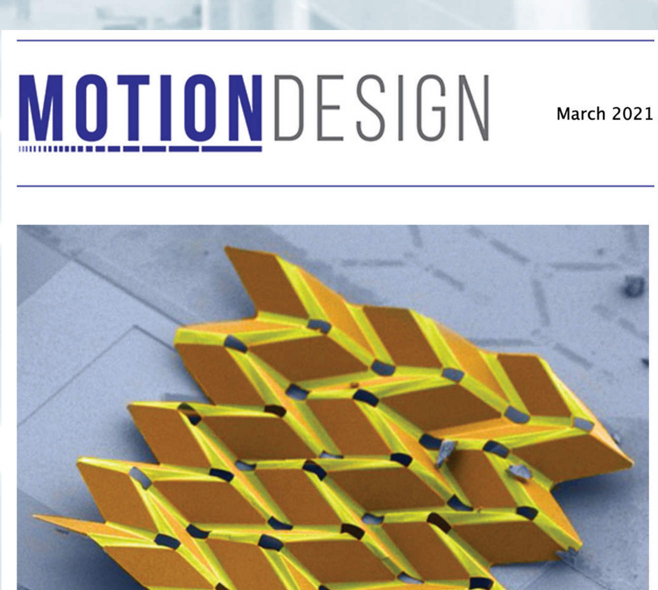
The team is working to integrate their shape memory actuators with circuits to make walking robots with foldable legs as well as sheet-like robots that move by undulating forward. These innovations may someday lead to nano-Roomba-type robots that can clean bacterial infection from human tissue, micro-factories that transform manufacturing, and robotic surgical instruments that are ten times smaller than current devices, according to Cohen. But an equally important question driving the team is: what are the principles that need to change in order to design, manufacture and operate machines at this scale?

The team worked with co-authors David Muller, the Samuel B. Eckert Professor of Engineering, to image their nanoscale structures, and Tomas Arias, professor of physics and a Stephen H. Weiss Presidential Fellow, to better understand the process driving the actuation. Co-authors include doctoral students Wei Wang, Michael Reynolds, and Michael Cao '14; and former postdoctoral researcher Marc Miskin, who is now an assistant professor at the University of Pennsylvania.

"Dr. Cohen and his team are pushing the boundary of how quickly and precisely we can control motion at the micro- and even nano-scales," said Dean Culver, program manager for the Army Research Office, an element of the U.S. Army Combat Capabilities Development Command's Army Research Laboratory, which supported the research.

"In addition to paving the way for nano-robots, the scientific advancements from this effort can enable smart material design and interaction with the molecular biological world that can assist the Army like never before."

Additional support was provided by NSF, the CCMR, the AFOSR, and the Kavli Institute at Cornell for Nanoscale Science. This work was performed in part at the CNF, a member of the NNCI, which is supported by the National Science Foundation (Grant NNCI-2025233).



Another cover for the nano crane! https://www.techbriefs.com/component/content/article/tb/insiders/md/38891?utm_source=TB_Motion_News&utm_medium=email&utm_campaign=20210329&oly_enc_id=7910E5507689F4R

Inspired by His Education, Alumnus Creates Fast COVID-19 Test

By Syl Kacapyr
December 9, 2020
Cornell Chronicle

Greg Galvin, M.S. '82, Ph.D. '84, MBA '93, founder and CEO of Rheonix, shown here in 2015, stands outside his lab. Cornell University File Photo

Entrepreneur Greg Galvin, M.S. '82, Ph.D. '84, MBA '93, didn't factor the pandemic into his business plans last year. He didn't expect the shutdowns or the equipment shortages. And he didn't plan on quickly pivoting his biotechnology company to provide a quick, accurate COVID-19 test that enabled Cayuga Health System to open one of the first drive-through testing sites in the nation.

Galvin, the 2014 Cornell Entrepreneur of the Year, is founder and CEO of Rheonix, an Ithaca-based company that is ramping up production of a fully automated, same-day test for SARS-CoV-2, the virus that causes COVID-19.

