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NanoMeter

The newsletter of the Cornell NanoScale Facility

Winter 2020 • Volume 29 • Issue 2

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New NSF Grant Number Effective Immediately for all CNF-Research Related Acknowledgements

NNCI-2025233

Effective immediately, please use NNCI-2025233 in all your CNF-related research patent, presentation, and publication acknowledgements.

Proper grant citation is critical to our continuing funding from NSF.

Our website and CNF acknowledgements webpage have been updated with this new number.

https://www.cnfusers.cornell.edu/acknowledgements

As a reminder:

Formal publications require a statement acknowledging CNF and NSF support. For all papers, simply include the following acknowledgement:

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

Or if space is an issue:

- This work was performed in part at the Cornell NanoScale Facility (CNF), an NNCI member supported by NSF Grant NNCI-2025233.

Your attention to this update is greatly appreciated.

CNF Cornell NanoScale Science and Technology Facility · National Nanotechnology Coordinated Infrastructure · Cornell University · New York State of Opportunity. Empire State Development · NSF

This material is based upon work supported by the National Science Foundation under Grant No. NNCI-1542081. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

CNF Receives Five-Year, $7.5M Renewal from NSF

By Melanie Lefkowitz
August 24, 2020
Cornell Chronicle

Duffield Hall, home of the Cornell NanoScale Science & Technology Facility, as captured by DLJ Photography

The National Science Foundation (NSF) has renewed its funding for the Cornell NanoScale Science and Technology Facility (CNF), with a five-year, $7.5 million grant to continue supporting academic and commercial research in nanofabrication. The grant funds CNF's participation in the National Nanotechnology Coordinated Infrastructure (NNCI), a network providing engineers and scientists from academia, government and industry with rapid, hands-on access to advanced nanofabrication tools and staff expertise they couldn't afford on their own.

"We are halfway through the 10-year life of this network program, and we are delighted to be a part of it," said Christopher Ober, the Francis Norwood Bard Professor of Materials Engineering in the College of Engineering, and the Lester B. Knight Director of CNF. "CNF is the pioneer of nanofabrication facilities and we've been a constant for the last 40 years as the network has changed and grown. We're thrilled to be opening up the next exciting chapter."

"NNCI helps scientists and engineers in diverse fields solve challenging convergent research problems," said Dawn Tilbury, NSF assistant director for engineering. "Research and education through NNCI will continue to yield nanotechnology innovations — from interconnects for quantum systems to high-resolution imaging to brain-implanted sensors — that bring economic and societal benefits to us all."

Housed in Duffield Hall, CNF's tool set encompasses more than 180 advanced instruments and services that include nanolithography, materials deposition and etching, along with special facilities for soft materials used for biomedical technology.

"This NSF award allows us to make our facility, which is one of the best in the world, available to users from across the country," said Lynn Rathbun, laboratory manager. "We have a significant role in economic development for startup companies in Ithaca, startup companies around the country and even now and then major companies who want to try something novel that they don't want to try at home."

The facility has a mission to enable rapid advancements in science, engineering and technology at the nanoscale, and also receives funding from Cornell University, the Empire State Development Corp, and the CNF Users.

"The NSF grant really helps us provide the opportunity for continued infrastructure that's needed to enhance the whole nation's nanotechnology research," said Ron Olson, CNF director of operations. "It allows us to strengthen our capabilities for the next emerging technologies."

The network also contributes to nanotechnology education at the professional, collegiate and K-12 levels. These programs include a partnership with 4-H, which is managed by Cornell Cooperative Extension in New York State. CNF has also established an exchange program to help talented undergraduates study abroad and encourage them to pursue graduate education in science and engineering.

"We help train the next generation of nanotechnologists," Ober said. "We offer the services, we offer the ability to make tiny things, and we enable industries, but we also train the workforce of tomorrow."

Welcome to the Winter NanoMeter: Directors' Column

"Difficulties mastered are opportunities won."
- Winston Churchill

The year 2020 will definitely take its place in history as one marked with surprise, uncertainty, introspection and challenge. However, it also provided multiple opportunities for re-evaluation and growth during the 2.5 months the CNF was forced to suspend all operations and close the doors due to the COVID-19 pandemic. Despite the changes to work and personal lives and the fluidity of the situation, the CNF was able to return to 24/7 operational status for users who were approved and retrained in accordance with the new safety and protocol standards developed in response to the pandemic. The CNF has continued to work diligently as a team to accept and train new users. A new on-boarding process was introduced utilizing a combination of Zoom, CULearn, and one-on-one training techniques with social distancing.

The CNF was proud to host the first NYS Academic Cleanroom Virtual Workshop in October (highlighted on page 7). The goal of the workshop was to unite NYS industry, and universities with similar facilities and common interests. The ensuing discussions focused on understanding the possible collaborations that would best serve New York State as a collective unit within the larger national and regional arena. CNF is currently planning follow-up activities that will utilize small focus groups charged with refining details and determining next steps/activities that will further drive NYS impact.

The CNF is pleased to continue its membership in the National Nanotechnology Coordinated Infrastructure (NNCI) with renewed support provided by the NSF as well as the NYSTAR/ESD Matching Grant Program from NYS. With this support, CNF strives to provide a comprehensive, start-to-finish nanofabrication tool set enabling the convergence of nanofabrication research and processing. The highly skilled staff members (with over 500 years of combined experience) remain the strongest, individual CNF asset. Their continued support and dedication during the trying times presented during the past year was nothing short of exemplary.

In this edition of the NanoMeter we are delighted to introduce our new Associate Director, Prof. Claudia Fischbach-Teschl who is responsible for life science strategies and services. Claudia's background and perspectives are highlighted on page 6.

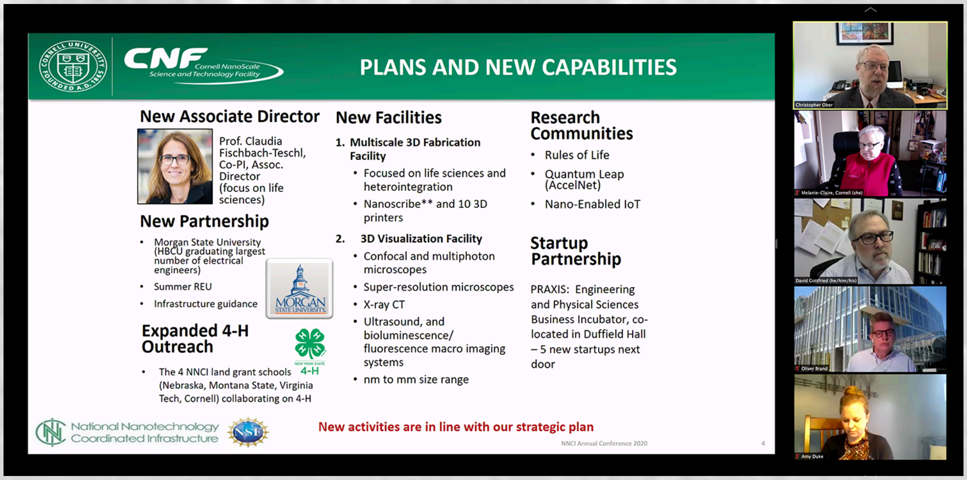
We are also pleased to share that Tom Pennell was recognized as an award winner in the NNCI Education and Outreach category. He has found his passion in the delivery of hands-on, nanotechnology education to a diverse group of engineering and science students. Tom strives to foster interest and curiosity in STEM careers among K-12 and undergraduate students. His creative capabilities and expertise in micro- and nano-fabrication processes have enabled the CNF to continue to serve as a strong presence in the youth outreach arena. Congratulations Tom and thank you for your dedication!

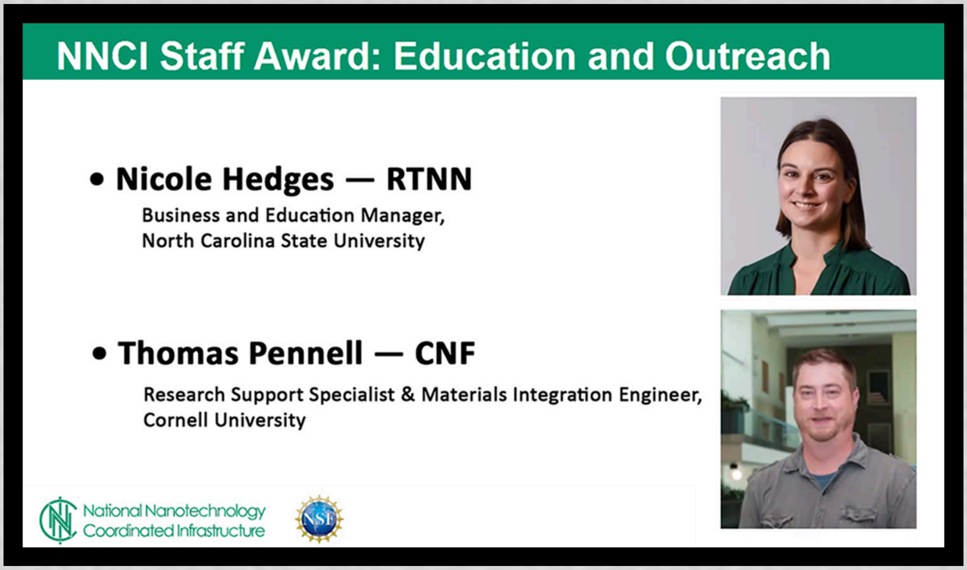
The CNF also extends best wishes and congratulations to Jerry Drumheller, Denise Budinger, and Kathy Springer on their retirement from the CNF. Jerry and Denise both retired with 26 years of service and Kathy with 17 years of service. Thank you for your commitment to the CNF mission. We wish you all the very best in the coming years.

Thank you to CNF's corporate sponsors, speakers, poster session participants, staff (and especially IT staff) and attendees who helped to make the virtual 2020 Annual Meeting a great success. A special congratulations is extended to the Annual Meeting award winners listed on page 9.

The CNF appreciates each of the many users who continue to lend support, patience and understanding as we continue to navigate the opportunities presented by the COVID-19 challenges. Your commitment to the CNF has shown that we are stronger together even at a distance.

The entire CNF family extends to you all the best wishes for a warm, holiday season — and a happy, healthy, peaceful New Year!





Christopher Ober
Lester B. Knight Director
director@cnf.cornell.edu

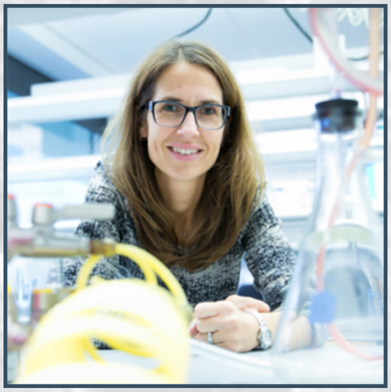
Ron Olson
Director of Operations
olson@cnf.cornell.edu

Claudia Fischbach-Teschl
Associate Director, Life Sciences
cf99@cornell.edu

PHOTOGRAPHY & FORMAT CREDITS

Most photographs in this issue were provided by the researcher, author, CNF staff, or as noted. The cover image and director photographs on this page were taken by University Photography. The NNCI Annual Meeting photos are screen catures taken by Melanie-Claire Mallison. This issue's background image is from Golsa Mirbagheri's research, figure 2, page 17.

The NanoMeter is formatted by Melanie-Claire. Send your comments and corrections to mallison@cnf.cornell.edu



Introducing Claudia Fischbach-Teschl, CNF Associate Director

https://www.engineering.cornell.edu/ faculty-directory/claudia-fischbach

My name is Claudia Fischbach-Teschl and I was recently appointed as CNF Associate Director to help foster integration of Cornell's exceptional capabilities in nano-and microfabrication and the life sciences.

I started at Cornell as an assistant professor in biomedical engineering in 2007, and my lab's research focuses on how microenvironmental conditions regulate cancer development, progression, and therapy. My very first research proposal was funded through Cornell's NSF-funded Nanobiotechnology Center (NBTC), whose research capabilities have since been integrated into CNF. Together with Abe Stroock (professor, Chemical and Biomolecular Engineering), we proposed to develop microfluidic devices to improve understanding of how tumors recruit blood vessels. This work has catalyzed numerous follow-up research projects that critically depended on the convergence of nano- and microfabrication with life sciences research.

