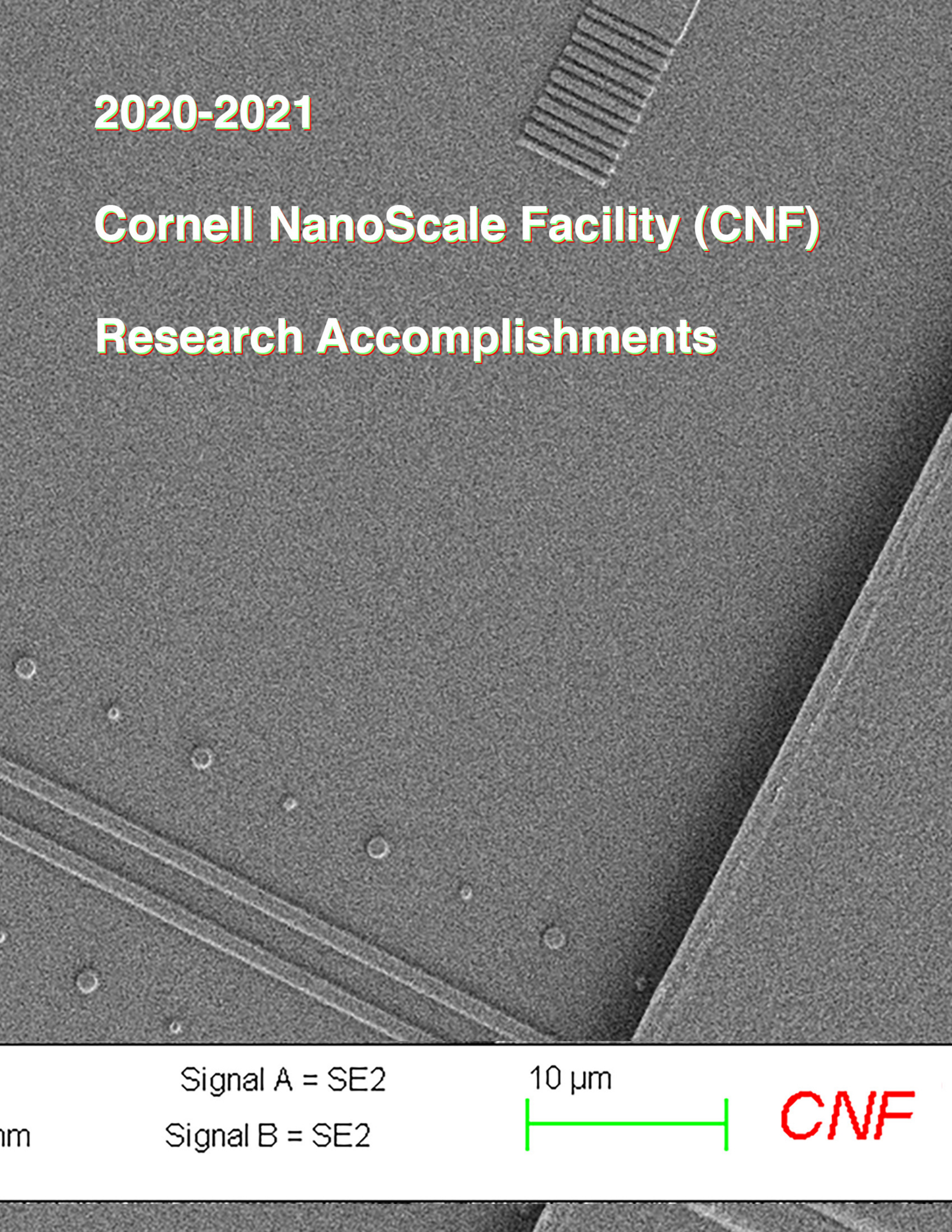
2020-2021

Cornell NanoScale Facility (CNF)

Research Accomplishments



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Cornell NanoScale Facility 2020-2021 Research Accomplishments

