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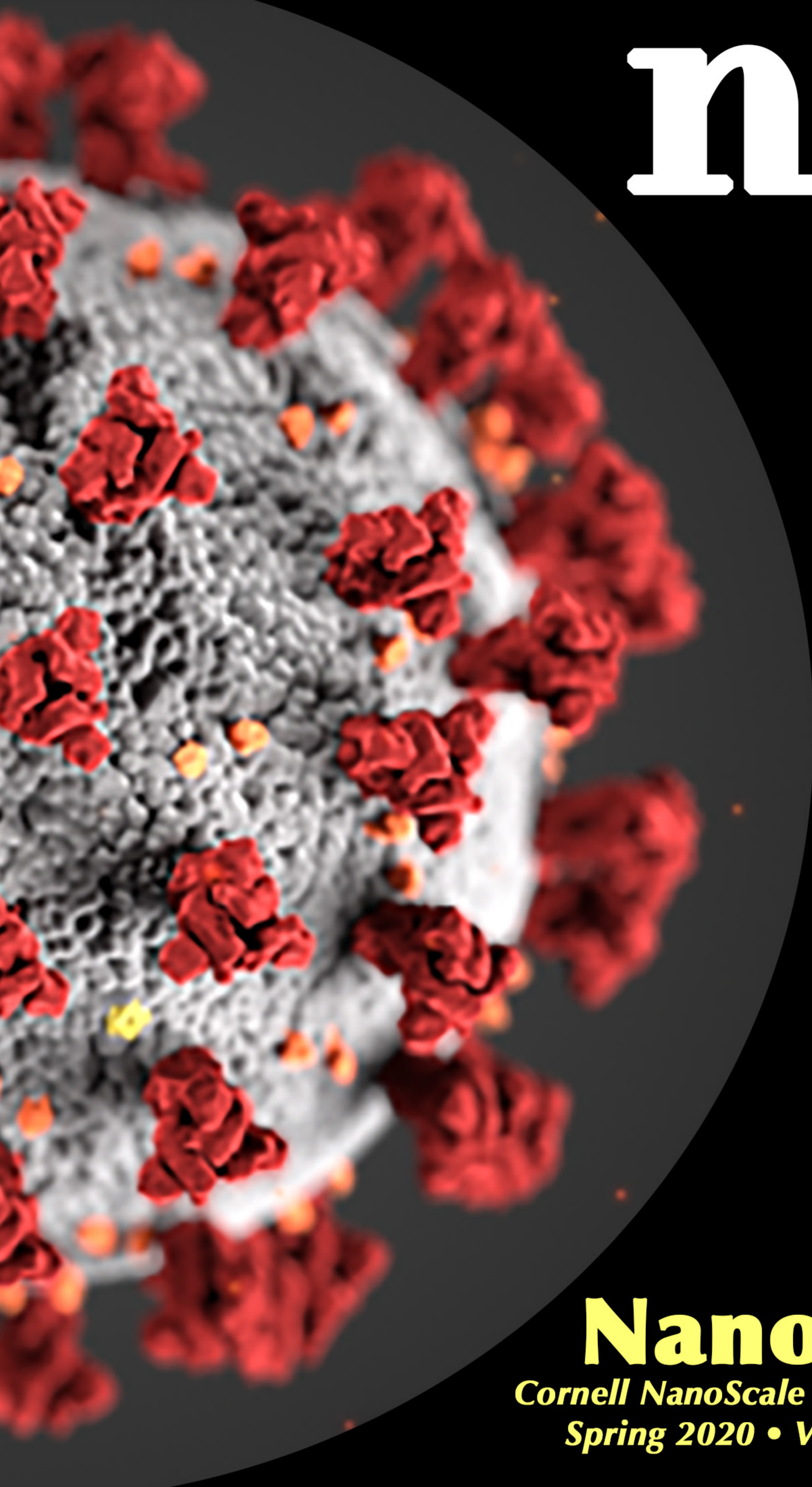

NanoMeter

Cornell NanoScale Facility Newsletter
Spring 2020 • Volume 29 • Issue 1

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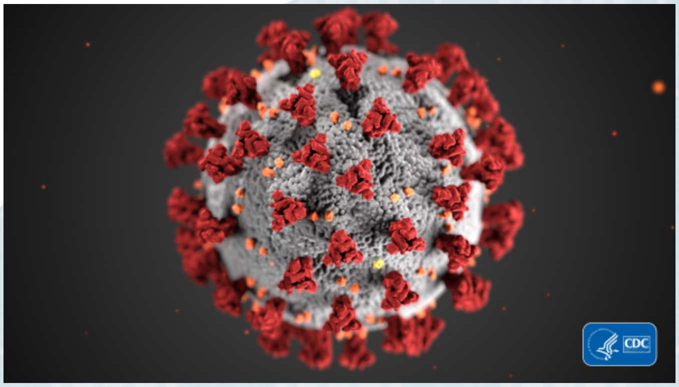


Cover: This illustration, created at the Centers for Disease Control and Prevention (CDC), reveals ultrastructural morphology exhibited by coronaviruses. Content Providers(s): CDC/ Alissa Eckert, MS

COVID-19 & CNF UPDATE Friday, May 22, 2020

As many of you know, Western New York, Central New York, North County, Finger Lakes, Southern Tier, and Mohawk Valley Regions have met all seven of Governor Cuomo's metrics required to begin phase one of the state's regional phased reopening plans.

The CNF is looking forward to reopening once given the go ahead by Cornell University. Although we don't have a date yet we hope it will be in a month or less.

When the lab reopens and processes and equipment are verified and validated, the CNF staff will initially be coordinating an effort to perform as many remote operations as they can (within the constraints of the defined work, priority, feasibility, efficiency, optimization, and clear expectations).

During this first phase of reopening, projects will be coordinated directly with staff and performed as schedules permit. Please contact Michael Skvarla and Chris Alpha (skvarla@cnf.cornell.edu, alpha@cnf.cornell.edu) to discuss your remote project in advance of the CNF opening.

Like every other segment of society, we are coping with the constraints on us, but have committed to reopening for research as soon as safety permits.

https://cnf.cornell.edu/covid-19

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.

Welcome to the Spring NanoMeter
Directors' Column

To say the beginning of 2020 has been eventful is an understatement! Following directives received from Cornell University in response to the COVID-19 pandemic, the CNF cleanroom, office, 2nd floor labs, and CAD room closed their doors on March 17th. The CNF is continuously evaluating the situation and working closely with the University to determine a reopening date in the near future while keeping the safety of the staff and users as the top priority.

Despite the physical closure of the CNF in March the staff quickly adjusted to the new "normal" presented by working from home. The team utilized the early part of the year to update processes and receive and install new equipment in order to enhance the CNF's five, key strategic areas of growth (Nanoscience in the Life Sciences, 2D Materials, Quantum Information Systems, Heterointegrated Systems, and 3D Fabrication and Characterization).

The cleanroom was improved with the installation of the C&D Semiconductor custom designed lift off tool. With the initial liftoff process verification and validation complete, the cleanroom now offers this enhanced process capability to Users. The NanoScribe Photonic Professional GT2 (installed), Plasma-Therm Atomic Layer Etching system (currently in the process of being installed), the Woollam M-2000 *in situ* and RC2 tabletop Spectroscopic Ellipsometers (ready to be installed / delivered in March), and a Yes EcoClean System Plasma stripper (also ready to be installed), are highlighted in articles in this issue.

CNF is also excited to announce an additional AJA International Orion-5 load locked sputter dep system; currently in the installation phase. The new AJA has three two-inch guns and is expandable up to five guns. The tool contains two DC power supplies enabling co-sputtering of metals and the ability to deposit magnetic materials. This tool will offer gold sputtering capability, which has been of great interest to the CNF community. The tool should be available in Summer of 2020. Along with other tools in the CNF, this supports the facility's ongoing efforts in 2D materials and Quantum Information Systems.

CNF has purchased an HDP-CVD system from Plasma-Therm and is anticipating delivery and installation later this year. This system will be capable of high density SiO_2, Si_3N_4, α-SiC, and α-Si films at low temperatures, ranging from 80°C to 175°C. These materials will be exceptionally smooth and conformal; perfect for a number of use-cases where ALD or PECVD may not be possible due to deposition rate or temperature limitations. This new system will be replacing the GSI PECVD system and further supports efforts in 2D materials and Heterointegration, and will have impact on Photonics, Biotech, MEMS and CMOS projects.

Finally, the CNF is waiting for results from the MRI proposal submitted to the National Science Foundation for acquisition of a Heidelberg MLR 150 Maskless Aligner. Procurement of this tool will greatly advance the CNF's lithography capabilities.

Vince Genova and Tom Pennell have been working closely with members of the User Community to enhance CNF's capability in aluminum nitride (AlN) sputter deposition and etching. Preliminary findings show significant variation in crystal structure dependent on the surface where AlN is deposited. This variation in crystal structure across the wafer translates to variation in etch rate in a chlorine based ICP etch. This effect can be minimized by modifying the underlying oxide and metal deposition processes to obtain films more suitable for subsequent AlN crystal growth. Results from this work will be published in the Summer of 2020. The CNF staff have also been working diligently to develop new ozone based ALD processes detailed in this issue.

Cadence software and training covering an array of capabilities is available to all academic Users. Training topics include layout design, SKILL programming for layout automation, circuit simulation and modeling, VHDL and Verilog design, and verification, as well as IC packaging and PCB design. Please reach out to Jeremy Clark or Lynn Rathbun for access.

CNF's collaboration with SEMI was established to speed technology progress and problem-solving in microelectronics manufacturing; driving new efficiencies through the use of machine learning (ML) and artificial intelligence (AI). Focusing on two critical processes — lithography and plasma etch — much progress has been realized, including automating data collection from process and metrology tools, developing a data pipeline to get the data to ML and AI algorithms, as well as optimization of the algorithms to predict and ultimately improve process results. An initiative has begun to create a data formatting standard for machine learning.