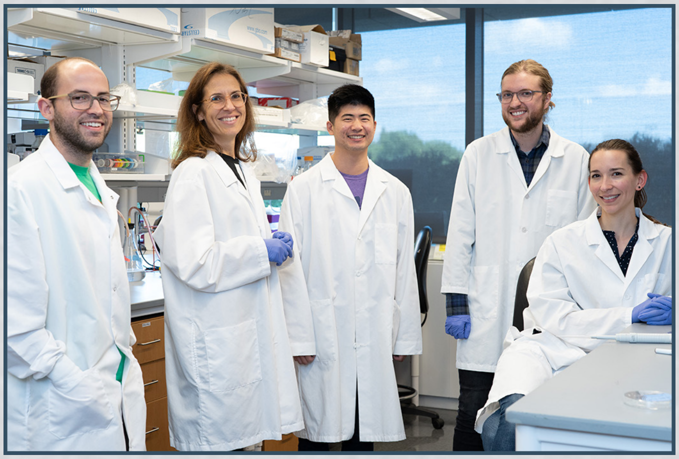
Currently, about a quarter of all CNF users work on life sciences projects. This impressive number can be attributed to Cornell's pioneering history in nanobiotechnology that was enabled through the vision and leadership of exceptional scientists like Harold Craighead, Barbara Baird, Mike Shuler, and Lois Pollack. Following new strategic planning and investment, the CNF is now turning to build on these prior accomplishments to help advance additional areas of life sciences research. Examples include precision medicine or biomanufacturing, which both depend on integration with additional fields such as genome biology, data sciences, and advanced imaging. As such CNF investments into these new activities will align well with Cornell's Radical Collaborations initiative and/or capitalize on existing strengths in Ithaca.

To help foster such multidisciplinary projects, I will be drawing on my expertise as Director of Cornell's National Cancer Institute (NCI)-funded Physical Sciences Oncology Center (PSOC), which integrates researchers from different departments, colleges, and across both campuses of Cornell.

One additional perspective I bring to the CNF is recognizing the different needs of life sciences users relative to more traditional engineering and technology applications. It will be important for CNF to understand and adjust to those needs to further increase its user base and make the exceptional expertise of CNF staff available to the broader community.

For example, life sciences-focused fabrication needs can sometimes be less sophisticated, but require a higher throughput than those of traditional users. I will help in communicating across scientific boundaries to serve users better and also to make Cornell's capabilities available to broader National Nanotechnology Coordinated Infrastructure (NNCI) of which CNF is a critical part.

It is an exciting time for nano and microfabrication at Cornell, and I am thrilled to help advance existing and new life sciences projects consistent with the strategic planning of the CNF. With this, my main priority will be to help implement protocols that best serve the needs of CNF users from both academia and industry. Providing access to leading-edge fabrication and characterization tools, instrumentation, and expertise will not only advance their specific research questions but also the training of the next generation of life scientists that fluently operate at the interface with nano- and microfabrication.



Photographs on this page are by Dave Burbank.

CNF Hosts NYS Academic Cleanroom Workshop

On October 14th, the CNF hosted a NYS Academic Cleanroom Workshop with over 50 participants from across the New York State area. The goal of this workshop was to bring together NYS industries and universities with micro- and nanotechnology, semiconductor processing/research and/or packaging facilities to get to know each other, understand each of our capabilities, and start a discussion to understand possible synergies. The workshop began with a brief overview by each NYS participant, then moved into four separate break-out sessions on topics like sharing resources, working together to help the state's economic growth, job creation, workforce training and how we as an alliance can bring funding and support to NY state, provided the initial foundation for discussions and possible next steps.

This initial discussion is important in the understanding and planning for possible opportunities that could come out of the national focus on semiconductor manufacturing and nanofabrication including the 2020 National Nanotechnology Initiative, the National Quantum Initiative Act and recently announced federal American Foundries and Endless Frontiers Acts. Subsequent discussions and actions will help provide the momentum to drive a greater impact in NYS.

In addition, Jon Cardinal, Director of Economic Development, Office of Sen. Charles Schumer and State Senator Anna Kaplan (D-Nassau County) who chairs the Economic Development Committee, joined us. Jon highlighted that increasing federal incentives will enable the advancement of research and development that it will help secure the supply chain and ensure long term national security and economic competitiveness in the semiconductor industry. These programs will help the United States innovate and maintain its lead in semiconductor technology and design.

Senator Kaplan provided inspiring comments encouraging us to work together in order to support economic growth, share resources, and improve and grow the state's research capabilities. She also highlighted that as an alliance we can work together to help bring in funding, provide workforce training, job creation for NYS and stated "I look forward to being a passionate supporter of your work and will be one of the loudest voices in New York State to proclaim the importance of funding these continued partnerships and to show our gratitude for your exceptionalism in this amazing field."

Contact Chris Ober and or Ron Olson to learn more about this collaborative work (director@cnf.cornell.edu, olson@cnf.cornell.edu).

- NYS Institutions Represented; Binghamton University, Colombia University, Cornell University, Rensselaer Polytechnic Institute, Rochester Institute of Technology, SUNY Polytechnic Institute, Syracuse University, University at Buffalo
- Industries Represented; Applied Materials, Corning Incorporated, GE Research, GlobalFoundries U.S. Inc., IBM Research, NY CREATES, Tokyo Electron America

Emmanuel Giannelis, Cornell Vice Provost for Research

Senator Anna Kaplan (D-Nassau County)

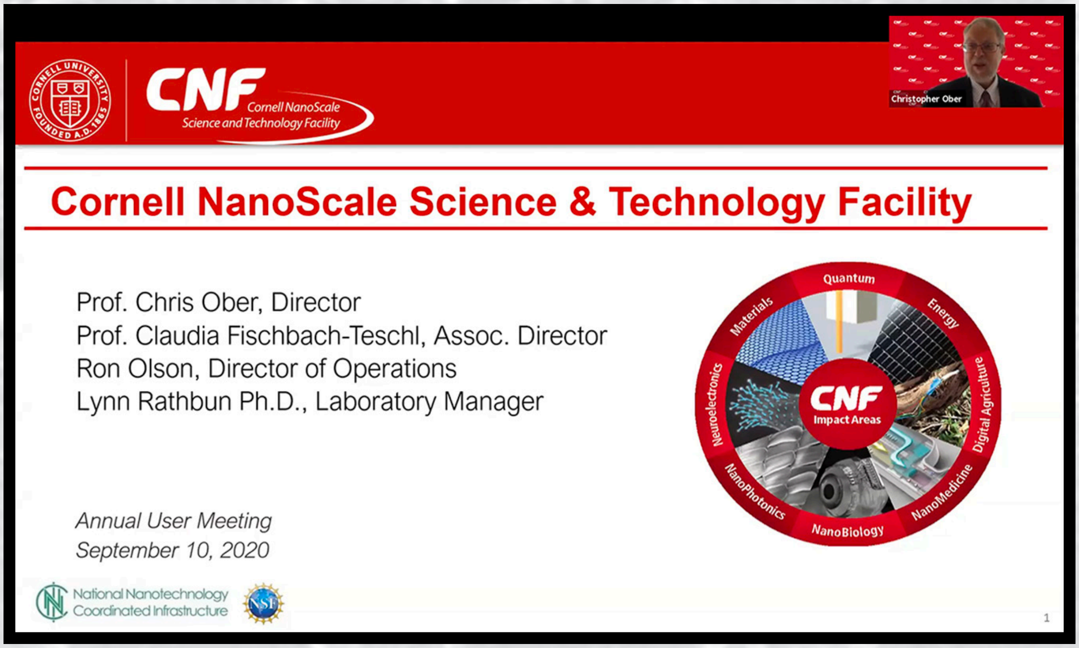
Images on this page are screen captures by Melanie-Claire Mallison

SCENES

FROM THE

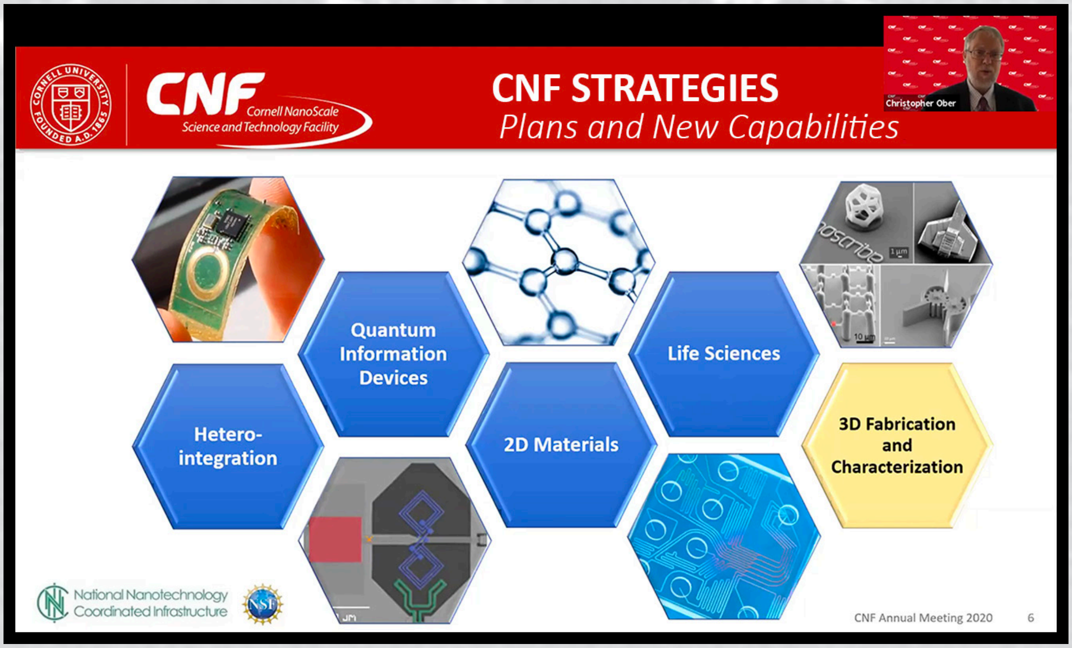
2020 CNF VIRTUAL ANNUAL MEETING

SEPT 10



We welcomed 177 participants — visiting us virtually from Brazil to the United Kingdom.

Not serving a lot of food and coffee was hard to get used to, but our guest speakers and invited user presenters served up a unique and interesting smorgasbord of nano-research to satisfy any palate.



Talks and posters are online at https://tinyurl.com/CNFam20

Images on this page and the next page are screen captures by Melanie-Claire Mallison

HOSTING A VIRTUAL MEETING DIDN'T STOP US FROM AWARDING THE FOLLOWING CNF USERS FOR EXCELLENCE IN RESEARCH:

BEST CNF USER POSTERS

Michael F. Reynolds, Making Microrobots with CMOS Control Circuits
Edward Szoka, Neural Probe Utilizing Micro-coil Magnetic Stimulation with CMOS Technology Integration for Spatially Programmable Neurostimulation
Wei Wang, Electrically Actuated Artificial Cilia for Microfluidic Applications (Best of the Best!)

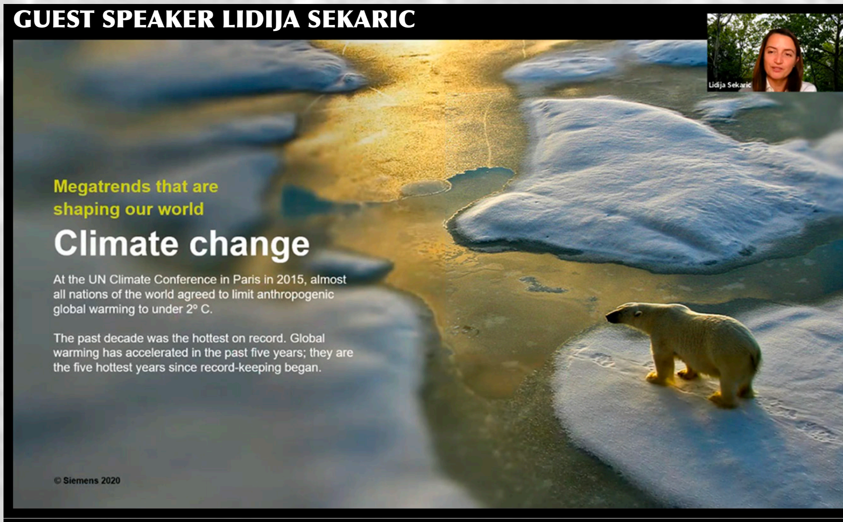
BEST CNF USER PRESENTATION

Alejandro Cortese, CFAB: Heterogeneous Integration for Microscopic Sensors and Robots

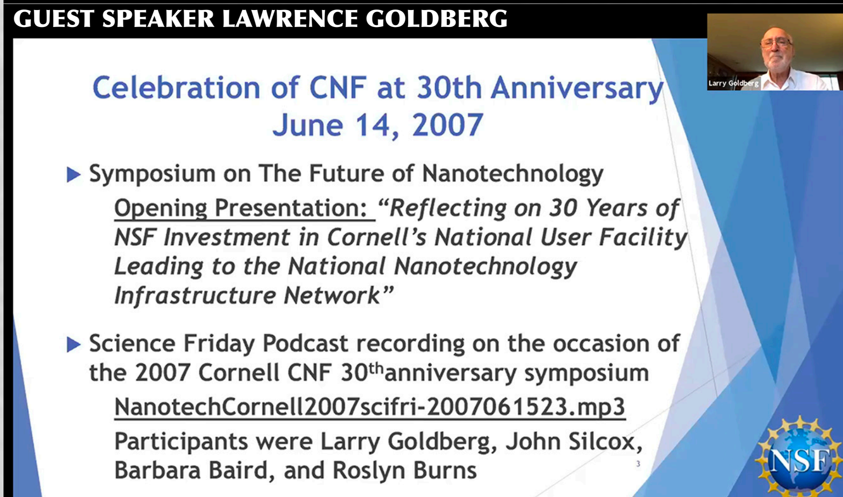
WHETTEN MEMORIAL AWARD WINNERS

Marissa Granados-Baez, Cardenas Lab, The Institute of Optics, University of Rochester (profile page 8)
Christine Harper, Hernandez Research Group, Cornell University (profile page 10)

GUEST SPEAKER LIDIJA SEKARIC



GUEST SPEAKER LAWRENCE GOLDBERG



GUEST SPEAKER NANCY STOFFEL

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2020 CNF Nellie Yeh-Poh Lin Whetten Memorial Award Winner Profile: Marissa Granados-Baez

Marissa Granados-Baez is currently a graduate student in The Institute of Optics at the University of Rochester, and is one of 2020's co-recipients of the CNF Nellie Yeh-Poh Lin Whetten Memorial Award (together with Christine Harper). 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.