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CNF Director of Operations:
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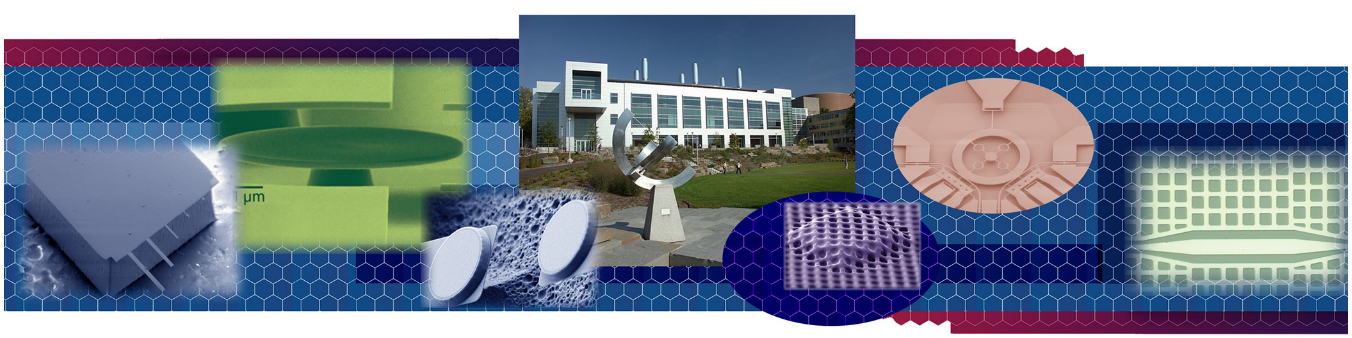
Cornell NanoScale Facility (CNF) is a member of the National Nanotechnology Coordinated Infrastructure *(www.nnci.net)* and is supported by the National Science Foundation under Grant No. NNCI-2025233, the New York State Office of Science, Technology and Academic Research, Cornell University, Industry, and our Users.

The 2020-2021 CNF Research Accomplishments are also available on the web:
http://cnf.cornell.edu/publications/research_accomplishments



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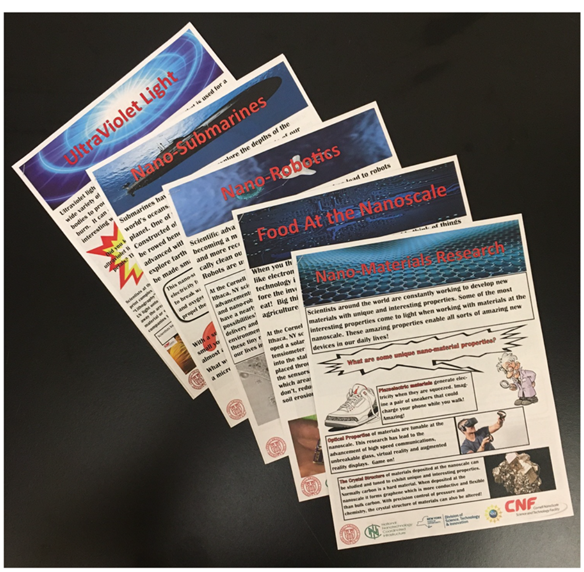
CNF Youth Outreach; At-Home Science Experiments



- CNF's Youth Outreach Program Coordinator, Tom Pennell has developed several at home science experiments for youth to explore the growing field of nanotechnology.
- These experiments will be accompanied by a three part virtual presentation at Cornell University's upcoming 4H Career Explorations event (June 2021).
- Students will have a live tour of the CNF cleanroom, live demonstrations and an introduction into interesting areas of nanoscale research.
- Researchers from the facility will also be available to discuss how they got into the field of nanoscale research with attendees.
- CNF will also be distributing these at home experiments to other schools and youth groups in the surrounding area.

Directors' Welcome

The Cornell NanoScale Science & Technology Facility presents the 2020-2021 CNF Research Accomplishments!

We are honored to showcase excellence in research demonstrated by users and research groups utilizing the plethora of resources offered at the CNF. We thank the users for their contributions to this publication. This collection of work demonstrates the wide range of emerging science and technology fields that utilize nanotechnology tools to achieve diverse state-of-the-art results. In addition to the 73 featured research reports, a section on CNF-research-related patents, presentations, and publications (close to 360 in 2020) is included.

National Nanotechnology Coordinated Infrastructure

NNCI and NNCI Awards

The CNF is delighted to continue its membership in the National Nanotechnology Coordinated Infrastructure (NNCI) with support provided by the National Science Foundation (NSF) and the NYSTAR/ESD Matching Grant Program from New York State. This support is essential to CNF and its position at the forefront of nanofabrication. Earlier this year the CNF submitted the year 6 annual report and participated in a successful, virtual, reverse site visit as part of the cooperative agreement with the NNCI.