CNF is a member of the National Nanotechnology Coordinated Infrastructure (NNCI) that provides researchers from academia, industry, and government open access to an exceptional facility with leading-edge fabrication, characterization tools, and expertise within many disciplines of nanoscale science, engineering and technology. The NNCI program is approaching its five-year renewal term. Extensive efforts have been dedicated to the renewal process for continued funding from the NNCI. A new proposal outlines some exciting expansion plans targeted at increasing the CNF's capabilities including: adding a new Associate Director, Prof. Claudia Fischbach-Teschl, partnering with both the Cornell Rapid Prototyping Lab and Institute for Biotechnology to create the Multiscale 3D Fabrication Facility (M3FF) and the 3D Visualization Facility (3VF), respectively. The proposal also highlights outreach activities like expanding 4-H interactions, an enhanced partnership with Morgan State University and a Veteran's Work Force Development Program with Corning Community College. The continued support from the National Science Foundation and membership in NNCI are vital components in the expansion of CNF's capabilities and ensuring CNF remains at the forefront of nanofabrication.

The CNF applied for the NYSTAR/ESD Matching Grant Program in February 2020 and welcomes support from New York State. It is estimated that past NYS investment played a critical role in approximately \$200 million/year of NYS economic activity as well as \$46 M/year in academic grants support and \$1.25 M/year in industry user fees. In addition, estimates reveal ~1.4 billion dollars of funding and revenue are being generated from startup companies that have launched from CNF. The capitalization value of companies launched from CNF is approximately \$3 billion.

CNF continues to work with NY CREATES to foster joint partnerships in order to establish nanotechnology workforce development programs and a New York State Nanofabrication Network. Coordinated efforts are aimed at increasing resources in cleanroom operation facilities at regional universities. Further focus is being directed towards assisting start-up companies as they move from ideation to early development and prototyping, to pilot and high-volume manufacturing.

Be sure to check out this issue for the latest status regarding the bi-annual short course offered by the CNF "Technology & Characterization at the Nanoscale" (CNF TCN) on the next page.

The entire CNF family extends best wishes and we all hope that you and your families are healthy. We look forward to welcoming our Users back to the CNF.

Below is a list of the remote software capabilities available to users. To get started, please contact Dave Botsch or Karlis Musa at computing@cnf.cornell.edu

- **AutoDesk**
- **Cadence**
- **CorelDRAW**
- **Coventor SEMulator3D**
- **GenISys Layout BEAMER**
- **GenISys Layout LAB**
- **GenISys ProSEM**
- **GenISys TRACER**
- **Java GDS Library (JetStream)**
- **JMP Pro Data Analysis Statistical Software**
- **L-Edit CAD Software**
- **LinkCAD pattern preparation software**
- **Litho Resources**
- **MATLAB**
- **Octave**

CNF TCN Updates

Bi-annually the Cornell NanoScale Facility (CNF) offers a short course on "Technology & Characterization at the Nanoscale" (CNF TCN). In January 2020, we had an outstanding number of attendees. Over 30 participants from various academic institutions and industry joined us for the in-house short course.

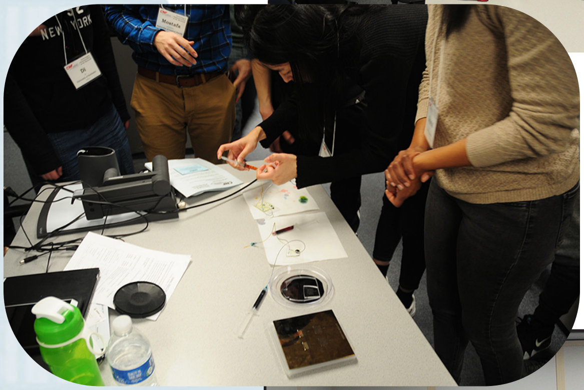
This year we have decided to move our educational programs online. The reasons for doing this are obvious since, like you, we are dealing with life in the COVID-19 world. These new programs will allow us to reach a much broader audience while continuing to provide a quality educational experience.

A CNF Virtual Tour is being developed that will allow people from around the world to explore the cleanroom and learn about the facility in an immersive 3D environment.

The staff is also developing an online video learning series that will guide viewers through the process of fabricating devices at CNF. As part of this online series, staff will perform virtual fabrication demonstrations in the areas of microfluidics, MEMS cantilevers, nano-electrodes and other cutting edge-devices. Viewers will be guided tool-by-tool through the critical fabrication processes of each device type and learn the important steps to creating the next generation of nanoscale devices.

These additions will allow CNF to expand its outreach and education potential on the road ahead. Again, we will inform the CNF community of their availability later this year.

Please contact Rebecca Lee Vliet, rlc12@cornell.edu, if you would like to be kept informed on this new video learning series hosted by CNF.

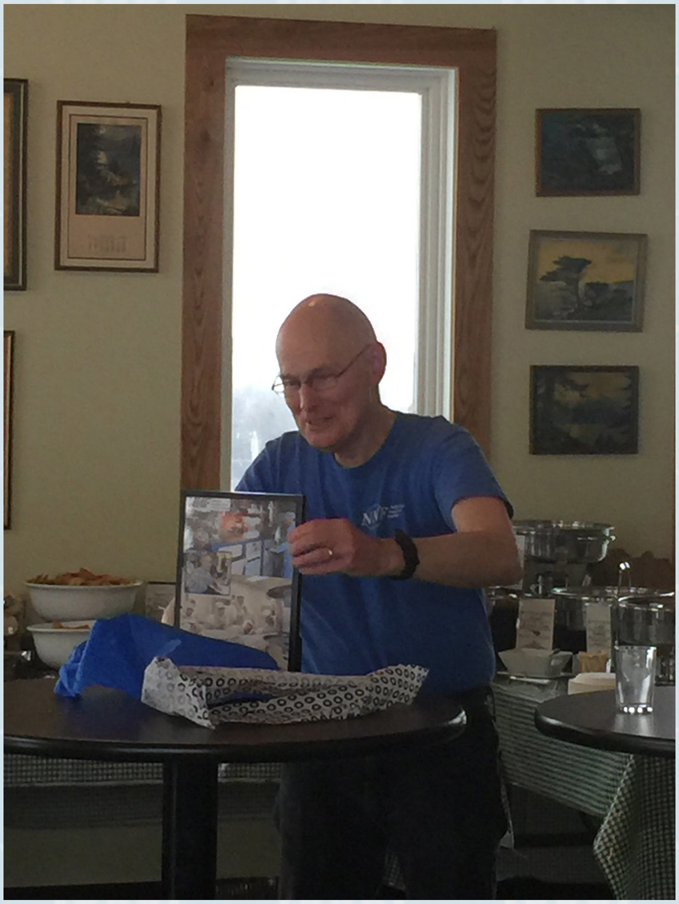


Jerry Drumheller Retires!

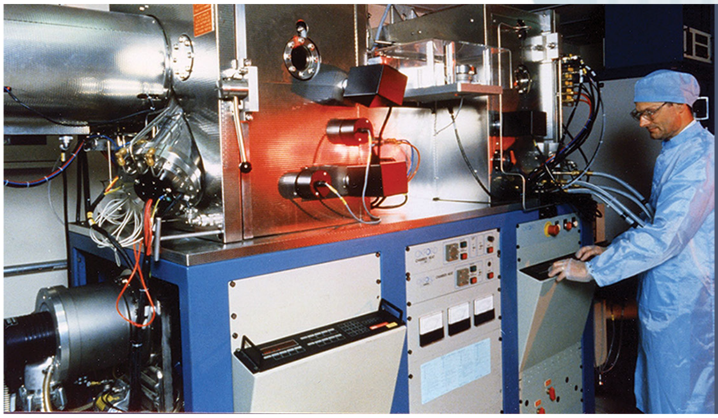
On January 31st, 2020, we officially bid adieu to Jerry Drumheller, CNF staff member from 1994-2020.

Between 1967 and 1994, Jerry worked for seven different companies — six of those jobs were rebuilding, repairing, and working with high vacuum deposition systems and some combination of work with optics, micro fabrication, lithography, and electronics. Jerry started at NNF / CNF in March 1994 and quickly found that it was the best job that he had ever had. Jerry says — "First and foremost the many people I worked with, staff and lab users, were all great people to work with and there were always plenty of challenges to work on and a lot of successes. Support from other staff members was **great**! Machine training supplied an interesting combination of challenge and fun, working with many different people. There was never any reason to leave CNF and many reasons to stay. Beyond CNF, I found Cornell a beautiful place to work, and I found so much to like about Ithaca, especially the music and dance scene!

Thank you all at CNF!!!!!"



Some of the tech staff took Jerry to lunch on his final day at CNF and gave him this plane as a going-away gift from them (nerds, all). Jerry sent a few photos of the plane, but it is possible he hasn't yet flown it....



Jerry back then.....

Jerry at a recent CNF TCN demonstration....

George McMurdy Joins the CNF Staff

George McMurdy joined CNF in January 2020 after graduating from Rochester Institute of Technology with a Master's Degree in Microelectronic Engineering.

While in Rochester, George's initial work with semiconductor devices was developing a new etch to remove the substrate of thin film GaAs solar cells. George's thesis work involved using ferroelectric hafnium oxide as the gate dielectric for MOS transistors.

At CNF, George's role is to support users through sputter tool maintenance, operation, and training. (See page 20 for information on one of George's tools).

In his free time, he enjoys golfing, running, and cheering for Boston sports.

Michael Skvarla Celebrates 45 Years at Cornell!