Marissa received her bachelor's degree in Physics from Universidad Nacional Autónoma de México (UNAM) in 2016. During her bachelor studies she did multiple internships that increased her interest in research. In the summer of 2012, she did a research internship at the Center for Nanoscience and Nanotechnology, UNAM, in ferroelectric-insulator-semiconductor (MFIS) structures. In 2013, she did a research internship at the Rena Zieve Group in the University of California, Davis, doing simulations of toroidal vortex in superfluid He-4, thanks to the support of the U.S.-Mexico Commission for Educational and Cultural Exchange, COMEXUS. In 2015, she did a third research internship in Dr. Jeff Lundeen's group at the University of Ottawa, designing and building a setup for General Polarization Transformations with Spatial Light Modulators (SLM), thanks to the Mitacs Globalink Program.

In the fall of 2016, she joined the Optics Ph.D. program at the University of Rochester, and she was granted a scholarship from the National Council of Science and Technology (CONACyT) in Mexico to pursuit her doctoral studies. She then joined the Cardenas Laboratory for Nanoscale and Integrated Photonics. The group's research focuses on integrated, nano, and nonlinear photonics and tackles high impact challenges using nanostructured devices on a chip. Current research is focused on four main areas: photonic packaging, 2D materials integrated photonics, nonlinear photonics, and on-chip quantum photonics.

Marissa's main research interest is enhancing passive silicon devices by integrating to them novel 2D materials with exciting optical and electrical properties. Her principal project consists on integrating monolayers of Transition Metal Dichalcogenides (TMDCs) to ring resonators that work as a cavity to build on-chip lasers based on these 2D materials. Silicon has revolutionized the field of photonics. However, the integration of 2D materials with silicon devices have attracted attention because their properties can provide a solution to silicon's lack of light emission, light detection, and weak or power-hungry effects for refractive index change that limits its applications. 2D materials are also attractive to further miniaturization of devices because they can be as thin as tenths of nanometers since they are few layers or monolayers of atoms, the most well known example being graphene, a monolayer of carbon atoms. Furthermore, they can be transferred on top of silicon or other 2D materials without the need to lattice match with

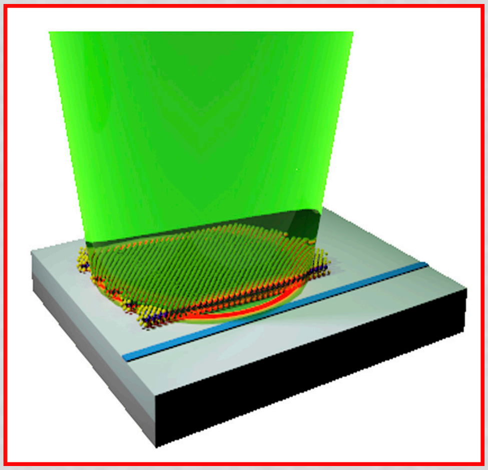


Figure 1: Schematic of the integration of a monolayer TMDC with a ring resonator. The material is pump from the top of the device with 532 nm laser light to excite the monolayer.

the substrate making them easy to integrate. From the vast range of current 2D materials, monolayers of TMDCs are of great interest for integration with passive silicon devices because they have a direct bandgap making them good emitters of light.

Marissa fabricates the silicon nitride micro-ring resonator devices at the CNF by depositing silicon nitride via low-pressure chemical vapor deposition (LPCVD) on thermally grown oxide on a silicon wafer. The ring and bus waveguide are patterned with electron-beam lithography. Before etching, a fill pattern that serves as a chemical mechanical polishing (CMP) stop layer, is written with contact lithography. Then, the nitride is etched in an inductively coupled plasma reactive ion etcher (ICP-RIE) using a CHF_3/O_2 chemistry.

The device is clad with 1 µm of SiO_2 via plasma enhanced chemical vapor deposition (PECVD). She polishes the upper cladding down to the nitride layer using CMP to increase the interaction between the optical field in the resonator and the monolayer. The smooth surface after the CMP step also improves the adhesion of the monolayer.

A mechanically exfoliated monolayer is transferred using a polymethilsiloxane PDMS-based all dry transfer technique and placed on top of the microring resonator. The monolayer is optically pumped from the top of the device with laser light at 532 nm to excite its atoms. The light emitted by the monolayer, after its atoms have decayed, couples to the ring the resonator where it is enhanced until reaching laser threshold and becoming laser light.

Part of the light is then coupled to the bus waveguide and travels to the edge of the chip where she collects it to study its spectrum. She and her colleagues in the Cardenas Research Group have demonstrated that the emission from the device shows the principal characteristics of laser light, paving the way for on chip lasers based on 2D materials.

Outside research, Marissa likes outdoors sports, such as rock and mountain climbing. She has done a little ice climbing and would like to try it more in the NY state region since the weather is so prone for this sport.

Marissa would like to express the honor it is for her to have received this Whetten Memorial Award and her sincere thanks to all the CNF staff for their help and advice during the fabrication process. She would also like to thank her advisor Dr. Jaime Cardenas for supporting her nomination for this award and his advice during the past years. She is extremely grateful for being able to work in this top class and fantastic facility.

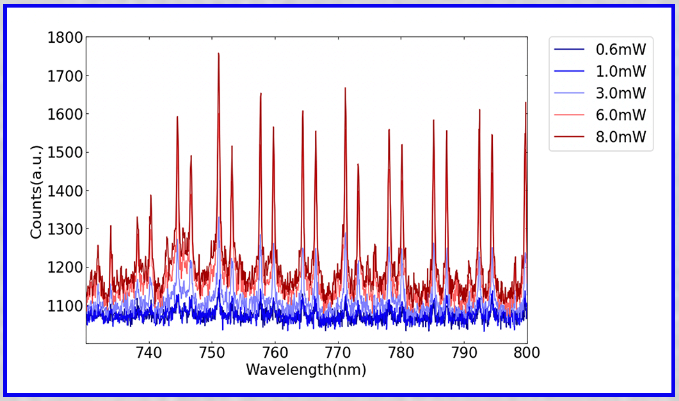
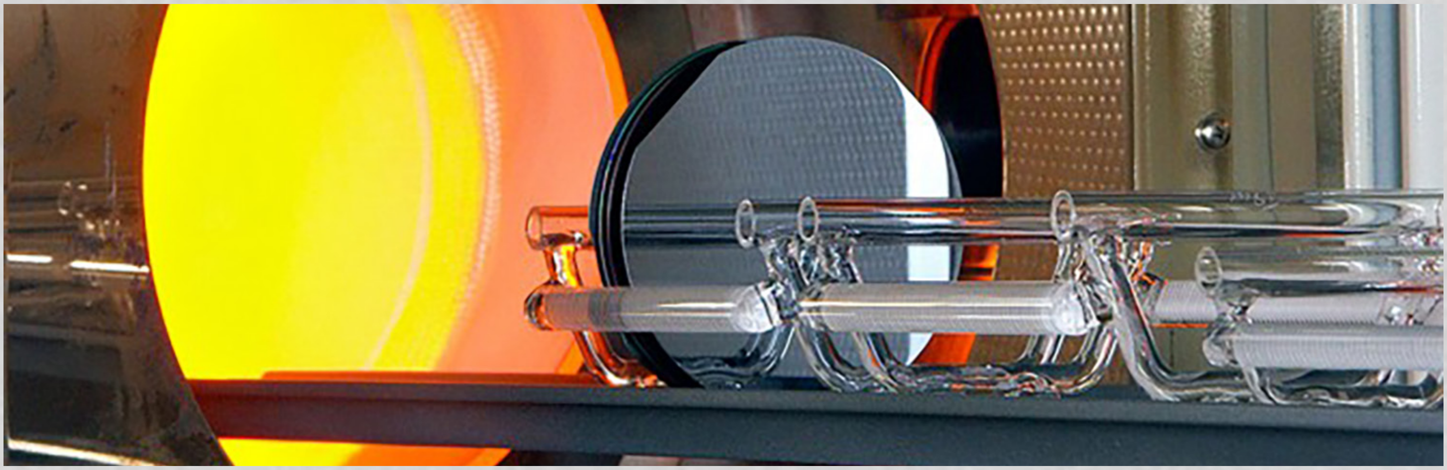


Figure 2: Output spectrum collected at the edge of the device. The spectrum shows the peaks corresponding to the resonances of the ring at different pumping powers.



The Cornell NanoScale Science and Technology Facility's Anneal 4 Furnace — an atmospheric furnace with a 40-inch flat zone capable of processing up to 6-inch diameter wafers. Charles Harrington Photography.

2020 CNF Nellie Yeh-Poh Lin Whetten Memorial Award Winner Profile: Christine Harper

Christine Harper is one of 2020's co-recipients of the CNF Nellie Yeh-Poh Lin Whetten Memorial Award (together with Marissa Granados-Baez). 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.

Christine received a bachelor's degree in biomedical engineering from Rose-Hulman Institute of Technology in Terre Haute, Indiana in 2017. As an undergraduate she researched the stability of orthopedic hip, knee, and shoulder replacements after implantation. After beginning Cornell's Ph.D. program in biomedical engineering, she joined Professor Christopher Hernandez's research group to study bacterial mechanics and mechanobiology (an area of research she did not even know existed until she came to Cornell).

Bacteria experience many mechanical forces in the environment. Bacteria experience mechanical forces as they swim through fluid, as they attach to surfaces, as they grow in biofilms, and as they interact with and infect hosts. While it has been clearly established that sensing and responding to mechanical forces is important for the development and function of mammalian cells, the field or bacterial mechanics and mechanobiology is still relatively new and unexplored. Two main general questions motivate Christine's research in bacterial mechanics and mechanobiology. How do the mechanical properties of the bacterial cell envelope enable bacteria to survive mechanical challenges? How do bacteria sense and respond to mechanical stimuli in order to thrive in a hostile mechanical environment?

Bacteria are generally less than a micron wide, an order of magnitude smaller than mammalian cells, so many of the methods established for investigating mammalian cell mechanics and mechanobiology cannot be used. The Hernandez group created a microfluidic device to apply controlled mechanical stress to individual bacterial cells.

The silica microfluidic devices were made using deep UV photolithography, and the smallest feature size is approximately 300 nanometers. The microfluidic devices are plasma etched and fused with a silica cover wafer. The microfluidic device has many narrow tapered channels in parallel (Figure 1). Bacteria are forced by fluid pressure into the tapered channels until they become stuck. The fluid pressure and the contact with the walls of the tapered channels cause the bacteria cells to deform and experience increased mechanical stress in the cell envelope. The bacteria remain alive in the tapered channels and can be observed growing and dividing. This microfluidic device provides a platform to observe how individual live bacteria cells respond to mechanical stimuli over time, and since the fluid pressure and cell deformation can be quantified, this microfluidic device can also be used to estimate the material properties of the bacterial cell envelope using finite element modelling.

In particular her research focuses on how mechanical stress affects bacterial mechanisms of antibiotic resistance. One intrinsic mechanism of antibiotic resistance in bacteria is multicomponent efflux pumps. Multicomponent efflux pumps form a channel through the bacterial cell envelope and are used to export antibiotics and toxins from the cell.