Congratulations are extended to Michael Skvarla and Phil Infante who were honored with national awards from the NNCI. Annually, the NNCI acknowledges the efforts of NNCI staff who provide exceptional service and support to network users in the categories of Technical Staff, Education and Outreach, and User Support. This year Mike was awarded the NNCI Staff Award in the User Support category and Phil was granted the NNCI Staff Award for Technical Staff. Phil and Mike will receive a plaque and acknowledgement at the NNCI Annual Conference as well as travel support to attend the conference. The 2021 NNCI Annual Conference, hosted by Northwestern University (SHyNE), will be held Monday, November 1st through Wednesday, November 3rd. The exceptional staff at the CNF have been consistently recognized with NNCI Outstanding Staff Member Awards. Past award recipients include Chris Alpha-Technical Staff (2018), and Tom Pennell-Education and Outreach (2020).

New User Fees Waived for the Remainder of 2021

In June the CNF fully reopened, allowing out of state users back into the facility. With this announcement we introduced an incentive benefiting new grad students and new external users looking to utilize the CNF — new user orientation fees have been eliminated for the remainder of the year.

If you or someone in your research group would like to become a new CNF user, please visit the Getting Started section of the CNF website to initiate the process Additionally, if you know of someone who may be interested in becoming a new CNF user, please feel free to share this announcement. (https://cnf.cornell.edu/howto)

New Partnerships

Cornell Visualization and Imaging Partnership (CVIP)

CNF and the Cornell Institute of Biotechnology (Biotech) partnered to further advance Cornell's excellence in life science characterization and imaging capabilities. CNF users now have access to a broad range of 3-D characterization tools including a variety of confocal microscopes, super-resolution microscopes, and micro/nano-x-ray-CT scanning. The mission of this partnership is to foster and enhance the convergence of research fields while unifying new approaches and ideas to inspire innovation and discovery. CNF cleanroom and Biotech users are now able to mutually access resources in both centers.

Cornell Multiscale 3D Fabrication Partnership (CM3FP)

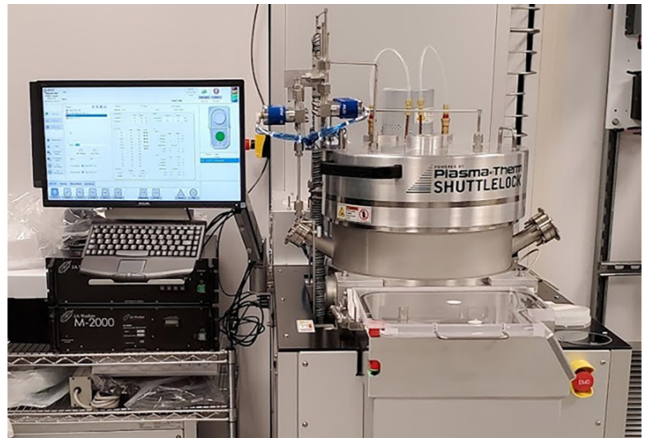
CNF has also partnered with the Rapid Prototyping Lab in the Mechanical Engineering department to provide access to additional multiscale, 3D printing resources. The objective is to provide a broader range of technologies to users. These expanded resources will leverage existing expertise, instrumentation/tools, and administrative support to impact research involving life sciences, heterointegration, and nano/micro-scale technology. CNF and RPL staff will serve as a gateway to new 3D printers, provide consultation, software services, design help, billing, and user support.

Please contact the user program managers (userprogram@cnf.cornell.edu) and/or visit the CNF websites below for additional information on utilizing these resources.

https://www.cnf.cornell.edu/howto/cvip
https://www.cnf.cornell.edu/howto/cm3fp

New Equipment

The CNF continues to upgrade its capabilities in order to remain at the forefront of nanotechnology. We thank you for your patience and continued support as it has been a major effort by the CNF staff to catch up on installation of these tools while dealing with supply chain issues, and other COVID-imposed obstacles. The following equipment has been acquired over the past year and either is installed or being installed.

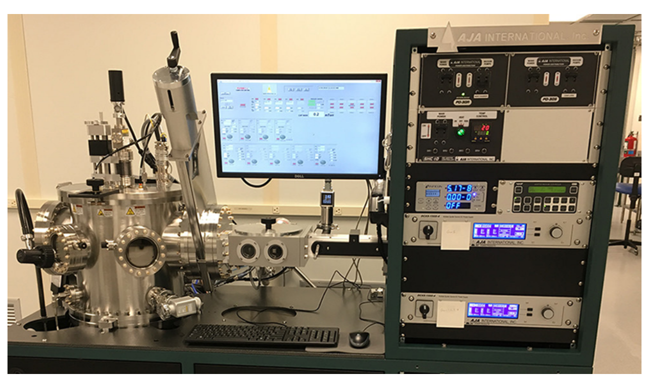


Plasma-Therm ALE (installed, developing the technology)