Rheonix's simple-to-use diagnostic system consists of an assay — a biomolecular analyzer that detects genetic material from a person's respiratory sample — and a specialized workstation, which does not require a technician or advanced knowledge to operate. The workstation can process up to 24 assays at once. Since February 2020, Rheonix has grown from 50 employees to 140 and doubled most of its manufacturing equipment. It is now installing 22,000 pounds of assembly line equipment in the company headquarters to meet the national demand for rapid testing.

Production of the assay and workstation has mostly been at the mercy of a crippled supply chain, Galvin says. But Rheonix has been meeting as much of the demand as possible ever since the Food and Drug Administration (FDA) authorized emergency use of its assay in April.

Rheonix is scoring high marks for the accuracy of its rapid testing. Comparative data released by the FDA in September show that, of the 58 molecular assays it compared, Rheonix's scored the fourth highest in its ability to detect a small amount of viral material in a given sample.

Rheonix's early entry into the coronavirus testing market came as the company had already been seeking FDA approval of a similar assay for rapid testing of sexually transmitted infections. The technology needed to produce a coronavirus test was so similar that Rheonix had a working prototype just three weeks after the Centers for Disease Control and Prevention published the virus's genetic sequence, in February. Galvin said it was just a matter of altering the system to detect a different genetic target — a business move that not only made sense financially, but also served the community.

"The sense of urgency was apparent and the need was personal for everyone at the company," says Galvin. "But also this ability to develop a product, put it out in our local community and create immediate benefits," he says, "I think it really helped motivate people."

Among the first organizations to receive the test were Cayuga Health System in Ithaca and United Health Services in Binghamton, New York. The assays enabled Cayuga Health to open one of the first drive-through testing stations in the nation. "We've delivered a total of 14 instruments to their lab," Galvin says, "which theoretically puts their capacity at over 7,000 samples per day."

Daniela Bocioaga, senior regulatory specialist, uses the company's Encompass MDx workstation. Nancy J. Parisi/Rheonix

"We were very pleased to see the results," Galvin says. "We knew our test was very sensitive, but what really surprised me out of that data was how wide the disparity between the different tests actually is. I really didn't expect the tests to be that different."

While Rheonix ramps up production of its COVID-19 assay, it will also be seeking FDA approval of a newly developed assay that can target four viruses at once: influenza A, influenza B, respiratory syncytial virus and SARS-CoV-2.

"The physical symptoms of COVID and the flu are very similar, so distinguishing between the two diseases is clinically important because the treatment protocols are completely different for them," said Galvin.

Although Rheonix is not based on Cornell technology, Galvin says it's still inspired by his Cornell education.

"Rheonix is an example of the much, much greater number of startup businesses that are created by Cornellians that don't necessarily use Cornell intellectual property," says Galvin. "The university is fostering a lot more entrepreneurial activity than just the number of startups that use Cornell technology. Whether it's Cornell intellectual property or a Cornell alum, it's still a Cornell creation."

Galvin is a former member of the Cornell University Board of Trustees and was the CNF Associate Director and Deputy Director from 1984-1989. He serves on the advisory councils for Cornell Engineering and the Department of Materials Science and Engineering. He is a frequent speaker on campus and has created a graduate fellowship to support engineering students. In 2014, he was named Cornell Entrepreneur of the Year. Galvin is also the proud father of three Cornellians, Thomas ENG'19, Kristen A&S'21 and Andrew ENG'23.

PRAXIS CENTER for Venture Development

Praxis Center and Engineering Startups Grow Together

By David Nutt
Cornell Chronicle
February 12, 2021

Nearly two years after launching, the Praxis Center for Venture Development is reconfiguring its structure to reflect the growth of engineering startups at Cornell and their specialized needs.

The center is differentiating into two thematically focused branches, with the Praxis Center for Engineering and Physical Sciences remaining in the current space in Duffield Hall, and the Praxis Center for Enterprise Software now based in nearby Rhodes Hall. The space in Rhodes Hall was renovated last year and is now occupied by a pair of software startups: Ava Labs and Exotanium. The success of both companies has demonstrated the effectiveness of the center's model as it helps Cornell researchers turn their innovative ideas into thriving businesses.