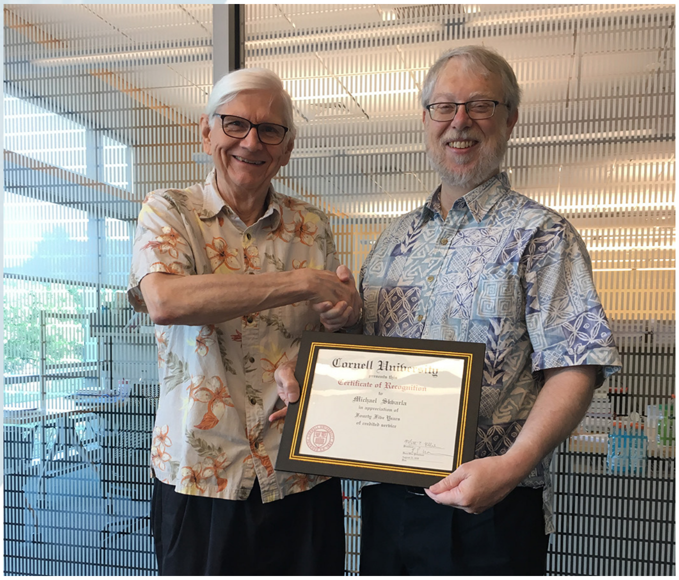
Michael joined the CNF about 35 years ago! Mike says….

Knight Lab had just been completed [when I started], the lab environment was new, and the research program was a blank slate. It was an exciting time, with much of the work in the category of facility development — searching for a purpose for these powerful techniques.

We had a small research community, some locals and a few outside visitors. There were so few people that everyone was on a first-name basis, and the start of an outside project called for a kick-off meeting in which all would gather and discuss ways to optimize the work. Folks were engaged and anxious to help.

That same concept has continued through the refinements of the last few decades. The welcome process now happens much more frequently (several new users per week) and often with a bit more intensity. But the attention-to-the-work and the dedicated, competent and enthusiastic staff have continued to define the interaction process.

The natural evolution of this original and very successful concept has resulted in distributed networks (NNCI), new instrumentation, and new research opportunities, serving as a model for other institutions and the accepted standard for addressing the research opportunities of the future.



CNF Director Christopher Ober presents Michael with his 45-year certificate from Cornell University.

CNF Jump-Starts Startups in New York State

By David Nutt
Cornell Chronicle
April 13, 2020

Electroplating — the process of using electricity to deposit one metal onto another — originated in the 19th century and can be found in everything from pennies to gold-topped cathedrals.

But electroplating is no easy task when you're creating groundbreaking microscale technology, as Kwame Amponsah '06, M.Eng '08, M.S. '12, Ph.D. '14, discovered several years ago while trying to fabricate microelectromechanical systems (MEMS) devices at the Cornell NanoScale Science and Technology Facility (CNF). Amponsah is CEO of the startup Xallent (https://xallent.com/), which builds nanoscale software and hardware products to test semiconductors and thin-film materials. Their fabrication dilemma had Amponsah and his engineers stumped.

"We tried to do this kind of electroplating, but we weren't getting the results that we wanted," he said. "Then we involved the CNF staff."

Founded in 1977, CNF enables scientists and engineers from academia and industry to conduct micro- and nanoscale research with state-of-the-art technology and expertise from its 23-member technical staff.

But perhaps the facility's greatest breakthrough is helping launch startup companies in New York State. Over the last four decades, at least 34 startups have launched at CNF and continue to use its services, with 14 — including Xallent — forming in the last ten years. These companies annually generate about $1.4 billion in funding and revenue.

Amponsah had used CNF throughout his graduate and postdoctoral research in th Amit Lal Group (Lal is the Robert M. Scharf 1977 Professor of Electrical and Computer Engineering). Amponsah went on to found Xallent in 2013 with Lal and tech executive Ashish Kumar, M.S. '93, Ph.D. '95. Now as an entrepreneur, Amponsah and his team at Xallent again turned to CNF, where staff members were able to recommend key steps that allowed them to successfully electroplate the MEMS devices. "It took two months," he says. "Without the CNF staff, it would have taken us six."

Xallent saved not only time, but thousands of dollars that would otherwise have been spent on employee and facility costs. The company also gained a customer: CNF was so impressed with Xallent's nanoscale probing technology that it purchased a pair of Xallent Nanoprobers — one that fits in an electron microscope (DARIUS) and a bench-top version (SAKYIWA).

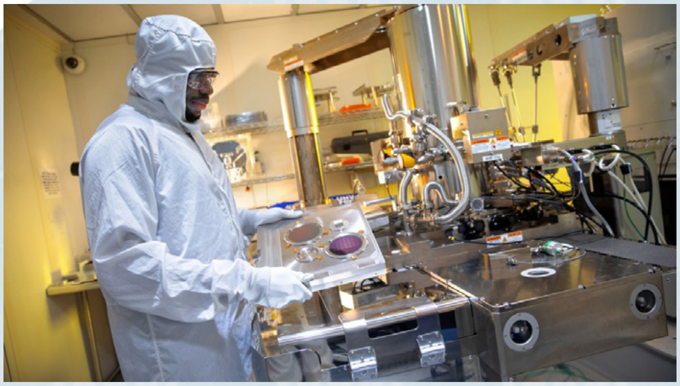


Figure 1: Xallent CEO Kwame Amponsah and his team of engineers use the Cornell NanoScale Science and Technology Facility to fabricate nanoscale probes to test semiconductors and thin-film materials. Lindsay France/Cornell University

"The expertise of the CNF staff is invaluable, and they have a portfolio of machines you might only find at two or three places in the U.S.," Amponsah said. "That allows us to always be at the cutting edge of research."

That cutting edge includes tools and processes like electron beam lithography, dry etching, constructing quantum devices, and use of one of the most advanced cleanrooms in the Northeast, if not the country.

Accessible to Companies and Colleges Alike

Each year CNF hosts approximately 600 users, from small startups to large corporations. Over the past decade, 72 New York companies and more than 100 colleges and universities from around the U.S. have relied on CNF. While other leading academic institutions have nanotechnology facilities, they generally work with faculty or major corporate clients. CNF strives to be accessible for burgeoning companies, as well, many of which have their roots at Cornell.

"That makes us really special in New York State, but it also makes us special nationally," said Christopher Ober, the Lester B. Knight Director of CNF. "New startup companies usually can't access commercial cleanrooms, and if they can, they can't afford them. Our business model is to encourage people to ask questions. We give free consulting. If somebody comes in, we charge them an hourly rate for a tool, but we don't charge them for consumables, like other places."

CNF policy also ensures that users retain all rights to their intellectual property.

"It's why startup companies like coming to us," said Ron Olson, CNF's director of operations. "Basically, their IP

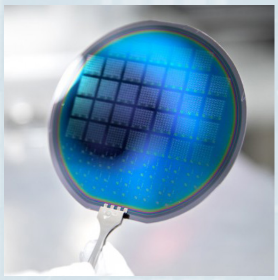


Figure 2, above: Xallent's fine pitch probes, fabricated at CNF, are used to test artificial intelligence chips. Figure 3, left: Kwame Amponsah used CNF throughout his graduate and postdoctoral research in the lab of Amit Lal, the Robert M. Scharf 1977 Professor of Electrical and Computer Engineering. Amponsah went on to found Xallent in 2013 with Lal and tech executive Ashish Kumar, M.S. '93, Ph.D. '95. Lindsay France/Cornell University

belongs to them." The facility operates with funding from the National Science Foundation; the Empire State Development Division of Science, Technology and Innovation, known as NYSTAR; Cornell; and user fees. This diverse support shapes the range of services CNF provides, including outreach efforts like providing research experience for undergraduates and engaging rural youth who are interested in science and technology through 4-H programs. CNF outreach may soon extend to workforce development.

Jonathan Alden, M.S. '12, Ph.D. '15, credits CNF with helping the company he co-founded, Esper Biosciences, raise $430,000 in small-business funding from the National Institutes of Health. The funding supported Esper's development of nanopore devices for DNA sequencing. This technology, which grew out of Alden's graduate work with Esper co-founder Alejandro Cortese, M.S. '14, Ph.D. '19, aims to make DNA sequencing so fast and affordable it can be used in doctors' offices for diagnosing infectious diseases.

"I suspect that one of the reasons I was able to get these grants from the NIH is because I could tell them I have experience using this state-of-the-art facility, and so I can make these devices efficiently and competently," said Alden, who along with Cortese did graduate work in the lab of Paul McEuen, the John A. Newman Professor of Physical Science in the College of Arts and Sciences.

"If I had to convince them that I was going to move across the country and use a different facility I had never tried before, that probably would have lost me a few points, which might have lost me the grant."

Many startups naturally gravitate to large cities, like Boston and San Francisco, that have tech-friendly venture capital and angel investors. But CNF's mix of access, equipment and expertise can be just as crucial to attracting investors.

The capitalization value of companies launched at CNF is estimated to be approximately $3 billion.

"My hope, from the start of my Ph.D., had been that I could come up with a technology that I could turn into a company," Alden said. "Frankly, there's no way I would have been doing this in NYS if CNF didn't exist."