CNF was able to obtain an advanced ALE instrument from Plasma-Therm. CNF and Plasma-Therm have partnered to develop processes and instrumentation for Atomic Layer Etching (ALE). ALE is an etching technology analogous to Atomic Layer Deposition (ALD) whereby atomically thin layers are added (in the case of ALD) or subtracted (in the case of ALE), by alternating self-limiting chemical reactions, allowing ultra-precise processing, one atomic layer at a time. The system is equipped with a Woollam M2000 in-situ spectroscopic ellipsometer and Langmuir probe. We look forward to developing and sharing new processes on this tool with the CNF and NNCI user communities.

AJA Sputtering Deposition System #3 (Installed, ready for use)

CNF installed an AJA Orion 5 system that supplements CNF's other two AJA Orion 8 RF and DC sputtering systems. The tool will have a host of standard materials available and will allow sputtering of materials like Gold that would not otherwise be permitted in the sputter tools. The Orion 5 tool currently has three 2-inch guns installed but has room for five guns total and has two DC power supplies to allow for co-sputtering. Please reach out to staff for information on criteria for new target additions to the sputter tools.



Veeco Savannah Atomic Layer Deposition System (ALD) (installed, ready for qualification)

This system joins CNF's other two ALD systems, the Oxford FlexAL and the Arradiance GemStar; The Savannah will be dedicated to the deposition of metal films, in particular Aluminum, Platinum, Palladium, and Ruthenium. It is equipped with an ozone generator to assist in lower temperature deposition and to broaden the spectrum of available precursors.

Plasma-Therm HDPCVD (installed, SiO_2 and Si_3N_4 process qualified)

CNF has obtained a high-density plasma chemical vapor deposition system (HPCVD or ICP-PECVD). This system is capable of depositing 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 has replaced the GSI PECVD system and further supports efforts in 2D materials and heterointegration, as well as photonics, biotech, MEMS, and CMOS projects.

Angstrom UHV Load-locked Evaporator (just arrived at the end of August)

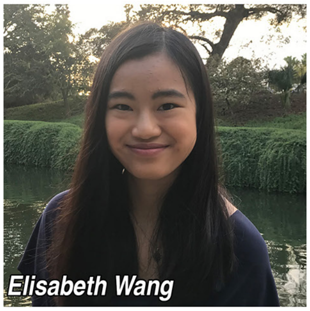
This custom tool from Angstrom Engineering includes in situ ion beam cleaning, GLAD (Glancing Angle Deposition) with rotation, and sample heating. With a load lock and an ultrahigh vacuum system this tool can deposit high purity metal films required for many CNF applications.

Bruker Dektak XT (installed, being qualified)

In order to increase the reliability and capability of our profilometry suite, the CNF has added a Bruker Dektak XT stylus profilometer with 4Å repeatability. We have sample stages to accommodate wafer pieces, as well as full size wafers up to 200 mm. The software gives us motorized stage translation and rotation in addition to sequencing for up to 200 sites. The tool is loaded with a 2 μm radius of curvature diamond-tipped stylus. The Vision64 software can also use the tool measurements to create a 3D map of the scanned surface.


Kareena Dash


Niaa Jenkins-Johnston


Elisabeth Wang


Zhangqi Zheng


Micah Chen


Francesca Bard

CNF REU Interns

Since 1991, we have hosted the Cornell NanoScale Science & Technology Facility Research Experiences for Undergraduates (CNF REU) Program.

After canceling the hands-on event last year due to COVID restrictions, we were pleased to welcome six interns from the Cornell College of Engineering undergraduate community this year. Four students participated as CNF REU interns — Kareena Dash (see page 56), Niaa Jenkins-Johnston (page 2), Elisabeth Wang (page 4), and Zhangqi Zheng (page 112). In addition, Micah Chen from the Cornell Center for Transportation, Environment, and Community Health's (CTECH) REU Program and Francesca Bard (page 54), a summer undergraduate student and CNF user, were "adopted" in order for them to benefit from our logistical support over the summer.

These six students worked diligently for ten weeks on their specific research projects focusing on topics that included biological applications, materials characterization, nanophysics, and evaluation of transportation sustainability. There were multiple opportunities to garner presentation skills by offering progress updates and concluding the program with the submission of a final report. Many of the participants will continue with their respective research groups into the fall semester.