Multicomponent efflux pumps are formed from the assembly of several separate proteins, and these efflux pumps can shift dynamically between an assembled and functional state and a disassembled and non-functional state. Since multicomponent efflux pumps span the cell envelope, and the cell envelope is the main mechanical stress-bearing element in a bacteria cells, the group investigated if applying mechanical stress to cells influenced amount of assembled and functional multicomponent efflux pumps. So far, the group has found in two different types of multicomponent efflux pumps that increased mechanical stress results in an increased number of disassembled pumps, meaning bacterial cells experiencing mechanical stress may have compromised multicomponent efflux pump function and may be more susceptible to antibiotics.

Some types of antibiotics selectively damage the bacterial cell envelope. In response to antibiotic mediated bacterial cell wall damage, it has previously been shown that bacteria can increase production of cell envelope components to restore cell envelope viability and enable antibiotic resistance. Christine is currently investigating how the bacteria sense cell envelope damage, and if mechanically induced cell envelope damage can elicit a similar upregulation in cell envelope production. She hopes to understand how modulation of the mechanical properties of the cell envelope enable cells to withstand antibiotics.

In her free time, Christine likes to play volleyball, travel (when there is not a global pandemic), listen to podcasts, and hang out with her partner and her cat.

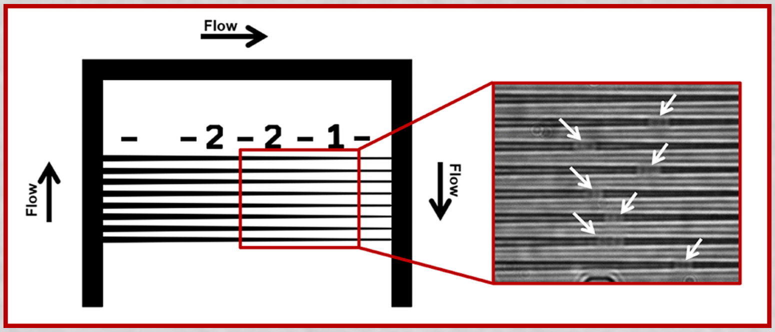


Figure 1: Microfluidic device design used to mechanically stimulate bacteria cells. Eight tapered channels are in parallel and a surrounding bypass channel provides constant fluid flow. Inset showing live E. coli cells trapped in the tapered channels (white arrows).

Photograph provided by Tim Whetten

Nellie Yeh-Poh Lin Whetten; CNF Memorial Award

This award is given in fond memory of Nellie Whetten (above) — 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 was 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

Bevy of Incubators and Resources Bolster Startup Culture

By Joe Wilensky
Ezra Magazine
October 26, 2020

Potential entrepreneurs looking to commercialize their inventions, applications of their research, or Cornell technologies have multiple paths and resources available to them across the university's campuses.

In addition to the McGovern and Praxis centers, the Weill Cornell Medicine BioVenture eLab and the Cornell Tech Runway Startup Postdocs program, there are:

- student-focused competitive programs like the Cornell eLab, which is run as an actual course, and student-run organizations such as Life Changing Labs;
- discipline-focused resources like the Food Processing Development Laboratory and the Cornell Food Venture Center within the College of Agriculture and Life Sciences and the Pillsbury Institute for Hospitality Entrepreneurship within the Cornell SC Johnson College of Business' School of Hotel Administration;
- technology-focused resources like the Cornell Center for Advanced Technology in Life Science Enterprise, the university's Center for Technology Licensing and the W.E. Cornell program, a Center for Regional Economic Advancement-supported program that helps women in STEM commercialize their innovations; and
- local community-focused incubators and workspaces like Rev: Ithaca Startup Works, which was created through a partnership between Cornell, Ithaca College and Tompkins-Cortland Community College, and eHub – 15,000 square feet of co-working space exclusively for students (5,000 in Kennedy Hall on the Ithaca campus and an additional 10,000 in Collegetown).

Even university facilities that are not technically incubators, such as the Cornell NanoScale Science and Technology Facility (CNF), have long and successful track records of helping launch startup companies in New York state. Since its founding in 1977, CNF has helped scientists and engineers from both academia and industry conduct micro- and nanoscale research.

At least 34 startups have launched with the help of CNF in the past four decades and continue to use its services, with 14 forming in just the past 10 years. These companies annually generate about $1.4 billion in funding and revenue.

Also crucial to the university's startup culture is the vast Entrepreneurship at Cornell program, which fosters entrepreneurial spirit across all Cornell colleges and schools; hosts events, competitions and internships; and is governed by a dozen deans and an advisory council of more than 100 members. Entrepreneurship at Cornell manages the eHub facilities and also maintains an online entrepreneurship ecosystem map, listing dozens of other entrepreneurship program resources.

Individual stories abound within the university's colleges as well. For example, at the College of Veterinary Medicine, Sean Bellefeuille, who arrived at Cornell with a biomedical engineering undergraduate degree from the Rochester Institute of Technology and a passion for 3D printing, met Jorge Colón '92, D.V.M. '95, a senior lecturer with the college's Center for Veterinary Business and Entrepreneurship. Colón connected him with the center's resources and introduced him to other CVM veterinary entrepreneurs.

Physical location matters. A technology-focused incubator like the Praxis Center for Venture Development benefits from being on the Ithaca campus, with close proximity to three major National Science Foundation-supported research and development laboratories: CNF, the Platform for the Accelerated Realization, Analysis and Discovery of Interface Materials (PARADIM) Labs, and portions of the Cornell Center for Materials Research (CCMR).

These entrepreneurial resources work together as engines of economic development, part of the university's founding land-grant mission.

Laser Jolts Microscopic Electronic Robots Into Motion

By David Nutt
Cornell Chronicle
August 26, 2020

In 1959, former Cornell physicist Richard Feynman delivered his famous lecture "There's Plenty of Room at the Bottom" in which he described the opportunity for shrinking technology, from machines to computer chips, to incredibly small sizes. Well, the bottom just got more crowded.

A Cornell-led collaboration has created the first microscopic robots that incorporate semiconductor components, allowing them to be controlled — and made to walk — with standard electronic signals.

These robots, roughly the size of paramecium, provide a template for building even more complex versions that utilize silicon-based intelligence, can be mass produced, and may someday travel through human tissue and blood.

The collaboration is led by Itai Cohen, professor of physics, Paul McEuen, the John A. Newman Professor of Physical Science — both in the College of Arts and Sciences — and their former postdoctoral researcher Marc Miskin, who is now an assistant professor at the University of Pennsylvania.

The team's paper, "Electronically Integrated, Mass-Manufactured, Microscopic Robots," published August 26 in Nature.

The walking robots are the latest iteration, and in many ways an evolution, of Cohen and McEuen's previous nanoscale creations, from microscopic sensors to graphene-based origami machines.

The new robots are about 5 µm thick, 40 µm wide and range from 40 to 70 µm in length. Each bot consists of a simple circuit made from silicon photovoltaics — which essentially functions as the torso and brain — and four electrochemical actuators that function as legs.

As basic as the tiny machines may seem, creating the legs was an enormous feat.

"In the context of the robot's brains, there's a sense in which we're just taking existing semiconductor technology and making it small and releasable," 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.

"But the legs did not exist before," McEuen said. "There were no small, electrically activatable actuators that you could use. So we had to invent those and then combine them with the electronics."

Using atomic layer deposition and lithography, the team constructed the legs from strips of platinum only a few dozen atoms thick, capped on one side by a thin layer of inert titanium. Upon applying a positive electric charge to the platinum, negatively charged ions adsorb onto the exposed surface from the surrounding solution to neutralize the charge. These ions force the exposed platinum to expand, making the strip bend. The ultra-thinness of the strips enables the material to bend sharply without breaking. To help control the 3D limb motion, the researchers patterned rigid polymer panels on top of the strips. The gaps between the panels function like a knee or ankle, allowing the legs to bend in a controlled manner and thus generate motion.

The researchers control the robots by flashing laser pulses at different photovoltaics, each of which charges up a separate set of legs. By toggling the laser back and forth between the front and back photovoltaics, the robot walks.

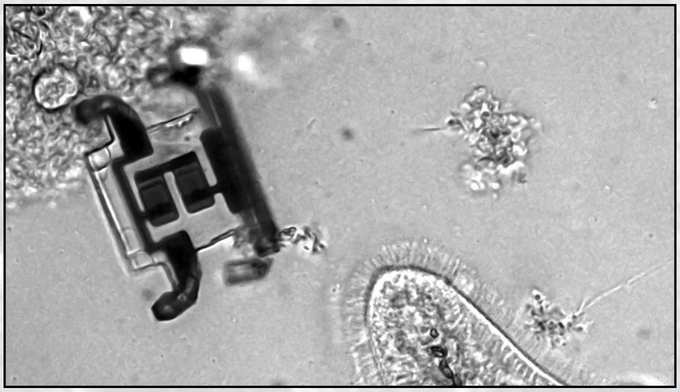


Figure 1: Researchers from Cornell and the University of Pennsylvania built microscopic robots that consist of a simple circuit made from silicon photovoltaics — essentially the torso and brain — and four electrochemical actuators that function as legs. When laser light is shined on the photovoltaics, the robots walk.

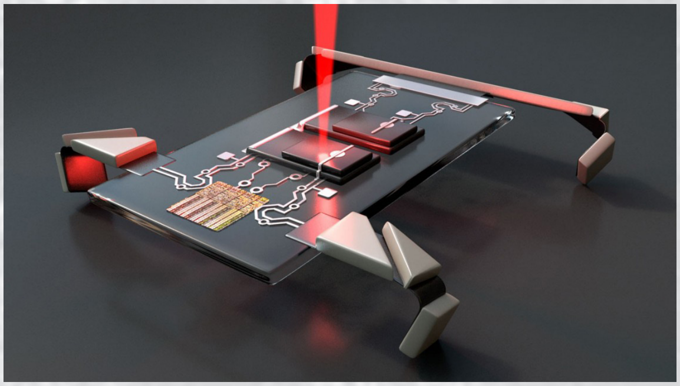


Figure 2: The robots are about 5 µm thick, 40 µm wide and range from 40 to 70 µm in length — roughly the same size as microorganisms like paramecium. Provided.

"While these robots are primitive in their function — they're not very fast, they don't have a lot of computational capability — the innovations that we made to make them compatible with standard microchip fabrication open the door to making these microscopic robots smart, fast and mass producible," Cohen said. "This is really just the first shot across the bow that, hey, we can do electronic integration on a tiny robot."

The robots are certainly high-tech, but they operate with low voltage (200 millivolts) and low power (10 nanowatts), and remain strong and robust for their size. Because they are made with standard lithographic processes, they can be fabricated in parallel: about one million bots fit on a 4-inch silicon wafer.

The researchers are exploring ways to soup up the robots with more complicated electronics and onboard computation — improvements that could one day result in swarms of microscopic robots crawling through and restructuring materials, or suturing blood vessels, or being dispatched en masse to probe large swaths of the human brain.

"Controlling a tiny robot is maybe as close as you can come to shrinking yourself down. I think machines like these are going to take us into all kinds of amazing worlds that are too small to see," said Miskin, the study's lead author.

Co-authors include David Muller, the Samuel B. Eckert Professor of Engineering; Alejandro Cortese, Ph.D. '19, a Cornell Presidential Postdoctoral Fellow; postdoctoral researcher Qingkun Liu; doctoral students Michael Cao '14, Kyle Dorsey and Michael Reynolds; and Edward Esposito, a former university staff member and technician in Cohen's lab.

"This research breakthrough provides exciting scientific opportunity for investigating new questions relevant to the physics of active matter and may ultimately lead to futuristic robotic materials," said Sam Stanton, program manager for the Army Research Office, an element of the Combat Capabilities Development Command's Army Research Laboratory, which supported the research.

Additional support was provided by the Air Force Office of Scientific Research, the Cornell Center for Materials Research, which is supported by the NSF's Materials Research Science and Engineering Center program, and the Kavli Institute at Cornell for Nanoscale Science.

The work was performed at the Cornell NanoScale Science and Technology Facility.