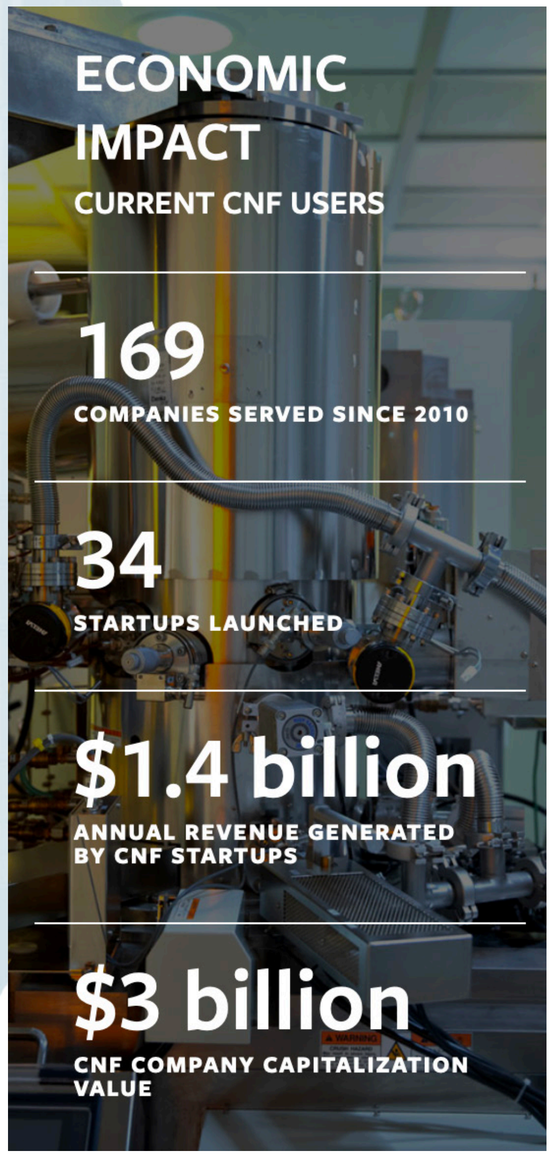


Figure 4: Every day, in every county in New York, individuals, schools, businesses, entrepreneurs, local governments and communities depend on Cornell to turn discoveries into real-world solutions and ensure a vibrant, healthy future for all New Yorkers. ny.cornell.edu

Physical Forces Affect Bacteria's Toxin Resistance, Study Finds

By Chris Dawson
Cornell Chronicle
December 5, 2019

A random conversation between two Cornell researchers at a child's birthday party led to a collaboration and new understanding of how bacteria resist toxins, which may lead to new tools in the fight against harmful infections.

Physical forces have been known to affect how cells in our body grow and survive, but little has been understood about the role these forces play in prokaryotes — single-cell organisms, including bacteria.

Christopher Hernandez, associate professor in the Sibley School of Mechanical and Aerospace Engineering, had an idea for a microfluidic device that would subject individual bacteria to known amounts of force and mechanical deformation. But he knew of few ways to measure the effects — until a chance encounter with Peng Chen, the Peter J.W. Debye Professor in the College of Arts and Sciences' Department of Chemistry and Chemical Biology.

Chen had developed a way to tag and observe a specific molecule that pumps toxins from the inner membrane of certain bacteria. By putting their ideas together, the researchers have shown conclusively that mechanical stresses can interrupt the ability of bacteria to survive exposure to toxins.

Their paper, "Mechanical Stress Compromises Multicomponent Efflux Complexes in Bacteria," published Nov. 26 in the Proceedings of the National Academy of Sciences.

Gram-negative bacteria are characterized by their dual-membrane cell envelope and have the ability to assemble molecular pumps to rid themselves of toxic substances that manage to migrate into the cell, including antibiotics. Hernandez and Chen's research showed that when *E. coli* bacteria were placed into a microfluidic device and forced to flow into very tight spaces, the resulting mechanical stresses alone were enough to cause these pumps to break apart and stop working.

"This is one of the first studies to look at the mechanobiology of bacteria," Hernandez said. "Our findings provide evidence that bacteria are similar to other types of cells in that they respond to mechanical forces through molecular complexes."

"Our work shows that you can disrupt the pump complex of bacteria with mechanical means," Chen said, "and this may give us a new tool to enhance treatments of bacterial diseases."

The methodology Hernandez and Chen created can be used to examine all sorts of prokaryotic cell structures, functions and behavior.

"Some possible next steps for us," said Hernandez, "are to look at related complexes that also work at the dual-membrane cell wall of Gram-negative bacteria and to explore how these bacteria create this cell envelope to begin with."

The transenvelope protein complexes that bacteria assemble to pump out toxins play a role not just in antibiotic resistance, but also in other crucial processes such as the translocation of outer-membrane components and cell division. If other types of these protein complexes are similarly affected by mechanical stresses, this suggests other physiological mechanisms in bacteria could be sensitive to mechanical forces, opening the door to possible enhanced treatments for a range of illnesses caused by bacteria.

Graduate students Lauren Genova (chemistry and chemical biology) and Melanie Roberts (mechanical engineering) were the co-first authors. Herbert Hui, the Joseph C. Ford Professor of Engineering, also contributed.

This research was supported by grants from the Army Research Office, the National Science Foundation and the National Institutes of Health. Some of the work for this study was done at the Cornell NanoScale Science and Technology Facility, and at Cornell's Biotechnology Resource Center.

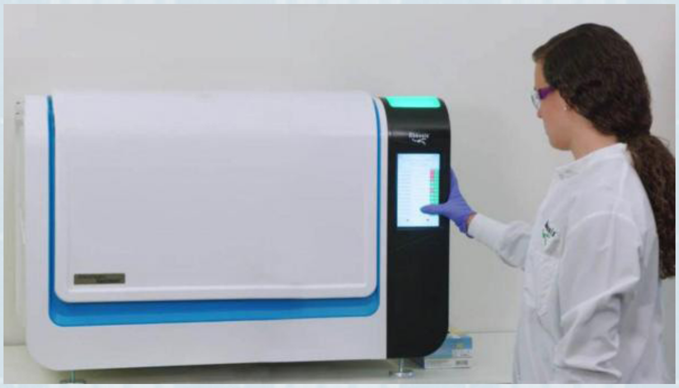
RADICAL
COLLABORATION

Rheonix & Same-Day COVID-19 Testing

Staff Report
Ithaca Times
April 30, 2020

After Ithaca-based Rheonix received approval from the Food and Drug Administration on a same-day testing turnaround method for COVID-19 results, they have now formed a partnership with Cayuga Health to introduce the testing to Tompkins County.

Rheonix was granted authorization from the FDA on April 29th, and can now use a "rapid sample-to-answer" test system which "enables the fully automated detection of SARS-CoV-2, the virus that causes COVID-19, directly from respiratory samples."



Rheonix, which is based out of Cornell, designed the device above that conducts the testing. Taken with permission from Original Article by Ithaca Times staff writers. The article can be found, in full, at

https://www.ithaca.com/news/ithaca/same-day-covid-19-testing-results-now-available-in-tompkins-county/article_83d37d0e-8b00-11ea-b9d0-27ad86969043.html

New Cornell Site Touts Radical Collaboration Stories

A new website for the Radical Collaboration initiative showcases university storytelling around research partnerships and highlights how Cornell faculty are reaching across disciplines to make breakthrough discoveries. The site describes collaborating faculty's efforts as "collisions of thoughts and perspectives from vastly different fields that lead to unexpected and unconventional solutions and deepen our way of thinking."

Learn more at https://news.cornell.edu/stories/2020/03/radical-collaboration-sees-new-hires-custom-approaches

RADICAL COLLABORATION

McEuen Miskin TED Talk

Take a trip down the microworld as roboticists Paul McEuen and Marc Miskin explain how they design and mass-produce microrobots the size of a single cell, powered by atomically thin legs — and show how these machines could one day be "piloted" to battle crop diseases or study your brain at the level of individual neurons.

This talk was presented at a TED Institute event given in partnership with The Kavli Foundation, the Simons Foundation, and the National Academy of Sciences. Work described was performed in part at the Cornell NanoScale Science & Technology Facility (CNF).

Tiny Robots with Giant Potential, https://www.ted.com/talks/paul_mceuen_and_marc_miskin_tiny_robots_with_giant_potential

Read more about the TED Institute, https://www.ted.com/about/programs-initiatives/ted-institute

Mass-Produced Microscopic Sensors See the Light

By David Nutt
Cornell Chronicle
April 17, 2020

Theologians once pondered how many angels could dance on the head of a pin. Not to be outdone, Cornell researchers who build nanoscale electronics have developed microsensors so tiny, they can fit 30,000 on one side of a penny.

There's more to these tiny sensors than just their diminutive size: They are equipped with an integrated circuit, solar cells and light-emitting diodes (LEDs) that enable them to harness light for power and communication. And because they are mass fabricated, with up to 1 million sitting on an 8-inch wafer, each device costs a fraction of that same penny.

The team's paper, "Microscopic Sensors Using Optical Wireless Integrated Circuits," was published on April 17th in PNAS.

The collaboration is led by Paul McEuen, the John A. Newman Professor of Physical Science, and Alyosha Molnar, associate professor of electrical and computer engineering. Working with the paper's lead author, Alejandro Cortese, Ph.D. '19, a Cornell Presidential Postdoctoral Fellow, they devised a platform for parallel production of their optical wireless integrated circuits (OWICs) — microsensors the size of 100 µm, mere specks to the human eye.

"In a certain sense, it's an old idea, building tiny sensors like this," said McEuen, who co-chairs the Nanoscale Science and Microsystems Engineering (NEXT Nano) Task Force, part of Cornell's Radical Collaboration initiative. "But we pushed it another order of magnitude down in size and made it mass fabricate-able. A lot of times when people would make these little doodads, they would wire them all together by hand. You didn't get a million at a time. So we constrained ourselves and said we're not going to do it unless we can make them by the million."

The OWICS are essentially paramecium-size smartphones that can be specialized with apps. But rather than rely on cumbersome radio frequency technology, as cellphones do, the researchers looked to light as a potential power source and communication medium.

Placing tiny circuits on a silicon wafer is relatively easy in the nanotech arena, McEuen said, but adding LEDs is a special challenge because they are made with a different material: gallium arsenide. In order to transfer the LEDs to a wafer with the electrical components and integrate them, the researchers developed a complicated assembly method that involved more than 15 layers of photolithography, 30 different materials and more than 100 steps.

"There are a lot of people working at larger scales where you can pick up things and see them with your eye and touch them. This is not that," Cortese said. "It's at a scale that you legitimately cannot see what you're doing unless you're under a microscope. So you really have to gain an intuition about the nanoscale and the microscale."