The expansion allows the center's five startups that have an engineering and physical sciences bent to remain in close proximity to the technical resources offered by Cornell NanoScale Science and Technology Facility (CNF) and Cornell Center for Materials Research (CCMR) in Duffield Hall.

"Rhodes Hall is an office environment, so it really fits the sort of analytical things that don't require any testing or laboratories," said Robert Scharf '77, Praxis' director. "This lets us keep the physical and engineering sciences teams in Duffield, where the laboratories, model shops and testing facilities are concentrated. It has no effect on the productivity or the effectiveness of the facility for the software teams."

The Praxis Center opened in March 2019 with the goal of supporting engineering and physical science startups through mentorship while also boosting business development in New York state. The new structure will allow Praxis to better connect these companies with more specialized mentors and advisory groups who can help them later on to focus their products, perfect their pitches and plot their next steps.

"There are different business models and advisory roles that fit each specific kind of venture," Scharf said. "We certainly wouldn't want a software company talking to someone with deep experience in chemical manufacturing, where there's really a low level of relevance of the possible interactions. This will help us attract the right kind of advisors, mentors and guides to each branch, because now they'll have a much more distinctive identity and a clear reason for participating."

That mentorship was instrumental for helping get Exotanium off the ground, said CEO Hakim Weatherspoon, associate professor of computer science, who founded the company in 2018 with Robbert van Renesse, professor of computer science; and PostDoc researcher Zhiming Shen, Ph.D. '17.

Exotanium's software enables businesses to reliably run their applications on servers in the cloud at low-cost using cheap unreliable servers. When these "spot" servers become unavailable, Exotanium's technology automatically migrates these application servers to stable environments without any interruption, a kind of high-tech game of Whac-A-Mole that can slash a company's cloud-computing costs by an order of magnitude.

From left, Exotanium co-founders Robbert van Renesse, prof of computer science; PostDoc researcher Zhiming Shen, Ph.D. '17; and Hakim Weatherspoon, associate prof of computer science.

The startup joined the Praxis Center in fall 2019, and last year raised more than $1 million in pre-seed funding, with another round of seed funding planned for this year. "Praxis has been critical for us to evolve from three people who are professors and a Ph.D. to three people and a company that is very successful in the market," Weatherspoon said.

"And Praxis is critical to Cornell. Cornell is a great idea generator, but a lot of scientists are not trained in business. To have a successful business, you need a place like the Praxis Center. I don't know where we'd be without something like that."

The Praxis Center has also helped provide a "center of gravity" to keep businesses like Exotanium in New York state, when so many software companies are lured to big tech meccas like Silicon Valley, Seattle and Boston.

Exotanium's neighbor in Rhodes Hall, Ava Labs, was one of the Praxis Center's first clients and is now the largest. The company has grown to be an international operation, with a total of 72 employees, the majority of whom work in the company headquarters in Brooklyn, which opened in July 2019.

"We went from being a nascent company that just had one idea, which was mostly undefined, to a small seed company that receives funding from the giants of Silicon Valley, all the way to being a company that has launched a network that has billions of dollars' worth of value in it," said Ava Labs co-founder and CEO Emin Gün Sirer, associate professor of computer science and co-director of the Initiative for Cryptocurrencies and Smart Contracts.

"Every relationship changes. I feel like we spent our infancy at Praxis. And when we were in our teenage years and needed to prove ourselves, we went down to where the big folks are in NYC," Sirer said. "Now, I would like to retain our connection to Praxis and pay forward our dues. I would love to help them in the future, whether it's in the form of advising other financial technology startups or helping others connect with people, whatever it might take."

To that end, Scharf is looking to develop a new mentorship model for companies that are no longer tenants at the center but maintain a relationship with the university.