RADICAL COLLABORATION

The Cohen McEuen robots are also featured in the CNF introductory video on our main page, https://cnf.cornell.edu/

Hyperbolic Metamaterial Filter for Angle-Independent TM Transmission in the Infrared Regime

By Golsa Mirbagheri
CNF User
November 2, 2020

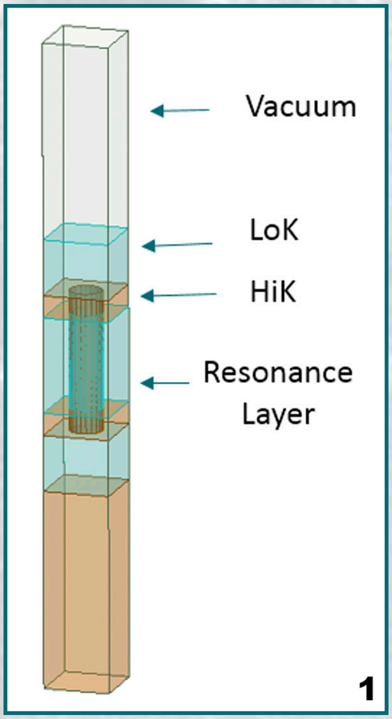
In this project, a hyperbolic metamaterial Bragg stack is designed and fabricated in the mid-wave infrared regime.

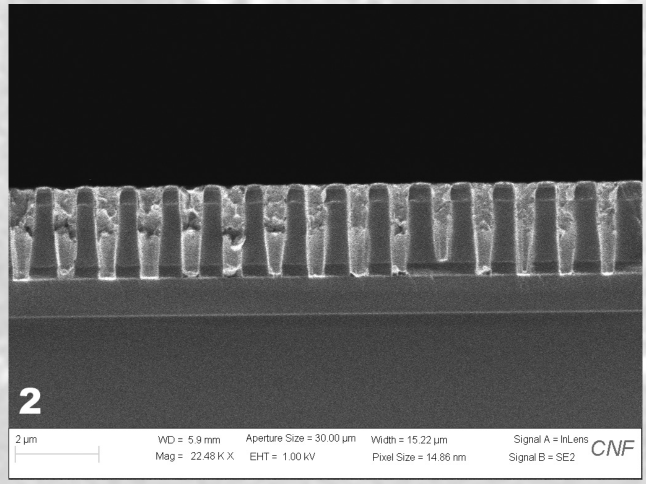
The proposed narrowband notch filter is independent of the center-wavelength of angle of incident light for the transverse magnetic (TM) polarization.

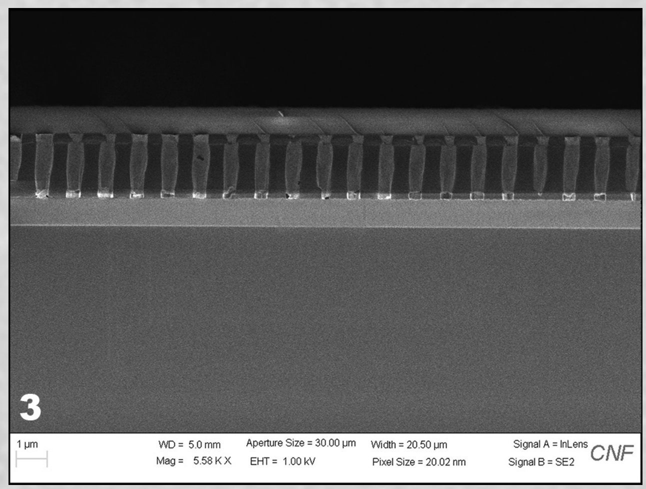
In order to accomplish the angle-of-incidence independence, an array of metal wire subwavelength sized are penetrated vertically in the three middle layers of the filter.

The novel method in the fabrication of the hyperbolic metamaterial Bragg stack (HMBS) is using separate lithography for etching the three alternative dielectric layers of the seven-layer filter which shows the perfect alignment. Furthermore, after doing chemical-mechanical polishing, the wafer was broken into pieces to look at cross-sections on the SEM, and therefore, the rest of the electroplated copper was polished by hand, and made an amazing result.

Narrowband notch filters have been used in many sensing and imaging applications, including remote sensing and hyperspectral imaging.







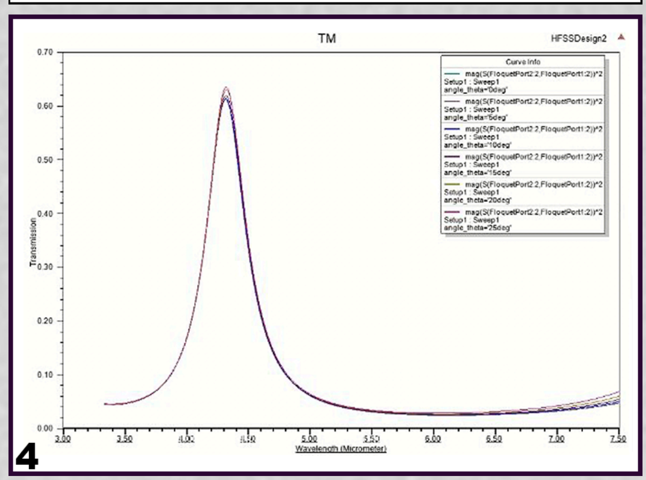


Figure 1, top left: HFSS simulation of one unite of HMBS. Figure 2, top right: The electroplated copper is hand-polished (see the newsletter background!). Figure 3, middle: The final 7-layer filter. Figure 4, bottom: Locked center-wavelength for different angle of incident light.

Ph.D. Graduate: Golsa Mirbagheri
Advisor: Dr. David Crouse (Ph.D.)
Affiliation: Department of Electrical and Computer Engineering, Clarkson University

Engineering Startups Harness Cornell's Entrepreneurial Energy

By Casey Verderosa
October 29, 2020
Cornell Chronicle

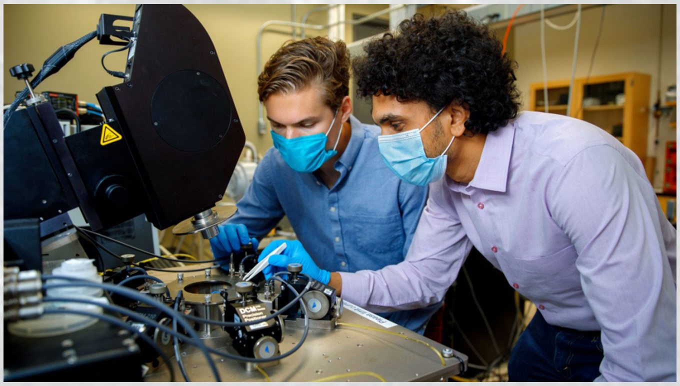


Figure 1: Soctera co-founders Reet Chaudhuri, M.S. '16, right, and Austin Hickman work on their aluminum nitride-based power amplifier, which produces millimeter-wave frequency signals that can travel farther than existing technology allows. Jason Koski/Cornell University.

Growing up in Huntington, West Virginia, Austin Hickman had always envisioned "wheeling and dealing" as a businessperson. As he gravitated toward more concrete subjects in high school, such as math and science, practicality gained the upper hand.

"But it never really left me, the thought that entrepreneurship is exciting," he said.

Now a Ph.D. candidate in electrical and computer engineering, Hickman has been developing an aluminum nitride (AIN)-based power amplifier with the ability to produce millimeter-wave frequency signals that can travel farther than existing technology allows.

He mentioned his interest in business to his academic adviser, who suggested Cornell Engineering's Commercialization Fellowship program.

"My entrepreneurship experience prior to the fellowship was essentially zero," Hickman said. "That's really when it all hit the next level. Once you start, it's a rapid acceleration — like a rocket ship — and you just hold on."

The commercialization fellowship is one of many resources available to engineering students in the robust entrepreneurial ecosystem the university has cultivated in recent years. Hickman's company, along with two other startups affiliated with the College of Engineering, are taking advantage of every opportunity they can.

A trademark of the fellowship is enrollment in the National Science Foundation's I-Corps Teams Program, which trains researchers to identify the market for their product. Cornell is one of three universities that comprise the Upstate New York I-Corps Node. It's there that Hickman, like many other Cornell researchers, learned how to discover his customers.

He enrolled in I-Corps in 2019 and learned through the experience that his technology could be used in defense radar systems and telecommunications — especially in the global race to develop sixth-generation wireless (6G) networks.

"It can be a little overwhelming because it's such a large space with so many competitors and established technologies that it's a lot to wrap your head around," Hickman said. "A year and a half ago I had no idea what the business environment surrounding 6G was like."

In early 2020 he co-founded a company, Soctera, based on technology from his doctoral research (https://www.soctera.com/). This has been a busy year for his startup. The company was a recipient of the College of Engineering's annual Scale Up and Prototyping Award, which provides funding for academics whose technology may otherwise be passed up by institutional investors before their commercialization paths become clear.

The company secured membership with Launch NY, a nonprofit venture development organization serving upstate New York. It's also receiving mentorship from the Praxis Center for Venture Development, Cornell's on-campus incubator for startups in engineering, digital and physical sciences.

During their final year as Ph.D. students, Hickman and another Soctera's co-founder, Reet Chaudhuri, M.S. '16, will optimize their transistor technology and look for funding.

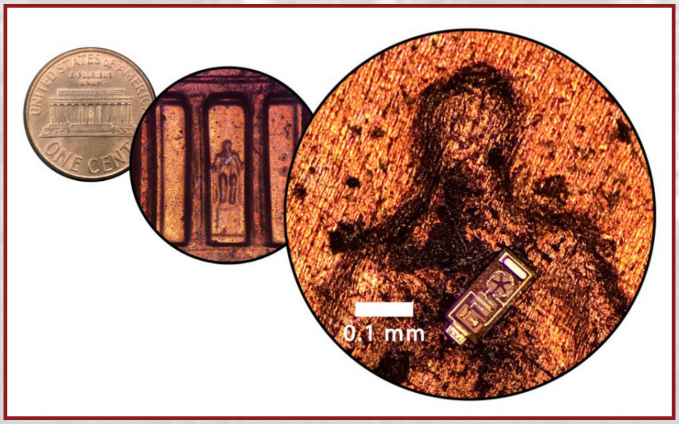


Figure 2: A microscopic optical wireless integrated circuit, or OWiC, created by Alejandro Cortese, M.S. '14, Ph.D. '19, may one day carry identification codes that could be used in anticounterfeiting applications, such as product authentication. Provided.

The allure of starting his own business also appealed to alumnus Alejandro Cortese, M.S. '14, Ph.D. '19. His company, OWiC Technologies, is an early-stage startup performing initial prototyping of its optical wireless integrated circuit, or OWiC.

"I always knew I wanted to build technologies that could be genuinely useful for a large group of people," he said. "I'm interested in technology that I can envision a lot of positive applications for in my lifetime. For me, entrepreneurship made a lot of sense."

The company is working to outfit its microscopic circuits to carry ID codes which, when a light is shone on them, would "blink out" the code; the object containing the circuit could then be uniquely identified. The technology has implications for anticounterfeiting applications, such as product authentication.

Cortese has been working on his circuits in the Cornell NanoScale Science and Technology Facility.

"It's a magical facility," he said. "You can build things there that would be impossible to build in 99% of universities in the U.S. — things that seem impossible until you're looking at them through a scanning electron microscope."

The company conducted 100 customer interviews this summer through the I-Corps Teams program, to refine the potential applications of its tech. Since its founding in November 2019, OWiC Technologies has also already patented its circuits through CTL; received a $225,000 NSF Small Business Innovation Research award; won this year's BenDaniel Venture Challenge, part of Big Red Ventures, Cornell's student-run venture capital fund; joined the Praxis Center; and is being mentored through Launch NY.

"There are a ton of startups coming out of Cornell and its commercialization culture is getting better and better," Cortese said. "It would be very hard to find another concentration of entrepreneurship resources like this in one place."

Alice Li, CTL executive director, agrees.

"With growing support of new ventures in the ecosystem, we have seen an increase in the number of Cornell inventions used as the founding technologies for startups, which account for roughly half of the exclusive licenses these days," she said. "With better understanding of market needs through programs such as Upstate New York I-Corps and Commercialization Fellowships, and support from incubators such as the Praxis Center and Rev: Ithaca Startup Works, student and faculty entrepreneurs are much better prepared for their endeavors with higher success rates for fundraising and product development."

Cornell's entrepreneurship hub has grown substantially over the last decade. Faculty, alumni and any entrepreneur looking to operate in New York's Southern Tier region can find plenty of opportunities to strengthen their business using Cornell resources.

"Learning how many entrepreneurial resources Cornell offers and how interconnected they are has been really eye-opening," Hickman said. "It's clear that the university wants entrepreneurship to happen and it's a really good time to get in because they want you to succeed."

Graphene Sensors Find Subtleties in Magnetic Fields

By David Nutt
August 20, 2020
Cornell Chronicle

As with actors and opera singers, when measuring magnetic fields it helps to have range. Cornell researchers used an ultrathin graphene "sandwich" to create a tiny magnetic field sensor that can operate over a greater temperature range than previous sensors, while also detecting miniscule changes in magnetic fields that might otherwise get lost within a larger magnetic background.