Once the OWICs are freed from their substrate of silicon, they can be used to measure inputs like voltage and temperature in hard-to-reach environments, such as inside living tissue and microfluidic systems. For example, an OWIC rigged with a neural sensor would be able to noninvasively record nerve signals in the body and transmit its findings by blinking a coded signal via the LED.

As a proof of concept, the team worked with the lab of Chris Xu, professor of applied and engineering physics and a co-author of the paper, and successfully embedded an OWIC with a temperature sensor in brain tissue and wirelessly relayed the results.

McEuen, Molnar, and Cortese have launched their own company, OWiC Technologies, to commercialize the microsensors. A patent application has been filed through the Cornell Center for Technology Licensing. The first application is the creation of e-tags that can be attached to products to help identify them.

The tiny, low-cost OWICs could potentially spawn generations of microsensors that use less power while tracking more complicated phenomena.

"The circuits in this paper were quite simple," Cortese said. "But you can potentially fit thousands of transistors on one of these devices. And that means you can increase the range of things the device can sense, how the device communicates out, or it's ability to complete more complex tasks. We really developed this as a platform so that a lot of people have space to develop new devices, new applications."

Molnar and Xu are members of the Kavli Institute at Cornell for Nanoscale Science, which McEuen directs.

Contributing authors include doctoral students Conrad Smart, Michael Reynolds, Samantha Norris, Yanxin Ji, Fei Xia, Aaron Mok, and Chunyan Wu; postdoctoral researchers Sunwoo Lee and Tianyu Wang; and Nathan Ellis, machine shop manager of the Laboratory of Atomic and Solid State Physics. The researchers developed their fabrication process with the assistance of the Cornell NanoScale Science and Technology Facility.

The research was supported by the Cornell Center for Materials Research, with funding from the National Science Foundation's Materials Research Science and Engineering Center program, the Air Force Office of Scientific Research and the Kavli Institute. Additional funding was provided by the National Institutes of Health and the NSF Graduate Research Fellowship.

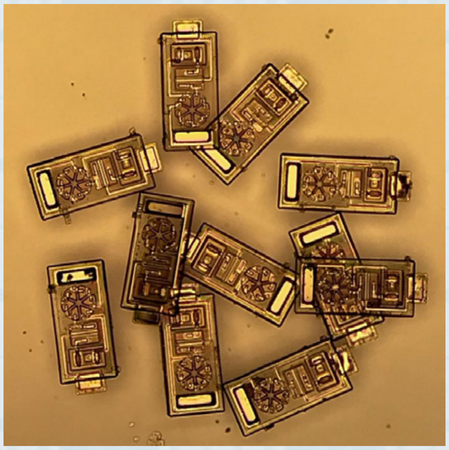


Figure 1: This collection of OWICs is barely visible to the naked eye. Alejandro Cortese/Provided (Also, see next column.)

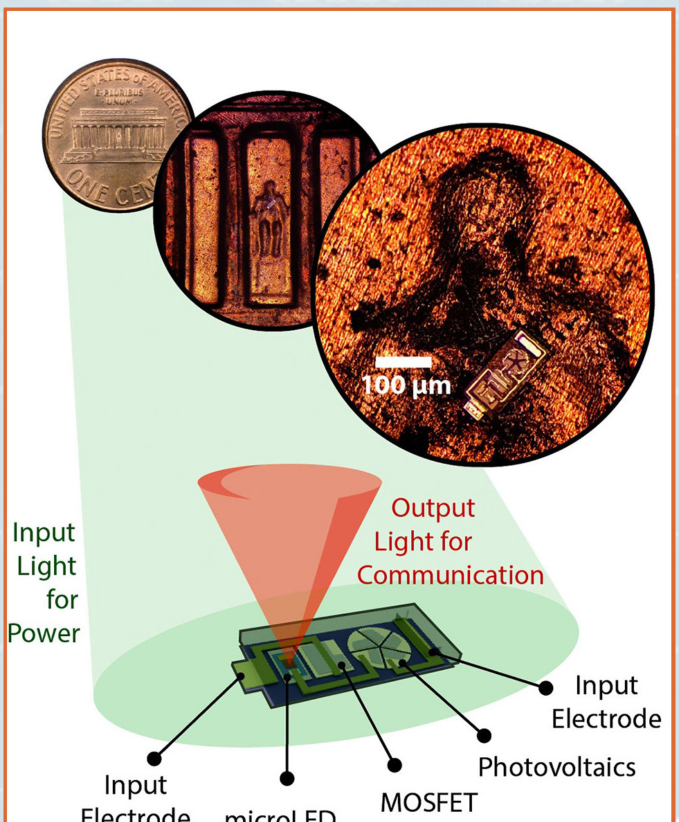


Figure 2: This image shows a voltage-sensing OWIC as it fits inside the Lincoln Memorial on the back of a penny, and a schematic of an OWIC's components. Alejandro Cortese/Provided

OWiC Technologies wins BenDaniel Venture Challenge

By Debra Eichten
Cornell Chronicle
April 22, 2020

A company developing microscopic optical scanning technology was named winner of the annual BenDaniel Venture Challenge, held virtually on April 17.

Five finalists presented at the annual pitch competition, hosted by BR Venture Fund. Traditionally, the competition takes place during the Entrepreneurship at Cornell Celebration event, held on campus in April. A total of $25,000 in cash was awarded, with an additional $25,000 in matching services provided by Cornell's Center for Technology Licensing.

The winning company, OWiC Technologies, was founded by Alejandro Cortese, M.S. '14, Ph.D. '19. The technology is an optical wireless integrated circuit (OWIC) in a microscopic footprint with a simple light-based interface for hand-held scanning.

OWICs can be mass-produced at low cost and embedded as a chip in a multitude of products, including anti-counterfeiting technologies.

Runner-up in the competition was mPOD, an *in vitro*, point-of-care medical device designed for rapid detection of species-specific pathogens in biofluids.

Co-founder and CEO Jeffrey Ly '15, M.Eng. '17, said the technology, originally aimed at improving sepsis outcomes, is now being re-developed for possible use as a COVID-19 test.

The next step for the team is working in collaboration with New York-Presbyterian Hospital in Queens, New York, on a 100-sample validation study that has been approved by Cornell's Institutional Review Board for Human Participant Research.

The event is named for the late David BenDaniel, the Don and Margi Berens Professor of Entrepreneurship and professor of management, who died in 2017.

See the collection of OWICs in the other column, Figure 1. Alejandro Cortese/Provided

RADICAL COLLABORATION

Physics Tool Helps Track Cancer Cell Diversity

By David Nutt
Cornell Chronicle
February 20, 2020

Cancer cells are a wily adversary. One reason the disease outfoxes many potential treatments is because of the diversity of the cancer cell population. Researchers have found this population difficult to characterize and quantify.

A Cornell-led team took a novel, interdisciplinary approach to analyzing the behavior of breast tumor cells by employing a statistical modeling technique more commonly used in physics and economics. The team was able to demonstrate how the diversity, or heterogeneity, of cancer cells can be influenced by their chemical environment — namely, by interactions with a specific protein, which leads to tumor growth.

The researchers' paper, "Lymphoidal Chemokine CCL19 Promoted the Heterogeneity of the Breast Tumor Cell Motility Within a 3D Microenvironment Revealed by a Lévy Distribution Analysis," published February 14 in Integrative Biology.

"It's pretty tough to treat cancer. A lot of people in the field believe that is because of the diversity in the cancer population," said senior author Mingming Wu, professor of biological and environmental engineering in the College of Agriculture and Life Sciences. "While immune cells are rounded and kind of similar and move in the same way, cancer cells are different in shape and move at different speed. We know that fast movers are very lethal. How would you quantify that heterogeneity?"

Another challenge is that only a few cancer cells move fast and do the most damage, and they're difficult to find.

The effort to track these rare cells is similar to the search for elusive particles being conducted in the lab of co-author Anders Ryd, professor of physics in the College of Arts and Sciences. During a conversation over coffee, Ryd and Wu realized the cancer cell research could incorporate the same type of sophisticated statistical tools that have helped particle physicists understand rare energy phenomena, such as the much-sought Higgs boson.

"What we do in particle physics is really statistical data analysis, trying to figure out what functional forms describe our data," Ryd said. "And in this case here, the interest was to look at the outliers, the cells that migrated further, and characterize that. A lot of the tools that we are using in particle physics lend themselves very well to this analysis."

Wu's Biofluidics Lab worked with the Cornell NanoScale Science and Technology Facility (CNF) to fabricate a microfluidic device with three parallel channels, each roughly the width of a human hair. The team introduced breast tumor cells into the device, along with the chemokine protein CCL19, which is secreted by lymph nodes and is highly expressed in malignant tumor cells.

In order to model the cancer cell trajectories, the team used Root, an open-source software for performing statistical analysis in high-energy physics and in certain economics applications. The researchers found that the presence of chemokine caused the targeted cancer cells to move faster, and heterogeneity increased.

"It is similar to how we as a society are trying to make the population more diverse, because we know that if the population is diverse, it's more robust, more healthy," Wu said. "I think that cancer is the same way. They are making their population more diverse, more indestructible."

A treatment that inhibits the receptor to CCL19 could potentially decrease the invasiveness of tumor cells, although it might also cause the cancer cells to adopt new, even stealthier strategies to survive, Wu said.

By analyzing how these cells respond to environmental cues — such as chemical gradients, temperature, light intensity and mechanical force — Wu's team hopes to elucidate the underlying principles of biology, which aren't as cut and dried as the fundamental laws of physics. Her team may borrow a few techniques, too.

"There are a lot of tools in physical science already, because physical science has always been a very quantitative field," Wu said. "It's only recently that quantitative biology is starting to shape up. So I feel like this integration is powerful because you don't have to reinvent the wheel to do this modeling."