The Praxis Center is also strengthening its ties with CNF. Both groups now share the same director of operations, Ron Olson, and program safety officer, Phil Infante, consolidating the technical support on which so many engineering startups depend.

"We're centralizing the administrative functions, and that's going to be a productive thing for everyone," Scharf said. "The synergies of all these things are beginning to become evident."

Study Highlights Promise of 3D Printing for Electrochemical Reactors

By Syl Kacapyr
Cornell Chronicle
April 30, 2021

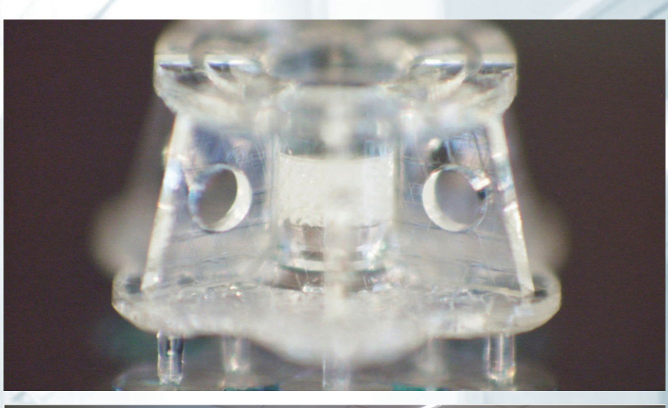


Figure 1, top: 3D-printed gas diffusion layer for an electrochemical reactor, printed at the CNF using two-photon polymerization. Figure 2, below: Members of Cornell's Sobhani Lab. Sobhani/Provided

Electrochemical reactors that can capture carbon dioxide and transform it into valuable products are a relatively new and promising technology for reducing greenhouse gas emissions. While many challenges exist to scaling up the technology, a new study highlights the benefits of using 3D printing, also known as additive manufacturing, to significantly improve cost, yield and efficiency.

In electrochemical reactors like those that were studied, gaseous carbon dioxide travels through a porous gas diffusion layer for distribution to the catalyst, where it dissolves into a liquid electrolyte and converts to various products like fuels, lubricants and polymers. Using additive manufacturing to rapidly prototype reactors with unique shapes and topologies, designs could be optimized for improved conversion rates, according to study co-author Sadaf Sobhani, assistant professor in MAE.

"Instead of focusing on engineering the catalyst, electrode or electrolyte, we focused on how the geometry — the distance between the electrodes or connections between compartments — influences system performance," said Sobhani, who began the research as a PostDoc associate at the Lawrence Livermore National Lab before continuing at Cornell.

The findings are detailed in the study "Advanced manufacturing for electrosynthesis of fuels and chemicals from CO_2," published in the journal Energy & Environmental Science.

Computationally simulating the chemical phenomena inside reactors, Sobhani was able to identify the conditions leading to mass-transport limitation, where the rate at which CO_2 travels to the catalyst is slower than the catalyst chemical conversion rate.

"This can provide the framework for distinguishing the operational limitations for any reactor and system design," Sobhani said, "as well as understanding the primary drivers that can lead to better designs to overcome these limitations."

Sobhani is continuing her research into how geometry and surface properties influence overall reactor performance, leveraging the resources at the Cornell NanoScale Science and Technology Facility (CNF) to print sub-micrometer surface features and advanced microstructuress.