The group's paper, "Magnetic Field Detection Limits for Ultraclean Graphene Hall Sensors," published August 20 in Nature Communications. The team was led by Katja Nowack, assistant professor of physics and the paper's senior author.

Nowack's lab specializes in using scanning probes to conduct magnetic imaging. One of their go-to probes is the superconducting quantum interference device, or SQUID, which works well at low temperatures and in small magnetic fields.

"We wanted to expand the range of parameters that we can explore by using this other type of sensor, which is the Hall-effect sensor," said doctoral student Brian Schaefer, the paper's lead author. "It can work at any temperature, and we've shown it can work up to high magnetic fields as well. Hall sensors have been used at high magnetic fields before, but they're usually not able to detect small magnetic field changes on top of that magnetic field."

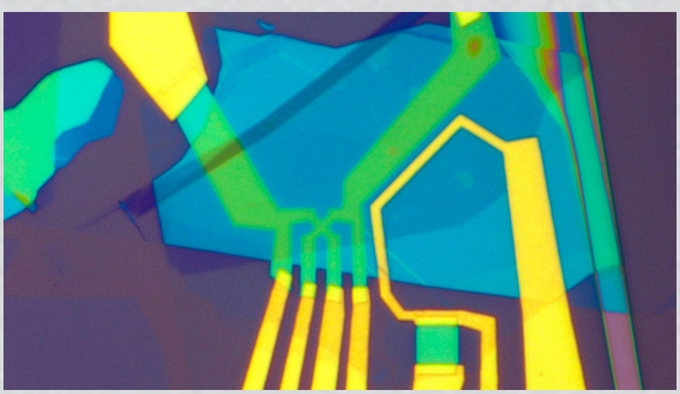


Figure 1: The Nowack Group created this µm-scale Hall-effect sensor by sandwiching graphene between sheets of hexagonal BN, resulting in a device that operates over a greater temperature range than previous Hall sensors. Provided.

The Hall effect is a well-known phenomenon in condensed matter physics. When a current flows through a sample, it is bent by a magnetic field, creating a voltage across both sides of the sample that is proportional to the magnetic field. Hall-effect sensors are used in a variety of technologies, from cellphones to robotics to anti-lock brakes. The devices are generally built out of conventional semi-conductors like Si and GaAs. Nowack's group decided to try a more novel approach.

The last decade has seen a boom in uses of graphene sheets — single layers of carbon atoms, arranged in a honeycomb lattice. But graphene devices often fall short of those made from other semiconductors when the graphene sheet is placed directly on a silicon substrate; the graphene sheet "crumples" on the nanoscale, inhibiting its electrical properties.

Nowack's group adopted a recently developed technique to unlock graphene's full potential — sandwiching it between sheets of hexagonal boron nitride (BN). Hexagonal BN has the same crystal structure as graphene but is an electrical insulator, which allows the graphene sheet to lie flat. Graphite layers in the sandwich structure act as electrostatic gates to tune the number of electrons that can conduct electricity in the graphene.

The sandwich technique was pioneered by co-author Lei Wang, a former postdoctoral researcher with the Kavli Institute at Cornell for Nanoscale Science. Wang also worked in the lab of co-senior author Paul McEuen, the John A. Newman Professor of Physical Science and co-chair of the Nanoscale Science and Microsystems Engineering (NEXT Nano) Task Force, part of the provost's Radical Collaboration initiative.

"The encapsulation with hexagonal BN and graphite makes the electronic system ultraclean," Nowack said. "That allows us to work at even lower electron densities than we could before, and that's favorable for boosting the Hall-effect signal we are interested in."

The researchers were able to create a micron-scale Hall sensor that functions as well as the best Hall sensors reported at room temperature while outperforming any other Hall sensor at temperatures as low as 4.2 kelvins. The graphene sensors are so precise they can pick out tiny fluctuations in a magnetic field against a background field that is larger by six orders of magnitude. Detecting such nuances is a challenge for even high-quality sensors because in a high magnetic field, the voltage response becomes nonlinear and therefore more difficult to parse. Nowack plans to incorporate the graphene Hall sensor into a scanning probe microscope for imaging quantum materials and exploring physical phenomena, such as how magnetic fields destroy unconventional superconductivity and the ways that current flows in special classes of materials, such as topological metals.

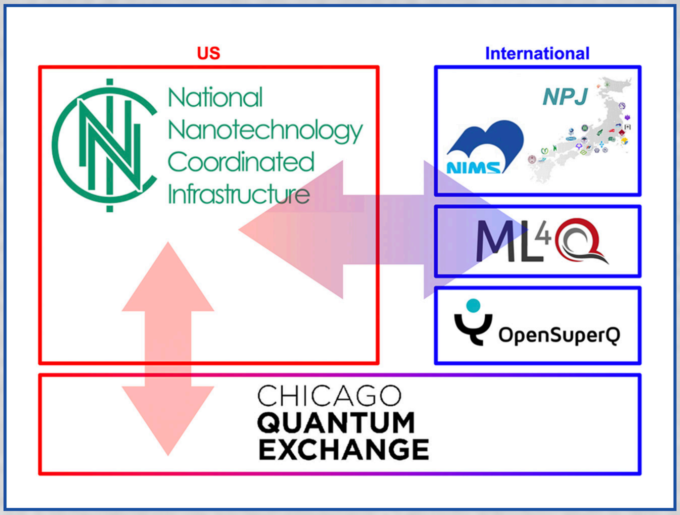
"Magnetic field sensors and Hall sensors are important parts of many real-world applications," Nowack said. "This work puts ultraclean graphene really on the map for being a superior material to build Hall probes out of. It wouldn't be really practical for some applications because it's hard to make these devices. But there are different pathways for materials growth and automated assembly of the sandwich that people are exploring. Once you have the graphene sandwich, you can put it anywhere and integrate it with existing technology."

Co-authors include doctoral student Alexander Jarjour, and researchers from the National Institute for Materials Science in Tsukuba, Japan. The research was supported by NSF and CCMR. The researchers made use of the CNF and the Columbia Nano Initiative.

Announcing ACCELNET:Global Quantum Leap

CNF is pleased to be part of a new program within NNCI, Global Quantum Leap, funded by NSF under a new program called ACCELNET. The ACCELNET program seeks to establish linkages between international research networks to form a "Network of Networks".

This effort is focused on international cooperation and collaboration in the rapidly growing area of materials and devices for quantum information science. For the US portion of this program, CNF is partnering with the University of Minnesota, Georgia Tech, and the University of Chicago, all part of the National Nanotechnology Coordinated Infrastructure. Our international partners are the Nanotechnology Platform Japan, ML4Q | Matter and Light for Quantum Computing (Germany), and OpenSuperQ (E.U.), as well as the domestic Chicago Quantum Exchange. Cornell's particular mission in this program is based on its long interactions with the Nanotechnology Platform Japan and the National Institute for Materials Science in Tsukuba, Japan.



Under this five-year program which began October 1, 2020, ACCELNET:Global Quantum Leap will engage with its partners to sponsor international student exchanges, workshops and conferences as well facilitate faculty to faculty research collaborations.

Due to COVID, initial activities will be virtual. Please look for activities to be announced in the near future.

Stretchable Sensor Gives Robots and VR a Human Touch

By David Nutt
November 12, 2020
Cornell Chronicle

It's not a stretch to say that stretchable sensors could change the way soft robots function and feel. In fact, they will be able to feel quite a lot.

Cornell researchers have created a fiber-optic sensor that combines low-cost LEDs and dyes, resulting in a stretchable "skin" that detects deformations such as pressure, bending and strain. This sensor could give soft robotic systems — and anyone using augmented reality technology — the ability to feel the same rich, tactile sensations that mammals depend on to navigate the natural world.

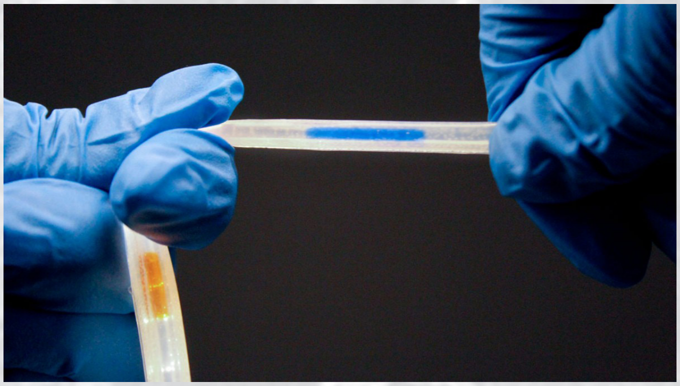


Figure 1: SLIMS sensors detect deformations such as pressure, bending and strain, and pinpoint their exact locations and magnitudes. Provided.

The researchers, led by Rob Shepherd, associate professor of mechanical and aerospace engineering in the College of Engineering, are working to commercialize the technology for physical therapy and sports medicine.

Their paper, "Stretchable Distributed Fiber-Optic Sensors," publishes November 13 in Science. The paper's co-lead authors are doctoral student Hedan Bai '16 and Shuo Li, Ph.D. '20.

The project builds upon an earlier stretchable sensor, created in Shepherd's Organic Robotics Lab in 2016, in which light was sent through an optical waveguide, and a photodiode detected changes in the beam's intensity to determine when the material was deformed. The lab has since developed a variety of similar sensory materials, such as optical lace and foams.

For the new project, Bai drew inspiration from silica-based distributed fiber-optic sensors, which detect minor wavelength shifts as a way to identify multiple properties, such as changes in humidity, temperature and strain. However, silica fibers aren't compatible with soft and stretchable electronics. Intelligent soft systems also present their own structural challenges.

"We know that soft matters can be deformed in a very complicated, combinational way, and there are a lot of deformations happening at the same time," Bai said. "We wanted a sensor that could decouple these."

Bai's solution was to make a stretchable lightguide for multimodal sensing (SLIMS). This long tube contains a pair of polyurethane elastomeric cores. One core is transparent; the other is filled with absorbing dyes at multiple locations and connects to an LED. Each core is coupled with a red-green-blue sensor chip to register geometric changes in the optical path of light.

The dual-core design increases the number of outputs by which the sensor can detect a range of deformations — pressure, bending or elongation — by lighting up the dyes, which act as spatial encoders. Bai paired that technology with a mathematical model that can decouple, or separate, the different deformations and pinpoint their exact locations and magnitudes.

Whereas distributed fiber-optic sensors require high-resolution detection equipment, SLIMS sensors can operate with small optoelectronics that have lower resolution. That makes them less expensive, simpler to manufacture and more easily integrated into small systems. For example, a SLIMS sensor could be incorporated into a robot's hand to detect slippage.

The technology is also wearable. The researchers designed a 3D-printed glove with

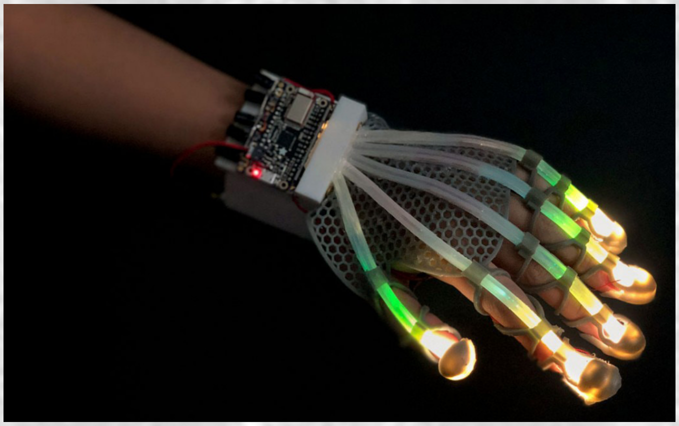


Figure 2: Cornell researchers in the Organic Robotics Lab designed a 3D-printed glove lined with stretchable fiber-optic sensors that use light to detect a range of deformations in real time. Provided.

a SLIMS sensor running along each finger. The glove is powered by a lithium battery and equipped with Bluetooth so it can transmit data to basic software, which Bai designed, that reconstructs the glove's movements and deformations in real time.

"Right now, sensing is done mostly by vision," Shepherd said. "We hardly ever measure touch in real life. This skin is a way to allow ourselves and machines to measure tactile interactions in a way that we now currently use the cameras in our phones. It's using vision to measure touch. This is the most convenient and practical way to do it in a scalable way."

Bai explored SLIMS' commercial potential through the National Science Foundation Innovation Corps (I-Corps) program. She and Shepherd are working with Cornell's Center for Technology Licensing to patent the technology, with an eye toward applications in physical therapy and sports medicine. Both fields have leveraged motion-tracking technology but until now have lacked the ability to capture force interactions.

The researchers are also looking into the ways SLIMS sensors can boost virtual and augmented reality experiences.