Other contributors included co-lead authors Beum Jun Kim, Ph.D. '04, now a senior engineer at Rheonix, and Pimkhuan Hannanta-anan '12, a faculty member at King Mongkut's Institute of Technology Ladkrabang in Thailand; and Melody Swartz, professor of molecular engineering at the University of Chicago.

RADICAL
COLLABORATION

The research was supported by the National Cancer Institute, the Swiss National Science Foundation, the Cornell Center on the Microenvironment and Metastasis, and the Cornell NanoScale Facility (CNF).

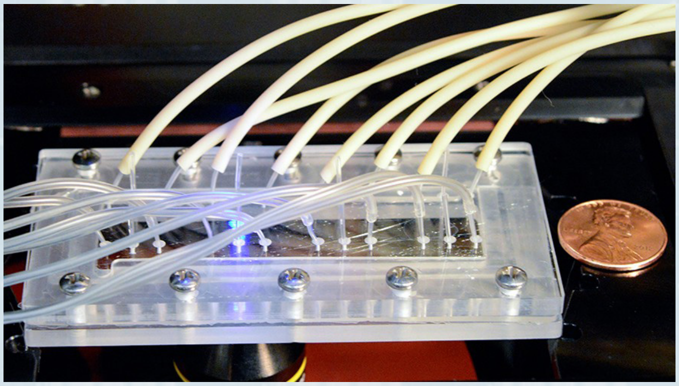
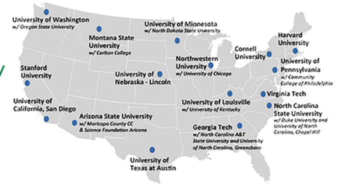


Figure 1: A research team led by Mingming Wu worked with CNF to fabricate this microfluidic chip containing four identical three-channel devices. The team put breast tumor cells and the chemokine protein CCL19 into each device and then used open-source software to analyze the cancer cell behavior. Mingming Wu / Provided

Zach Manzer Wins Poster Award

Zach Manzer, PhD Student in the Daniel Research Group, Robert Frederick Smith School of Chemical and Biomolecular Engineering, Cornell University, received the Synthetic and Systems Biotechnology 3rd Prize Poster Award on December 5th, for his poster titled "Spatially Controlled Cell-Free Protein Synthesis and Glycosylation on Chip" — congratulations, Zach!

National Nanotechnology Coordinated Infrastructure

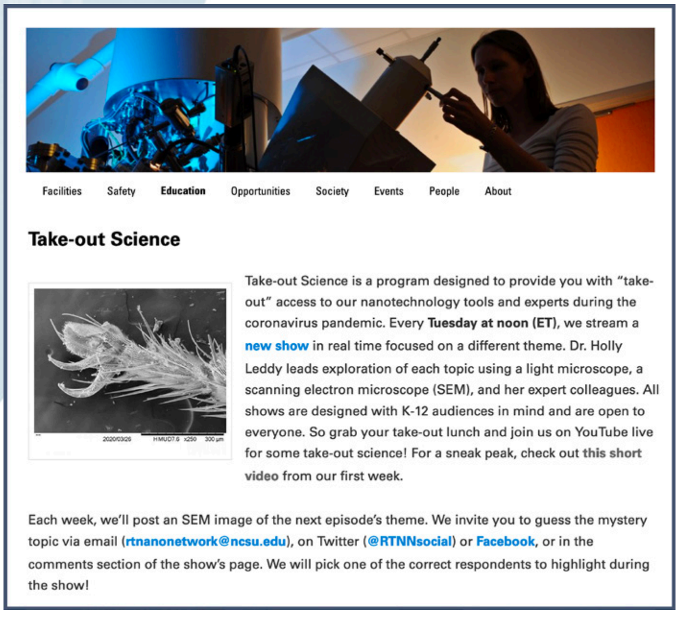


NNCI Virtual Classroom Resources: Kitchens, Backyards, and Beyond

In the Time of COVID-19, National Nanotechnology Coordinated Infrastructure (NNCI) has stepped up to create virtual experiences in the STEM fields.

For instance, the Research Triangle Nanotechnology Network (RTNN) — a partnership between NNCI site North Carolina State University working with Duke University and UNC Chapel Hill — presents the "Take-Out Science" program every Tuesday at 12 noon (Eastern) with a new show streamed in real time, each focused on a different theme. The shows are designed with K-12 audiences in mind, but are open and interesting to everyone! Episodes include "What's cooking?", "Under the sea", and "Here be dragons" — and all are posted online at https://www.rtnn.ncsu.edu/science-take-out/ Take-out Science provides access to the RTNN nanotechnology tools and experts during the coronavirus pandemic.

NNCI network resources are listed online at NNCI Resources: Virtual Classrooms Kitchens Backyards and Beyond, www.nnci.net/nnci-resources-virtual-classrooms-kitchens-backyards-and-beyond. Enjoy!



Engineering Dean Lance Collins Departing for Virginia Tech

By Syl Kacapyr
Cornell Chronicle
February 3, 2020

Lance Collins, the Joseph Silbert Dean of Engineering, will be joining Virginia Tech as the inaugural vice president and executive director of its new Innovation Campus following the completion of his second term as dean on June 30.

A committee led by Provost Michael I. Kotlikoff is conducting an international search for a successor and a replacement is expected to be announced before Collins' departure.

"This is an exciting endeavor for me and a natural evolution of the work I've been doing at Cornell Engineering in Ithaca and Cornell Tech in New York City," said Collins, who will be charged with overseeing the development of the Innovation Campus, to be located in Alexandria, Virginia, from the ground up. The first academic buildings are scheduled to be completed in 2024, with some academic programs beginning earlier at a temporary location.

Collins is no stranger to launching a new campus. Among his achievements during a decade-long tenure as dean, Collins was a member of the core leadership team that won the Cornell Tech bid for Roosevelt Island in New York City. He has since served on the board of directors for the Jacobs Technion-Cornell Institute at Cornell Tech, the joint venture between the Technion-Israel Institute of Technology and Cornell. Collins has also played an instrumental role in the hiring and promotion of faculty, and the launching of new degree programs at Cornell Tech.

"One of the things I appreciate the most about Lance is he wants to take on the very hard, very challenging things, and be very thoughtful about it," said Greg Morrisett, the Jack and Rilla Neafsey Dean and Vice Provost of Cornell Tech. "Lance played a critical role in forming the ideas behind Cornell Tech, along with [former dean] Dan Huttenlocher and others."

Collins joined Cornell in 2002 as a faculty member specializing in the application of numerical simulations to turbulent processes. As the first African American director of the Sibley School of Mechanical and Aerospace Engineering, and later as the first African American dean at Cornell University, Collins prioritized diversifying the college's faculty and study body. As dean, he has more than doubled the proportion of students from underrepresented communities, from 8% to 19%, and increased the enrollment of undergraduate women from 33% to 50%, while keeping graduation rates and average GPA equal among genders.

For his diversity efforts, Collins received the inaugural Mosaic Medal of Distinction in 2017 and the 2018 Edward Bouchet Legacy Award.

"Many people are asking me, because I'm in my last year as dean, to name my biggest achievement," Collins said. "It is this — a remarkable milestone I didn't imagine in my entire lifetime — an undergraduate population that is equal numbers of men and women."

Collins led one of the largest capital campaigns in the college's history, and helped secure its two largest gifts, which established the Nancy E. and Peter C. Meinig School of Biomedical Engineering and the Robert Frederick Smith School of Chemical and Biomolecular Engineering.

Collins also prioritized experiential learning within the college, launching the Engineering Leadership Program and developing new entrepreneurship initiatives, such as the Commercialization Fellowship and the Scale-Up and Prototyping Awards.

Collins has welcomed leadership roles outside the college as well. He co-chairs the Sustainability Cornell Council, charged with advancing sustainability programming across campus. As a thought leader, he published opinion editorials nationally on topics including U.S. energy policy, the importance of social science education and the rehabilitation of the L-Train Tunnel in New York City — for which his involvement was heralded by commuters.

"I'm looking forward to serving out my last semester at Cornell," Collins said, "and although my time in Ithaca will soon end, I expect to discover the sentiment that many of our alumni have shared with me — namely, that Cornell University will always hold a special place in my heart."

Wireless Car Charging, Aluminum Nitride-Based Power Amplifiers and Microfluidic Technology Among Scale-Up Award Technologies

By Eric Laine
Cornell Chronicle
January 30, 2020

The College of Engineering has announced the winners of the annual Scale-Up and Prototyping Awards, which give teams of engineering faculty and students up to $40,000 to commercialize startup technologies that might otherwise have trouble obtaining funding.

"There is a funding gap between research support and commercial startup funding," says Robert Scharf, the College of Engineering's Entrepreneur-in-Residence and director of the PRAXIS Center for Venture Development.

"Many institutional investors are not comfortable with research ideas that have no commercial validation," said Scharf. "The goal of these awards is to provide commercial validation for ideas that have so far established only academic interest."

The awards, now in their third year, allow the winning teams to work closely with members of the college's Scientific Advisory Committee to identify potential markets and build a business case for their technology. The process also helps researchers prepare for subsequent investments to further their work.

The prototypes and teams are:

Aluminum Nitride-Based Power Amplifiers for Enhanced Radar Object Detection Range: Austin Hickman and Reet Chaudhuri, M.S. '16, doctoral students; Huili Grace Xing, professor of electrical and computer engineering, and of materials science and engineering; and Debdeep Jena, professor of electrical and computer engineering, and of materials science and engineering. Gallium nitride (GaN)-based power amplifiers are a core technology of modern radar systems, expanding the target's reflected signals and allowing for the detection and location of distant objects. But these amplifiers' radar performance is confined by limits in operating temperatures and power. Amplifiers using aluminum nitride (AlN) could surpass these limitations and offer a critical leap forward for high-power amplifier performance. The research team pioneered the concept and technologies of the AlN-based transistor, the key building block for AlN-based power amplifiers. The researchers will use their award to design and fabricate a first generation of AlN-based amplifiers, combining multiple individual transistors and components into a complete integrated device. The fabrication will take place at the Cornell NanoScale Science and Technology Facility in Duffield Hall.