RADICAL COLLABORATION

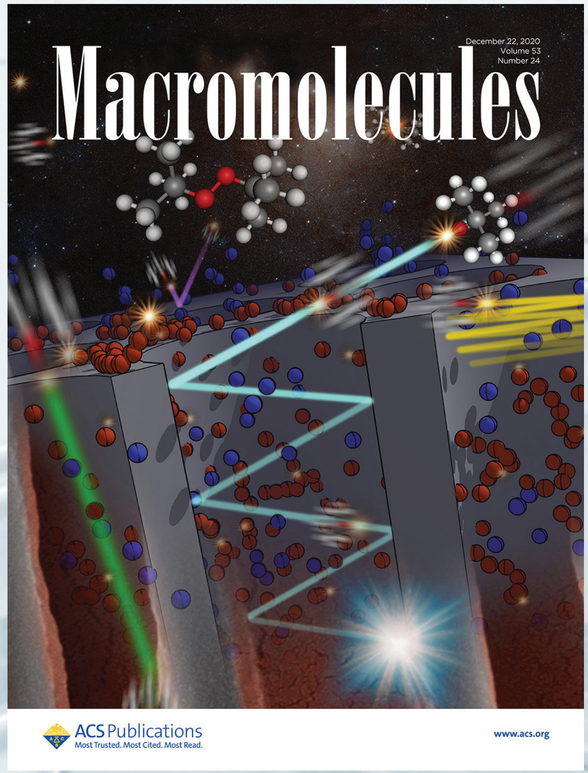
"Electrochemical conversion reactors are inherently interdisciplinary systems, and I have found that working collaboratively is one of the key strengths of Cornell researchers," Sobhani said.

cnf community news

Introducing CNF Fellow Giancarlo D'Orazio

Giancarlo is a 1st year PhD student working in the Sobhani Lab on combustion-related projects utilizing additive manufacturing.
On the macro-scale he is developing 3D printed ceramic structures for porous media combustion research, where the porous structure can produce efficient combustion with lower NOx emissions. He is also involved in the CO_2 Reduction Reactor project, producing micron-scale lattice structures (engineered Gas Diffusion Layers) on the Photonic Professional GT2. This project aims to understand the impact of the geometry and surface texture on wettability of the gas diffusion layer in a CO_2 Reduction Reactor using high energy X-ray imaging.

Cornell Professors and CNF PIs, Antje J. Baeumner and Julie M. Goddard, are co-chairs for the **2022 Nanoscale Science and Engineering for Agriculture & Food Systems Gordon Research Conference** being held at Southern New Hampshire University, June 19 - 24. Applications must be submitted by May 22, 2022. Find out more at https://www.grc.org/nanoscale-science-and-engineering-for-agriculture-and-food-systems-conference/2022/



CNF PI Rong Yang's publication, Kinetics of all-dry free radical polymerization under nano-confinement, made the cover of Macromolecules. https://doi.org/10.1021/acs.macromol.0c01534

Profs. Jena, Xing, and Molnar Recognized as 2020 Intel Outstanding Researchers

This award is based on our seminal contributions to the p-channel FETs in wide bandgap semiconductors. Sam Bader, Reet Chaudhuri, Kazuki Nomoto, Austin Hickman, and Hyunjea Lee are key contributors along with Prof. Al Molnar's group!
Profs. Debdeep Jena, Huili (Grace) Xing, and Alyosha Molnar, Cornell; Prof. Tomas Palacios, MIT; Wide-Bandgap pFETs: Materials, Devices, and Circuits
In collaboration with MIT, the Cornell team seeks a high-performance wide-bandgap PMOS solution for use in RF, power electronics, or digital/analog applications. The team looks to provide a holistic pFET solution through materials innovations, device processing, fabrication, and testing, as well as the development of transport and device physics and compact models, circuit models, and demonstration.

https://www.intel.com/content/www/us/en/research/blogs/intel-outstanding-researcher-award-2020.html

Bob Buhrman, Former Vice Provost for Research, Dies at 75

By Blaine Friedlander
Cornell Chronicle
April 16, 2021
(Abridged)

Applied physicist Robert "Bob" Buhrman, M.S. '69, Ph.D. '73.
Cornell University File Photo

Robert "Bob" Buhrman, M.S. '69, Ph.D. '73, the John Edson Sweet Memorial Professor of Engineering Emeritus and Cornell's second senior vice provost for research, and vice president for technology transfer and intellectual property, who helped expand emerging science and engineering programs, and obtain funding for research, died April 13 in Rochester, New York, with family by his side. He was 75.