"VR and AR immersion is based on motion capture. Touch is barely there at all," Shepherd said. "Let's say you want to have an augmented reality simulation that teaches you how to fix your car or change a tire. If you had a glove or something that could measure pressure, as well as motion, that augmented reality visualization could say, 'Turn and then stop, so you don't overtighten your lug nuts.' There's nothing out there that does that right now, but this is an avenue to do it."

Co-authors include Clifford Pollock, the Ilda and Charles Lee Professor of Engineering; doctoral student Jose Barreiros, M.S. '20, M.Eng. '17; and Yaqi Tu, M.S. '18.

The research was supported by the NSF; the Air Force Office of Scientific Research; Cornell Technology Acceleration and Maturation; the U.S. Department of Agriculture's National Institute of Food and Agriculture; and the Office of Naval Research.

The researchers made use of the Cornell NanoScale Science and Technology Facility and Cornell Center for Materials Research, both of which are supported by the NSF.

Video Online: Cornell researchers led by Rob Shepherd, associate professor of mechanical and aerospace engineering in the College of Engineering, have created a fiber-optic sensor that combines low-cost LEDs and dyes, resulting in a stretchable "skin" that detects deformations such as pressure, bending and strain. John Munson/Cornell University.

https://news.cornell.edu/stories/2020/11/stretchable-sensor-gives-robots-and-vr-human-touch

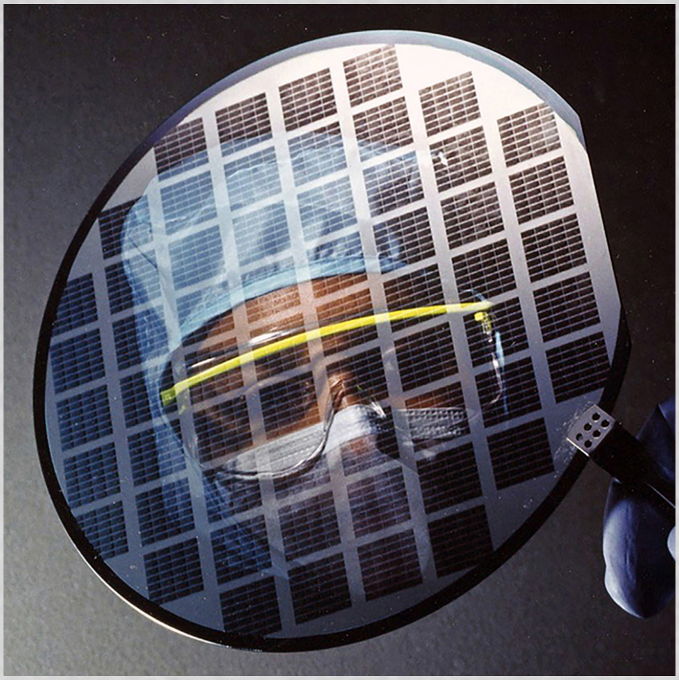


Photo from CNF Archives, Charles Harrington Photography

Rewritable Magnetic Patterning: Think Tiny Etch A Sketch

By Syl Kacapyr
June 2, 2020
Cornell Chronicle

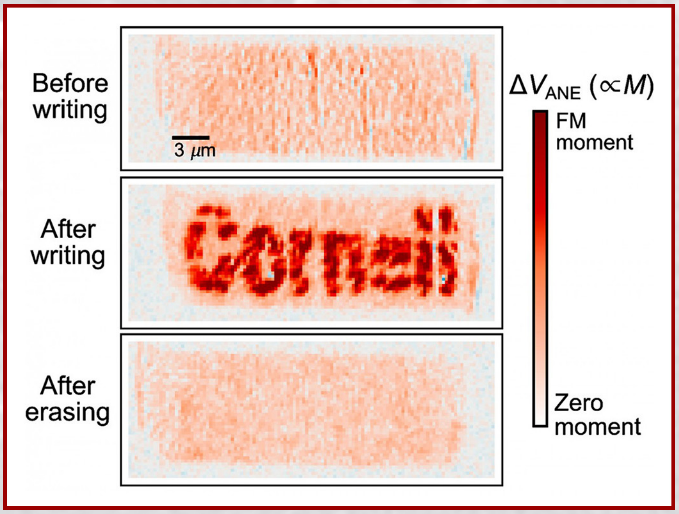


Figure 1: The magnetic strength of a sample of iron rhodium is shown before writing, after writing, and after erasing, with the darker shades of red representing stronger magnetism. Isaiah Gray/Provided.

Cornell researchers have demonstrated a technique for writing, erasing and rewriting microscopic magnetic patterns onto a material – a concept tested by writing and erasing "Cornell" eight times onto the sample. This achievement will aid in the research of magnetism for ultrafast computer memory and other applications.

The rewritable magnetic patterning, enabled using a combination of scientific approaches, is reported in "Local Photothermal Control of Phase Transitions for On-Demand Room-Temperature Rewritable Magnetic Patterning," published April 21 in Advanced Materials.

The research team sought to create a material that could simultaneously possess ferromagnetic and antiferromagnetic properties at room temperature, meaning the material could have different magnetic strengths depending on the configuration of its electrons. They worked with iron rhodium, a metal alloy that remains antiferromagnetic – no net magnetization – until it reaches a high enough temperature, when its electrons switch into a ferromagnetic phase, giving the material relatively strong magnetism.

Antonio Mei, a postdoctoral researcher in the group of Darrell Schlom, the Herbert Fisk Johnson Professor of Industrial Chemistry in the Department of Materials Science and Engineering, used molecular-beam epitaxy to stack atomically thin layers of iron rhodium in a strategic arrangement, so that its ferromagnetic and antiferromagnetic phases both became stable at room temperature.

"The sample is equally happy having either strong magnetism or no net magnetism," Schlom said, "like a teeter-totter that is equally stable resting on the ground with its left seat or its right seat."

Magnetic patterns are traditionally formed on materials by first configuring a ferromagnetic material's electrons all in one direction and then configuring selected regions in the opposite direction. But with iron rhodium, the material can begin as antiferromagnetic, and regions can be heated to be ferromagnetic, with those regions remaining strongly magnetic at room temperature.

"It's like an Etch A Sketch," said Schlom, referring to a toy in which images can be drawn onto a screen and erased, "where slight heating does the writing and if you wish, slight cooling does the erasing."

The research team produced a sample of iron rhodium that could exist in either its ferromagnetic or antimagnetic state at room temperature, but to prove the material could be easily transformed and patterned into a chosen state, the sample was brought to the lab of Greg Fuchs, associate professor of applied and engineering physics, who co-led the research with doctoral student Isaiah Gray.

"Based on ideas we had developed looking at iron rhodium in the past," Fuchs said, "it became clear to everyone that we could do something really interesting with this."

In 2015 Fuchs pioneered a technique known as magneto-thermal microscopy, in which a laser is used to study a material's magnetic properties. By heating a microscopic area of a material, the resulting electric voltage can be used to understand the orientation of electrons.

Using a near-infrared laser with a focus of six-tenths of a micron – its diameter 10 times smaller than a red blood cell – Fuchs and his group were able to change the ordering of the electrons within the iron rhodium. Anywhere the laser touched, that microscopic portion of the sample changed from antiferromagnetic to ferromagnetic.

"So if we want to make an image or pattern, we just have to pixelate it by using short laser pulses," said Fuchs, who developed a proof of concept by magnetically inscribing the word "Cornell" into the sample. Each letter was approximately three microns wide; the average human hair is 75 microns in diameter.

Finally, the researchers dipped the iron rhodium into liquid nitrogen to cool it back into its antiferromagnetic phase, erasing the magnetic "Cornell" pattern. They were then able to write a new pattern into the same sample and repeated the process eight times.

"There was no apparent wearing on the sample and there is no reason to believe it wouldn't last for more cycles," Fuchs said. "It's really a scientific tool now, because you can study magnetism in a configuration, experiment with it, then erase and rewrite."

The researchers said the magnetic patterning will be useful in a wide range of laboratory settings, including in the field of magnonics, in which scientists study magnetic devices, sometimes requiring days to grow and pattern a single sample.

"Our technique allows us to realize a magnetic structure in a couple of minutes, then we can study it – which might also be just a couple of minutes – then erase it and do something different," Fuchs said. "It's going to provide a lot of interesting opportunities to do magnetism research because it's just a very fast way to change what you have."

Co-authors include: Dan Ralph, the F.R. Newman Professor of Physics in the College of Arts and Sciences; graduate student Yongjian Tang; research support specialist Don Werder; Jason Bartell, Ph.D. '18, now a senior optical physicist at Draper; and Jürgen Schubert of the Forschungszentrum Jülich in Germany.

The research was supported by the Semiconductor Research Corporation, the National Science Foundation, the Cornell Center for Materials Research, the Cornell NanoScale Facility, and the Air Force Office of Scientific Research.

Collaboration Sparks New Model for Ceramic Conductivity

By David Nutt
October 21, 2020
Cornell Chronicle

As insulators, metal oxides — also known as ceramics — may not seem like obvious candidates for electrical conductivity. While electrons zip back and forth in regular metals, their movement in ceramic materials is sluggish and difficult to detect.

But ceramics do contain a large range of conductivities. This behavior was laid out in 1961 in the "small polaron hopping model," which described the movement of polarons – essentially electrons coupled to a lattice distortion – from one end of a material to the other.

An interdisciplinary collaboration led by Richard Robinson, associate professor of materials science and engineering in the College of Engineering, has shown just how outdated and inaccurate that model is, especially regarding complex oxide systems. By updating the model to reflect different pathways for conduction, the team hopes its work will help researchers who are custom-tailoring the properties of metal oxides in technologies such as lithium ion batteries, fuel cells and electrocatalysis.

Their paper, “Breakdown of the Small-Polaron Hopping Model in Higher-Order Spinels,” published Oct. 21 in Advanced Materials. The lead author is doctoral student Anuj Bhargava.

“This is the most commonly-used formula in the field, but it hadn’t been touched in 60 years. That’s a big deal because, nowadays, metal oxides are used in many applications where the performance is directly impacted by the conductivity – for example, in energy systems like electrical energy storage and generation, electrocatalysis, and in new-generation materials,” Robinson said. “Many people are putting a great amount of experimental effort into oxides right now, but they haven’t carefully examined how the charge carriers move in the material, and how the composition influences that conductivity.

“If we understood how electrons are conducted and we could customize the composition to have the highest conductivity, we could optimize the energy efficiency of a lot of materials out there,” he said.

To get a detailed look at the way electrons move in metal oxides and how their occupation sites can affect the material’s conductivity, Robinson turned to Darrell Schlom, the Herbert Fisk Johnson Professor of Industrial Chemistry. Schlom and his team used PARADIM and CNF resources to grow and characterize thin crystalline films of manganese-doped iron oxide ($MnxFe_{3-x}O_4$).

Robinson’s group then used the Cornell High Energy Synchrotron Source (CHESS) to determine the atomic locations and the charge state of the positively charged ions, called cations, and measured how the material’s conductivity changes at different temperatures.

They brought the material to Lena Kourkoutis, associate professor in applied and engineering physics, who used advanced electron microscopy to get an atomically precise view of the crystal’s substrate and compositional gradients, and confirmed the team’s findings.

Figure 1: An interdisciplinary collaboration led by Richard Robinson updated the “small polaron hopping model” to reflect different pathways for conduction in ceramics. Their work will help researchers who are custom-tailoring the properties of metal oxides in technologies such as lithium ion batteries, fuel cells and electrocatalysis. Provided.

Lastly, Robinson’s team consulted researchers at Technion – Israel Institute of Technology, who used computational methods to explain how polarons hop differently in materials based on the energy barriers and oxidation states. Their results uncovered the existence of large energetic barriers associated with “switching” conduction paths between the two different cations, and this provided the crucial final piece that was necessary to put a new formula together.

“This new finding gives us insight into something that’s been overlooked. Instead of the Edisonian, trial-and-error approach of just making and testing a bunch of new materials, we can now take a more systematic approach to figuring out why the materials behave differently, especially on this really important level, which is electronic conductivity,” Robinson said. “The important processes in energy materials involve conductivity, electrons coming in and out of the material. So for any application with metal oxides, conductivity is important.”

Co-authors include postdoctoral researcher Hanjong Paik and doctoral students Jiaxin Sun and Michelle Smeaton. The research was supported by the NSF. In addition to PARADIM, CHESS and CNF, the researchers made use of CCMR, which is supported by the NSF’s Materials Research Science and Engineering Center program.

Superfluid Shows More Surprising Phenomena

By David Nutt
September 24, 2020
Cornell Chronicle

The superfluid helium-3 has many notable qualities. With its low mass and small atomic size, it remains in a liquid state and when it transforms to the superfluid state, flowing without resistance — down to absolute zero, or minus 459.67°F — it is a pure system, without any disorder. And it is full of surprises.