Heart-Recovery Device for Infants and Young Children: James Antaki, Susan K. McAdam Professor of Heart Assist Technology in the Meinig School of Biomedical Engineering. Heart-assist pumps, also known as ventricular assist devices (VADs), are now the standard of care for treating adults with severe heart failure. They have saved tens of thousands of adults, but no suitable VADs exist to treat infants and young children with congenital or acquired cardiac defects. Existing heart-assist systems approved for children in the U.S. were designed nearly three decades ago, and control units for such systems weigh more than 400 pounds, meaning pediatric patients are almost exclusively confined to high-dependency hospital wards. Antaki and his colleagues have been working for more than 10 years on PediaFlow, a miniature heart-assist pump for infants and young children. Since children have a greater chance of cardiac recovery compared to adults, implantation of a VAD can potentially rehabilitate a child's heart back to health. The team's goal is to develop a prototype of a PediaFlow control unit that incorporates this recovery feature. The project will focus on the design and usability of the prototype, which the researchers hope will lead to future clinical studies with children.

Dynamic Capacitive Wireless Charging System for Electrified Vehicles: Khurram Afridi, associate professor of electrical and computer engineering. Autonomous material-handling vehicles used in modern warehouses and factories are powered by onboard batteries. Currently, these vehicles are taken offline and plugged in for recharging, or their drained batteries are swapped with pre-charged ones. Both approaches impose substantial costs, require additional space for spare vehicles or batteries, and does not scale well for dynamic applications. Afridi's alternative is to charge these vehicles wirelessly from the floor while they are performing their tasks, including when they are in motion. This approach substantially reduces the need for onboard batteries, which decreases vehicle costs while increasing productivity. The researchers will scale up their proof-of-concept system to a full-scale dynamic capacitive wireless charging prototype. This prototype will demonstrate the feasibility of high-power transfer levels at high efficiencies for vehicles traveling at speeds appropriate to warehouses and factories. The controlled environments of warehouses and factories are excellent testing grounds for this technology, which eventually could have a significant impact on the cost and range of roadway electric vehicles.

Microfluidic Technology for Single Cell Sample Processing: Harvey Tian, M.S. '12, M.Eng. '16, Ph.D. '17, and Adam Bisogni '08, Ph.D. 17, postdoctoral associates; and Harold Craighead, M.S. '77, Ph.D. '80, the Charles W. Lake Professor of Engineering Emeritus in the School of Applied and Engineering Physics. In today's single cell sample processing market, limited amounts of information can be extracted from rare cells, such as highly aggressive cancer cells, due to limitations in sample processing platforms. Craighead's team aims to offer a user-friendly automatable platform for sample processing of single cells, which would allow the user to extract more information from those cells than with current sample processing platforms. This technology would benefit industry scientists in pharmaceutical companies who wish to understand how multiple facets of a cell change in response to a new drug. It would also assist academics who are interested in identifying the deeper nature of aggressive cancer cells. The Craighead Lab has developed a specialized microfluidic device capable of performing on-chip cell processing as well as various on-chip chemistries such as DNA extraction, labeling and imaging. The award will help the researchers test scaling up their current microchip designs to increase sample throughput, and also test moving the technology from its current polymer construction to plastic, which is more amenable to manufacturing and fabrication processes.

Craighead

Woollam M-2000 *in situ* and RC2 Tabletop Spectroscopic Ellipsometers

CNF has acquired a Woollam M-2000 *in situ* spectroscopic ellipsometer and a Woollam RC2 tabletop spectroscopic ellipsometer. The existing Woollam variable angle spectroscopic ellipsometer (WVASE) will be moved to a CNF lab on the second floor of Duffield Hall and will be replaced in the cleanroom by the RC2. The M-2000 will be attached to the Plasma-Therm Atomic Layer Etch (ALE) system for real time *in situ* measurements of thin films.

Spectroscopic ellipsometry is a noninvasive technique that measures the changes in the polarization state (Ψ and Δ) of light reflecting from a substrate. From these parameters, thickness as well as optical properties of thin films and bulk material are determined. Spectroscopic ellipsometry is used for characterization of all types of materials: dielectrics, semiconductors, metals, organics, multilayers, doped films and more. It can characterize optical constants, multilayer thicknesses, composition, crystallinity, surface and interfacial roughness, anisotropy/birefringence, constituent and void fractions, bandgap and electronic transitions of a wide variety of thin films and thin film multilayers.

Woollam RC2 Spectroscopic Ellipsometer

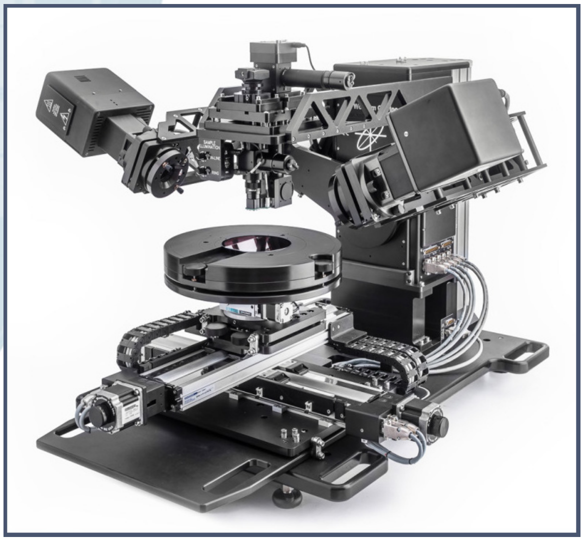
The RC2 has the same spectral range as the WVASE, 193-1690 nm, with a number of significant improvements:

- Dual Rotating Compensator (D-RCE) design with achromatic retarder enables acquisition of all 16 elements of the Mueller matrix, for materials that are both depolarizing and anisotropic, where the optical response changes with the sample orientation. Examples of anisotropic materials include quantum wells, some semiconductor oxides, porous silicon, thick liquid crystals, organic polymers for nonlinear optics, aluminum nitride and sol-gel thin films.
- All wavelengths are acquired simultaneously so the minimum data acquisition time is approximately 0.3 seconds; typical data acquisition times are 1 to 5 sec instead of tens of minutes for the WVASE.
- Automated motorized tip-tilt alignment of samples instead of manual alignment.
- Automated sample height (Z) alignment.
- Motorized horizontal sample stage for automated mapping of film properties over a 200 mm × 200 mm area.
- A multi-seat license for CompleteEASE software for data acquisition and analysis can be used for offline data analysis and for material model transfer to and from the M-2000 *in situ* ellipsometer. CompleteEASE includes new thickness pre-fit and B-Spline fitting methods and automatic comparisons of models with and without index grading and/or surface roughness.
- A camera to view the light beam location on the sample.

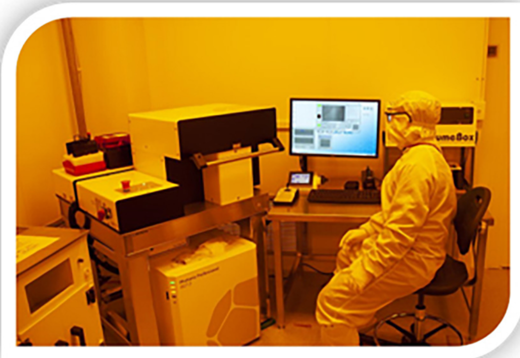
Woollam M-2000 *in situ* Spectroscopic Ellipsometer

The M-2000 *in situ* Ellipsometer also acquires all wavelengths from 370 nm to 1000 nm simultaneously, with minimum data acquisition time approximately 50 msec and typical data acquisition times of 1 to 5 sec. The ellipsometer light source and detector will be bolted onto the chamber of the ALE to monitor processes in real time. The CompleteEASE software can dynamically measure the sample in the chamber before, during and after processing.

Contact Alan Bleier to find out more, bleier@cnf.cornell.edu



Woollam RC2 Spectroscopic Ellipsometer



NanoScribe GT2

A NanoScribe GT2 Laser Lithography System was installed in CNF at the beginning of 2020 and is a state of the art two-photon polymerization volumetric maskless printer. It can create three-dimensional nanostructures using a NIR femtosecond laser via direct-write onto a photosensitive resin that is subjected to a non-linear two-photon absorption process.

This process involves cross-linking the resin via UV absorption. In essence, the laser sets a focal light cone where a concentration of the light intensity defines the exposure focal spot volume or a "3D Pixel". Using this technique a CAD design can be broken into and X, Y, Z coordinate system to define the structure pixel by pixel and layer by layer. The exposure side of the system sits in a fine-tuned vibration isolation table and a high-speed ultra-precise piezoelectric stage for movement in x-y-z, and finally a galvanic mirror defection system for focusing and beam rasterization.

Models for printing can be designed using the stand-alone software DeScribe which comes with the tool or with any CAD software capable of outputting DXF or STL file formats. The DeScribe software can import these formats.

CNF has three solution sets for particular scales and applications.

Contact Edward Camacho to learn more, camacho@cnf.cornell.edu

YES EcoClean Single Wafer Plasma Strip / Descum System

CNF has purchased the high-powered YES EcoClean as an upgrade to the YES downstream asher. The EcoClean is a single wafer, RF plasma stripper designed for photoresist and polyimide strip, descum, and inorganic substrate cleaning/surface modification. The oxygen plasma with an optional nitrogen additive allows the system to remove polyimide material without the need for fluorinated gas. The downstream design of the remote ICP source confines charged species to the plasma chamber, allowing only charge-neutral species to interact with the substrate.