"Bob Buhrman was a visionary and effective leader for more than 50 years at Cornell, helping to organize numerous research centers, serving as director of Applied and Engineering Physics and as vice provost for research," said Dan Ralph, Ph.D. '93, the F.R. Newman Professor of Physics in the College of Arts and Sciences (A&S). "He was a valued mentor to countless students and young faculty, providing wisdom on how to succeed in science and engineering."

At Cornell, Buhrman held a dual appointment in the College of Engineering and A&S.

Throughout his professional career, Bob examined applied condensed matter physics, in nanoscale science and engineering. Early on, he studied superconducting devices and materials for solar absorbers. Later, he pioneered ways to control magnetism in order to store digital information, according to Ralph and Gregory Fuchs, Ph.D. '07, associate professor of applied and engineering physics.

Buhrman led his field in developing methods to reorient nanoscale magnets (electrons) to make magnetic memories faster and more efficient. His innovations enabled spin-transfer-torque magnetic random-access memory, now in production at leading semiconductor foundries. His work was the first to demonstrate magnetic switching in a multilayer device driven by spin-transfer torque, and he also discovered a giant spin Hall effect in heavy metals, which can enable even more efficient magnetic switching.

While he helped to expand Cornell's science research programs and bring brick-and-mortar facilities to Cornell, friends and colleagues said he was always guided by his love for physics, engineering and teaching.

"As a doctoral student, my experience was that Bob always knew when not to help," Fuchs said. "He let you figure things out. If Bob thought it was the right thing to do, he would stand back, pull his hands away and let you learn."

Brian Moeckly, Ph.D. '94, the head of superconductor research at Commonwealth Fusion Systems, enjoyed Buhrman's acumen. Moeckly had been having trouble deciding on a postdoctoral career path, asked Buhrman for guidance — knowing that he eschewed offering advice. But Buhrman did.

"Bob said, 'If you don't know what you want to do, do that which will maximize your short-term happiness,'" said Moeckly. "I've never forgotten that sentence."

Robert Alan Buhrman was born in Waynesboro, Pennsylvania on April 24, 1945, and he grew up on a small farm in Smithsburg, Maryland. He earned a bachelor's degree in engineering physics at Johns Hopkins University in 1967, and his master's and doctoral degrees in applied physics from Cornell.

Bob Buhrman, the early years, with Michael S. Isaacson. 1983?

Buhrman joined the Cornell faculty in 1973 as an assistant professor in the School of Applied and Engineering Physics. He became an associate professor in 1978 and a professor in 1983. He was named the John Edson Sweet Professor of Engineering in 1993.

Buhrman served as the associate director of the National Research and Resource Facility for Submicron Structures (NRRFSS) from 1980-83.

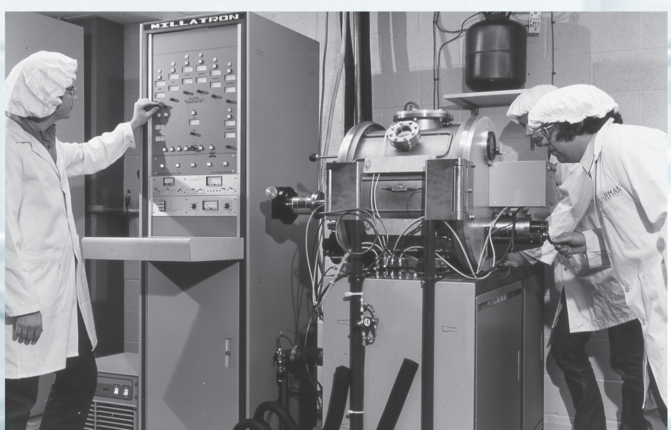
Now the Cornell NanoScale Science & Technology Facility (CNF), Bob was a valuable partner beyond estimation from his first NRRFSS project (number 2-78, X-Ray Lithography) to his longest running CNF project (# 111-80, Superconducting Devices and Submicron Structures at Very Low Temperatures), which brought well over 100 graduate student users to the CNF over the years.

Bob also served as director of the School of Applied and Engineering Physics from 1988-98. He was the first director of Cornell's Center for Nanoscale Systems in Information Technologies.