A Cornell-led collaboration, which set out to study the superfluid's thermal conduction, instead discovered a series of unexpected phenomena that reaffirm just how dynamic and unconventional the material is. The group's paper, "Thermal Transport of Helium-3 in a Strongly Confining Channel," published September 24 in Nature Communications.

The project was led by Jeevak Parpia, M.S. '77, Ph.D. '79, professor of physics in the College of Arts and Sciences, and his research group at Cornell, working with John Saunders, professor of physics at Royal Holloway, University of London.

Theoretical support was provided by Erich Mueller, professor of physics (A&S), and Dietrich Einzel at the Walther Meissner Institut in Germany. The paper's lead author was former postdoctoral researcher Dmytro Lotnyk.

Helium-3 is a rare isotope composed of two protons and a single neutron. Its superfluid state was first discovered by Cornell physicists David M. Lee, Robert C. Richardson and Douglas Osheroff, M.S. '71, Ph.D. '73, in 1972. The discovery was a breakthrough in low-temperature physics and earned the researchers the 1996 Nobel Prize in physics.

For several decades, Parpia has been exploring the superfluidity of helium-3; in recent years he has focused on the effects that result from confining helium-3 in microfabricated devices. By confining the liquid in a constricted space and cooling it down to 2 mK, the close contact with a surface material causes the thin layer of the superfluid to behave differently from how it does in bulk chambers.

"We are finding surprising effects when we confine helium," Parpia said. "Thermal conductivity is a very ordinary property of a system, but the thermal conductivity in helium-3 has not been measured for more than 40 years. In a sense, it's a little difficult to measure. The new phases that should be expressed in confinement could lead to all kinds of exotic transport."

Working with the Cornell NanoScale Facility (CNF), the researchers fabricated a silicon device 1.1 µm high and 3 µm wide, with a 100 µm-long channel that separated two chambers, all capped with a polished glass lid. They flowed the helium-3 into the channel and planned to measure the thermal resistance — essentially as a dry run for a more in-depth study that would examine the material's theoretically predicted phenomena. Those include the flow of heat along the edges of the device, and the way that imposing a temperature change in a longitudinal direction may also produce a lateral change in the system.

"We wanted to take the baby steps to this measurement," Parpia said. "So the experiment was more or less a warm-up."

However, when the researchers applied a heat pulse to one end of the device, increasing the flow of energy in the superfluid, they detected a response almost immediately on the other side. That's because special excitations, which are an analogue of the quasiparticles found in bulk helium-3, were dislodged from the superfluid's surface and traveled the entire length of the channel without interacting with ordinary excitations or diffusing their energy into the liquid.

"I think it's amazing that these excitations can travel such long distances without dying or being annihilated," Parpia said. "That's one of the most surprising things. It just shouldn't be happening. They're so exotic, they're not recognized by anything else.

"In the end," he said, "it's really a startling confirmation that there's something very interesting concerned with these excitations."

Parpia and his collaborators hypothesize that the flow of helium-3 and the resulting compression peels off these excitations, and runs them into the thermometer, where they deposit their energy.

The researchers now plan to microfabricate a device that can measure localized temperatures in the superfluid with greater precision.

"Ideally, we'd want to have 1,000 times more sensitive techniques to see all the phenomena," Parpia said. "And we need to make much smaller devices to do that sensing, whereas what we're doing is quite coarse. It's basically a very macroscopic measurement."

In addition to Mueller, co-authors included former postdoctoral researchers Anna Eyal and Abhilash Sebastian; Nik Zhelev, M.S. '13, Ph.D. '16; Michael Terilli '19; SUNY Geneseo student John Wilson, who participated through the Cornell Center for Materials Research's Research Experience for Undergraduates program; and research support specialist Eric Smith.

The research was supported by the National Science Foundation; the Engineering and Physical Sciences Research Council in the United Kingdom; and the CCMR, which is supported by the NSF's Materials Research Science and Engineering Center program.

CNF, part of the National Nanotechnology Coordinated Infrastructure network, is supported by the NSF and by the Empire State Development Corp.

The CNF hosted its first ever virtual cleanroom tour for students, working with the director and TAs of Cornell's AEP 1200 course, Introduction to Nanoscience and Nanoengineering. The students enjoyed watching a cleanroom tour created and narrated by Tom Pennell, and schmoozing CNF staff afterwards (top row; Jeremy Clark, Melanie-Claire Mallison, Xinwei Wu, and Amrita Banerjee. COVID-19 has certainly changed the way we do things around here, but the CNF staff continues to be dedicated to the education and involvement of the next generation of nano-researchers!

The CNF staff changes continue as we say “goodbye” to Denise Budinger and Kathy Springer. Denise was with the CNF for 26 years and Kathy was with us for 17. Letting go is hard! But we wish them both the best in their retirement.

Denise’s favorite CNF photograph, by Don Tennant.

Kathy stopped by to pick up her farewell swag! Photo by Ron Olson

New Capabilities & Tools

Virtual CAD Room Service

CNF Computing is announcing the availability of the CNF Virtual CAD Room service. Virtual CAD Room is a shared set of Windows 10 computers similarly set up to the Windows workstations in the physical CAD Room. Most software available on the CAD Room Windows workstations is also available on the Virtual CAD Room service.

Virtual CAD Room is a subscription-based service. Initial pricing is $30 / user / month - no sharing of user accounts per Cornell IT policy. CNF reserves the right to adjust pricing with notice. Subscriptions will auto renew each month unless cancelled.

To get started, please visit the Virtual CAD Rm web page at computing.cnf.cornell.edu - HowTos - Remote Access.

Thank you!

High Density PECVD

CNF has received a High Density Plasma Chemical Vapor Deposition (HDP-CVD) system from Plasma-Therm and is anticipating installation to be completed later this year. HDP-CVD is a special form of PECVD that employs an Inductively Coupled Plasma (ICP) source to generate a higher plasma density than that of a standard parallel plate PECVD system. This system will be capable of high density SiO_2, Si_3N_4, a-SiC, and doped a-Si films at low temperatures, ranging from 80°C to 175°C. These materials will be exceptionally smooth, dense, and conformal; perfect for applications where ALD or PECVD may not be ideal due to rate or temperature limitations. This new system will be replacing the GSI PECVD system and further supports efforts in 2D Materials and Heterointegration, as well as Photonics, Biotech, MEMS and CMOS projects.

Contact Jeremy Clark for more information, clark@cnf.cornell.edu

Atomic Layer Etching (ALE) Comes to CNF

CNF is pleased to announce the addition of atomic layer etching (ALE) to its extensive etch capabilities. This acquisition is made possible by the creation of a joint development agreement (JDA) between CNF and etch equipment manufacturer, Plasma-Therm LLC of St. Petersburg, Florida. The goal of the JDA is to advance atomic layer etching in nanoscale fabrication. Plasma-Therm will provide state-of-the-art ALE hardware and control software, while CNF will provide process and device development on a wide range of materials to serve the broad CNF research community.

ALE is derived from its counterpart atomic layer deposition (ALD) in that it is composed of a series of self-limiting steps, essentially etching one atomic layer per cycle, providing the precise control and low damage etching required for the fabrication of nanoscale devices. ALE ensures that CNF can meet the many challenges posed by the increasingly complex fabrication requirements of nanoscale photonics, advanced III-V devices, 2D electronics, magnetic and quantum-based devices.

The ALE system, based on Plasma-Therm's APEX SLR platform, will be equipped with advanced features such as pulsed inductively coupled plasma (ICP) generation, pulsed biasing, and low-frequency bias options. It can handle substrates up to 200 mm diameter and has a 12-channel gas pod with four ALE valves. The gas repertoire will include chlorine, bromine, and hydrofluorocarbon gases along with a number of additive gases to make the tool widely versatile. Plasma diagnostics include optical emission spectroscopy (OES) and a Langmuir probe which will provide elemental composition of the plasma and flux/energy distributions of the plasma respectively.

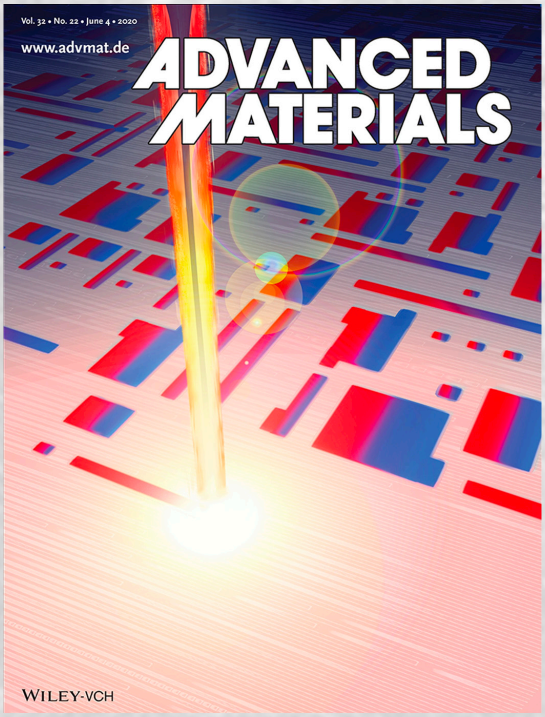
Etching will be monitored *in-situ* by a Woollam M2000 ellipsometer.

While the initial research effort will concentrate on ALE of more established materials such as Si, GaAs, and GaN, it will then progress to ALE of AlN, SiO_2, and Si_3N_4. Novel gas chemistries including $C_3H_3F_3$ and CH_3F will be used to etch SiO_2 and Si_3N_4 respectively. ALE will likewise be applied to ALD deposited high-k dielectrics such as HfO_2, Ta_2O_5, and others. The research effort will then evolve to include many two-dimensional (2D) materials such as MoS_2, WSe_2, graphene and others.

As CNF continues to progress through the evolution of nanoscale devices, the need for more effective methods of pattern transfer is more critical especially at single digit nanometer dimensions with high aspect ratio features. As devices shrink in size, the etched surface becomes a significant fraction of the total device area, and the etch surface must be free of any plasma induced damage for optimum device performance. ALE provides a direct solution by operating in a defined low energy range where only the chemically modified surface formed by precursor adsorption and reaction is removed without the creation of defects at the interface. Other benefits of ALE include the ability to etch materials with a resulting atomically smooth and pristine surface, with high selectivity to an underlying layer.

The attributes of ALE and the great versatility of this Plasma-Therm ALE system will ensure that CNF can meet the challenging demands of nanofabrication in many disciplines for many years to come.

For further information on ALE, please contact research staff member, Vince Genova (genova@cnf.cornell.edu).



Hi Melanie-Claire,

My former student Isaiah Gray (who graduated this summer) along with a postdoc Antonio Mei from Darrell Schlom's group got the inside cover of Advanced Materials for this work: https://onlinelibrary.wiley.com/doi/abs/10.1002/adma.202001080 (Published 02 June) and covered by the Cornell Chronicle (page 22).

Best regards, Greg Fuchs

Meet Zhiting Tian, New Associate Editor for the Journal of Applied Physics

Dr. Zhiting Tian is an associate professor, Eugene A. Leinroth Sesquicentennial Faculty Fellow in the Sibley School of Mechanical and Aerospace Engineering at Cornell University and a CNF principal investigator. Dr. Tian obtained her Ph.D. in Mechanical Engineering at MIT in 2014, M.S. in Mechanical Engineering at Binghamton University in 2009, and B.E. in Engineering Physics at Tsinghua University in 2007.

Dr. Tian's research areas include tunable thermal materials, thermoelectric energy conversion. thermal management of electronics, thermal transport in soft matter, and synchrotron x-ray measurements.

As part of the NNCI celebration of National Nanotechnology Day on October 9th, the CNF tech staff threw the First Ever CNF Cleanroom Fashion Show and it went off without a hitch! No one fell off their stilettos or suffered a wardrobe malfunction. Way to go, guys! Watch for yourself at https://www.youtube.com/watch?v=R40MXD5FStA (Left to right; Jeremy Clark, George McMurdy, and Kelly Baker. Inset: Narrator Tom Pennell. Screen captures by Melanie-Claire Mallison)

The Cornell NanoScale Science & Technology Facility (CNF) has been serving the science and engineering community since 1977. The CNF is supported by the National Science Foundation, the New York State Office of Science, Technology & Academic Research (NYSTAR), Cornell University, Industry, and our Users.

To be added to our CNF NanoMeter mailing list or to correct a mailing address, please send your request via email to: information@cnf.cornell.edu. You will also find the NanoMeter in PDF on our web site at: http://www.cnf.cornell.edu