The tool can process silicon and gallium arsenide wafers of 2″, 3″, 4″, 5″, 6″, and 8″ diameter. Additionally, individual cassette slots may be uniquely programmed to run different recipes for different wafers. Automated wafer loading combined with high power capabilities yields both fast throughput (30 seconds/wafer) and fast resist removal (> 2 µm per minute for standard resist). Tool capabilities include 3,000 W RF power and hot plate temperature up to 300°C.

Contact George McMurdy to find out more on this tool, mcmurdy@cnf.cornell.edu

PANalytical X-Ray Diffractometer

PANalytical X'Pert Pro MPD is a diffractometer for thin films, both single crystals and polycrystalline. Analysis capability is improved by the high-resolution goniometer using Heidenhain encoders. It is useful to examine nearly lattice matched materials or the structural perfection of materials. The sample holder accommodates samples up to four inches in diameter. Triple axis setup utilizes a three-bounce channel cut Ge crystal to provide an acceptance angle of 12 arc seconds. Rocking curve optics utilize interchangeable slits to control the background and detector resolution.

Contact Xinwei Wu for more information on this tool, wu@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 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 will handle substrates up to 200 mm diameter and has a 12-channel gas pod with four ALE valves. Plasma diagnostics include optical emission spectroscopy (OES) and a Langmuir probe that 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.

The first phase of the ALE development effort will concentrate on etching Si, GaN, AlGaN, and GaAs. Subsequent research will target materials such as AlN, ALD layers such as HfO_2, and 2D materials such as WS_2, MoS_2, and WSe_2.

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

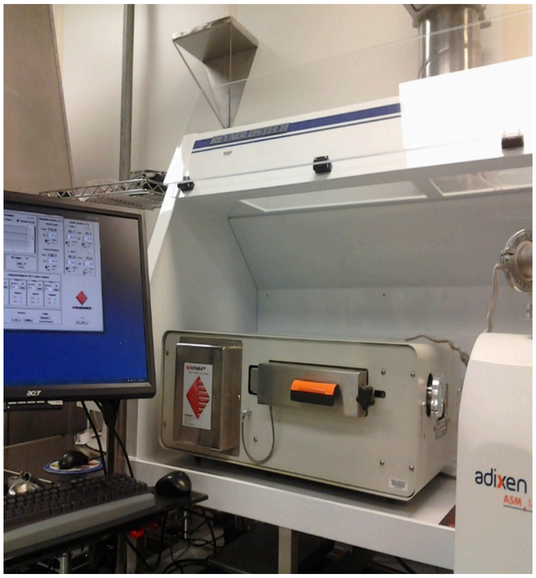
Ozone Generator Added to the Arradiance GEMStar 6 ALD System

CNF has upgraded its atomic layer deposition (ALD) capabilities with the addition of a Pacific Ozone Lab Series ozone generator to the Arradiance GEMStar 6 ALD system. The addition of ozone as a reactant in ALD thermal processes has advantages to the more conventional water (H_2O) reactant in the formation of metal oxide dielectrics, and also with platinum (Pt) ALD. H_2O-based-reacted ALD dielectric films can suffer from local delamination after higher temperature post-processing and can suffer from higher leakage currents as a gate dielectric in transistor based devices. In addition, H_2O can be very difficult to purge from vacuum systems with its high sticking coefficient, and this leads to extended purge times and longer ALD cycle times. Ozone, however, is generally more reactive on surfaces such as silicon leading to little or no incubation time for film growth, and allows ALD deposition to occur at lower temperatures, which is vital for those devices with lower thermal budgets. This is especially seen in Pt ALD processes where deposition can occur as low as 125°C and without a required nucleation layer such as Al_2O_3 needed for the oxygen (O_2) based Pt ALD process.

We have recently developed ozone based ALD processes for Al_2O_3, TiO_2, and Pt. The Al_2O_3 ozone process with trimethylaluminum (TMA) exhibits stable ALD growth in the 150-250°C range as shown in Figure 1.

XPS comparative analysis of the water and ozone based AL_2O_3 films show accurate film stoichiometry for each method as illustrated in Figure 2. The ozone based TiO_2 ALD process with the TDMATi precursor exhibits stable ALD growth in the 200-250°C range as shown in Figure 3.

The Pt-ozone-based ALD process using the Pt(MeCp)Me_3 precursor can be deposited on silicon without the need for the Al_2O_3 nucleation layer and at lower temperatures. A comparison of the XPS composition of the films is shown in Figure 4.



We plan to develop ozone-based processes for HfO_2 using the TDMAHf precursor and ZrO_2 using the TDMAZr precursor in the near future.

If you have questions regarding CNF ALD processing, please contact CNF research staff member Vince Genova (genova@cnf.cornell.edu) for more information.

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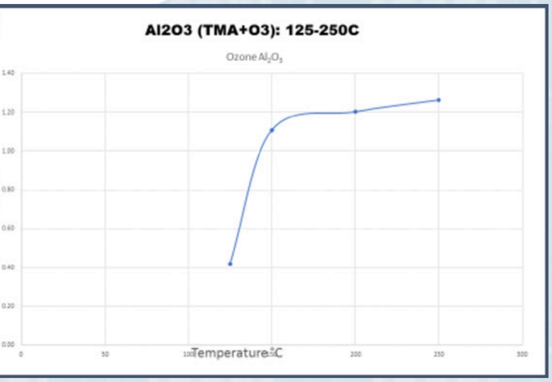

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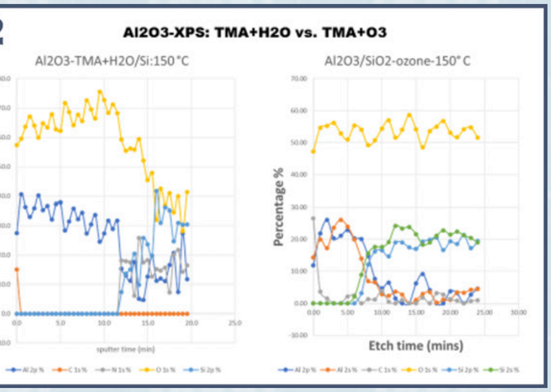

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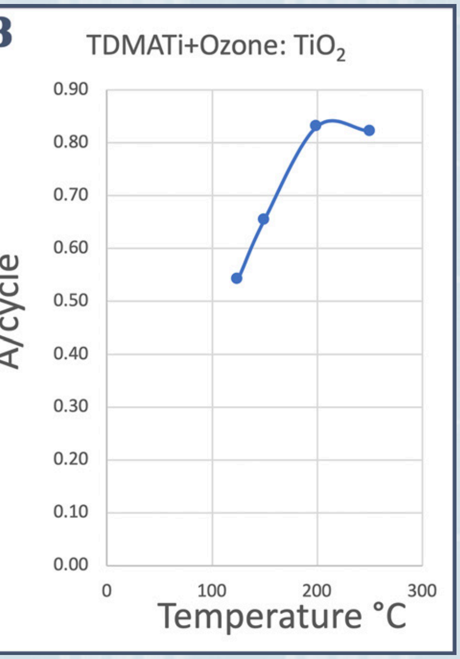

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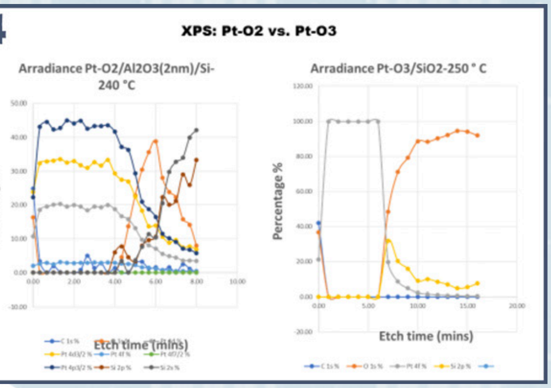

2020 CNF REU Program is Cancelled

And a look back at the 2019 NNCI REU Convocation, hosted by CNF

On March 25th, we sent out the following message to our 2020 CNF REU Interns

Dear CNF REU Interns:

This is a very difficult message to send to you, but we have evaluated the situation with COVID-19 and decided that the only way to keep you safe this summer is to cancel our 2020 CNF REU Program. We pride ourselves in running a highly effective REU program, but there are way too many uncontrolled variables to proceed this summer.

We know you were looking forward to join us for research this summer, and we were looking forward to hosting you. We also appreciate that this decision will have a significant impact, both economically and on your research career. We have successfully hosted REU students every year since at least 1997. But these are strange times and we must make difficult decisions. We hope we are making this decision in time for you to find other opportunities for the summer. Perhaps something close to your home, so we can all practice "shelter in place" and stay well.

Assuming 2021 is back to normal, we intend to offer you a position in next year's program even if you will have graduated by June 2021. You do not need to make any decision now, we will contact you next January. Just know that a CNF REU Program internship is yours for the taking next year.

On a personal note, I am heartbroken to be cancelling the program this year. Working with you interns over the summer is always a highlight of my career. I am very sorry. And I very much hope you'll join us in 2021 instead.

We all wish you the best of health in these troubling times.

Sincerely, Melanie-Claire

Melanie-Claire, CNF REU Program Coordinator
Lynn Rathbun, CNF REU Program Manager
Chris Ober, Director of CNF
Ron Olson, Director of Operations

In August 2019, the CNF was honored to host the NNCI REU Convocation. Here's a look back at better times!

PHOTOGRAPHY & FORMAT CREDITS

Most photographs in this issue were provided by the author, researcher, CNF staff, or as noted. The director photographs on page 3, at the 2019 CNF Annual Meeting, were taken by University Photography. The Duffield Hall photos were taken by Charles Harrington Photography. The REU photos on this page were taken by University Photography and Robyn Wisha.

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

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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 website at cnf.cornell.edu