As part of that center's funding, Buhrman planned for physics outreach throughout New York. His daughter Susannah Buhrman-Deever '00, Ph.D. '07, a biologist, suggested he create a Cornell Institute for Physics Teachers (CIPT) — modelled after the Cornell Institute for Biology Teachers.

He did, and the new institute served up workshops and a summer institute for high school teachers, and provided access to kits for hands-on activities through a lending-library, according to Monica Plisch Ph.D. '01, who was the first director of CIPT, now with the American Physical Society. Within five years, the CIPT had reached more than 25% of New York's physics teachers and Buhrman's Center for Nanoscale Systems had helped to start similar programs in Cleveland, Ohio; Jackson, Mississippi; Los Angeles and Singapore.

In 2007, Buhrman became the senior vice provost for research, succeeding the late Nobel laureate Robert Richardson. As vice provost, he oversaw the four national research centers, 12 Cornell research centers, the Cornell Center for Technology, Enterprise and Commercialization, the Center for



Dr. Lynn Rathbun, CNF Lab Manager, says: "During the early years of NRRFSS, there were a variety of research thrusts and each tool purchased on the original NSF award had to have a faculty member leader. Bob was one of the original faculty partners, and the tools he specified for inclusion in the Phillips Hall 417 cleanroom (prior to Knight Lab) were: top photo, a home-made x-ray lithography system; bottom photo, a Commonwealth Ion Mill (Millatron). These pictures would have been taken in in 1979 or 1980."

Animal Resources and Education, and several other research administrative offices, and helped secure essential funding for the Center for Nanoscale Systems in Information Technologies (CNS).

In 2011, Cornell added the position of vice president for technology transfer, intellectual property and research policy to Bob's responsibilities. That position reported to the Cornell president and provost. Buhrman held both VP positions until 2017, when he stepped down.

Buhrman treated staff with complete respect. Cathy Long, now executive director of administration and finance at the Division of Nutritional Sciences, started with Buhrman as department manager at Applied and Engineering Physics, and later joined him in the Office of the Senior Vice Provost for Research.

"Bob was an exceptional mentor and genuinely supportive of those who worked for him," Long said. "He always made time to listen. Often at the end of the day, we would sit down and recap it. He had a way of guiding and helping me and my colleagues learn how to evaluate issues and find solutions to help faculty and support the university's mission."

Andrew Bass, the Horace White Professor of Neurobiology and Behavior, and the senior associate dean for math and science in A&S, worked closely with Buhrman, when he was the associate vice provost for research.

"Traits that come to mind when I think about Bob's leadership include integrity, dedication, keen judgment and rigorous but compassionate mentorship of faculty, staff and students," Bass said. "He strove to maintain the very highest standards in scholarly research and administration. And Bob was a keen observer of the human condition — as his understanding of the universe went far beyond its physical principles. His death has left a deep void in the lives of many."

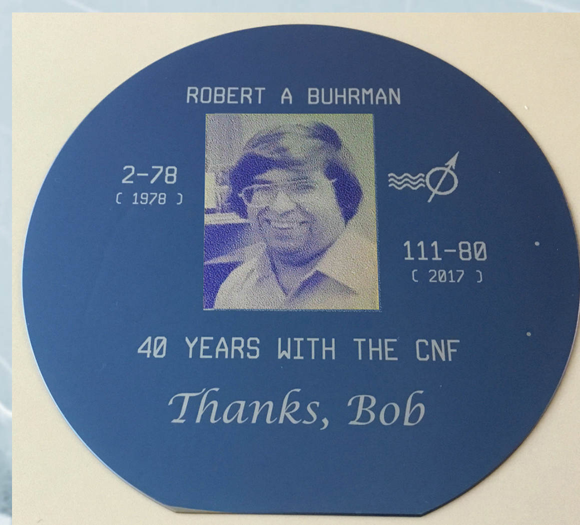
He leaves his wife, Karen Buhrman M.S. '70, as well as his children Kristina Buhrman '99; Susannah Buhrman-Deever; and John Buhrman '04, J.D. '08; and five grandchildren.

Interment will be private. A celebration of life will be held at a later date in Ithaca, NY. If desired, memorial contributions can be made to the Wilmot Cancer Institute in Rochester, NY.

Bob was a mainstay at the CNF Annual Meetings. Here, he converses with participants during the poster session at the CNF 35th Anniversary Celebration & Annual Meeting in July 2012.

When Bob stepped down as VPR, the CNF honored his many years of dedicated service and sound advice with a framed, etched wafer (below), and a note that read:

Fabricated by the Staff of
the Cornell NanoScale Facility.
Presented on the occasion of
our 40th anniversary to
Robert Buhrman
For his service and leadership to CNF
as Senior Vice Provost for Research



2021 CNF REU INTERNS + TWO "ADOPTEES"

COVID-19 put the kibosh on the 2020 CNF REU Program, but as the vaccines became available and the world became a little safer, here at the CNF, we decided that with an open mind, we could work within the parameters set by Cornell University and New York State — and offer a Cornell NanoScale Science & Technology Facility Research Experiences for Undergraduates (CNF REU) Program over the summer of 2021.

In short order, we solicited Cornell undergraduates, collected abbreviated applications, and hired four students to work with our principal investigators and experienced CNF users on hands-on nano-research projects. Over the ten weeks of the program (June-August), we will do our best to provide an interactive experience for the following students with a goal of their becoming independent nanoscale researchers in their own right.

And because the CNF REU Program Coordinator, Melanie-Claire Mallison, can think of nothing better than helping even more students experience the joys and challenges of our internships, the CNF "adopted" two summer students working outside of the CNF REU Program, but who are the only interns in their program and ergo, are in need of a home. Melanie-Claire does not refer to herself as a dedicated REU Mom for nothing! All six students will take part in group activities including an Orientation Day Brunch, presentations, trainings, and with any luck, a road trip or two!

Look for final reports from the five interns who will also be CNF Users in the 2020-2021 CNF Research Accomplishments, which will be available in September. In the meantime, we look forward to a successful summer with our 2021 CNF REU Interns … plus our two "adoptees"!

Ms. Kareena Dash
2021 CNF REU Intern
Biological Sciences & Chemistry, Cornell University
CNF REU PI: Christopher Ober
CNF REU Mentor: Florian Hermann Ulrich Kafer
CNF REU Project Title: A New Generation of Small Molecules for EUV Photolithography

Ms. Niaa Jenkins-Johnston
2021 CNF REU Intern
Biomedical Engineering, Cornell
CNF REU PI: Claudia Fischbach-Teschl
CNF REU Mentor: Matthew Lee Tan
CNF REU Project Title: Investigating Metabolic Regulation of Cancer Stem-like Cells in the Perivascular Niche

Ms. Elisabeth Wang
2021 CNF REU Intern
Biological Sciences, Music, Cornell University
CNF REU PI: Jan Lammerding
CNF REU Mentor: Richa Agrawal
CNF REU Project Title: Generating Microfluidic Devices to Study Confined Migration of Cancer Cells

Ms. Zhangqi (Jackie) Zheng
2021 CNF REU Intern
Unaffiliated (intended major: Engineering Physics), Cornell University
CNF REU PI: Paul McEuen
CNF REU Mentor: Samantha Norris
CNF REU Project Title: Growing and Patterning ALD Metal Actuators for Microscopic Robots

Ms. Francesca Bard
(Adopted CNF Student)
Materials Science and Engineering, Cornell University
CNF REU PI: Christopher Ober
CNF REU Mentor: Florian Hermann Ulrich Kafer
CNF REU Project Title: TBA

Mr. Micah Chen
(Adopted CTECH Student)
Engineering, Cornell University
CTECH REU PI: H. Oliver Gao
CTECH REU Mentor: Razieh Nadafianshahamabadi
CTECH REU Project Title: Understanding the Impact of Transportation on Air Quality, Climate, and Public Health
(CTECH = Center for Transportation, Environment, and Community Health)