The 2021 CNF REU Program reports, photo album, and final presentation videos will soon be available online at https://cnf.cornell.edu/education/reu/2021

We plan to conduct a nation-wide search for our 2022 CNF REU interns in November. Keep an eye on https://cnf.cornell.edu/education/reu for information regarding next year's application process.

TCN and Outreach

The CNF's Technology and Characterization at the Nanoscale (TCN) short course is offered twice each year. It continues to provide an excellent opportunity for the scientific community to learn about the field of nanofabrication from in-house experts. The TCN is open to participants from academia, industry and government, and includes lectures, demonstrations and activities in the cleanroom. Due to COVID we were pleased to offer this course virtually, which resulted in us reaching a broader audience with increased attendance. With this in mind, going forward, the CNF will be offering the January TCN course virtually and the June TCN course in person. The technical staff are also working to develop new educational modules based on developing technologies. Please reach out to Tom Pennell, our Youth Outreach Program Coordinator, if you are interested in having a specific device type featured in the instruction.

CNF's youth outreach program continues to partner with 4H and recently hosted students from across NY State for Cornell's annual Career Explorations event. Tom Pennell, created five new at home nanoscience experiments based on photolithography, materials science, and nanorobotics. He has packaged nearly 300 of them with the required materials to be distributed to any youth groups interested in learning more about our field. (See page iv for more....)

The youth outreach program will also be taking part in a national 4H summit in September, teaching students about nanotechnology and how it relates to space exploration.

Staffing News

Welcome

A warm welcome is extended to new User Program Assistant, Stacy Clementson who came to us from the Praxis Center for Venture Development at Cornell. Stacy will focus 75% of her time assisting with new User onboarding for the CNF and 25% of her time supporting Praxis.

Comments, feedback, and suggestions about CNF are always welcome. Feel free to use our online User Comment Form at https://www.cnfusers.cornell.edu/user_feedback

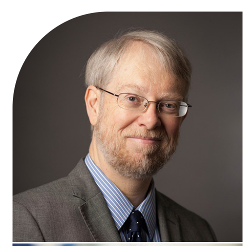
In Person Again

With the lifting of restrictions in June, almost all the CNF staff came back to work in the office full time, in person. We celebrated in the most typical CNF staff kind of way — we gathered with a BBQ party. A good time was had by all!

While we are back in the office for the most part, it's a good idea to call ahead if you want to meet with someone in particular, to make sure they are in fact "in person" that day.

THANK YOU to the CNF COMMUNITY!

Thank you to all CNF users for their continued patience and understanding during these unprecedented times. It is imperative we remain diligent in our efforts as a community to support ongoing safety protocols in order to help safeguard the progress we have made. We will continue to monitor the course of the pandemic and provide updates when warranted and directed by the University and Tompkins County Health Department.



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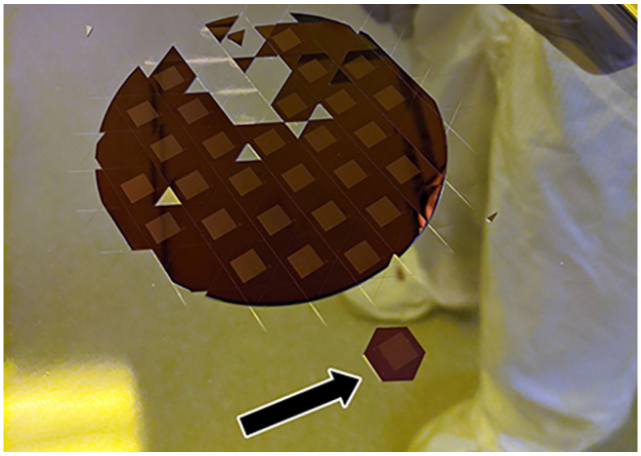
CNF in the NEWS

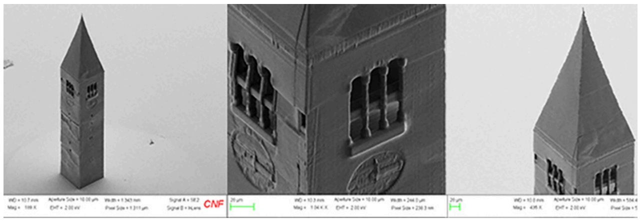


More than 27,000 Civil Air Patrol Names Headed to the Moon

The US Air Force Auxiliary Civil Air Patrol (CAP) partnered with the CNF to etch more than 27,000 CAP member names, 270 Air Force Association (AFA) StellarXplorers names, an 80th anniversary CAP logo, and messages from CAP and AFA leadership onto a microchip the size of a postage stamp. This microchip, carrying 27,285 names, messages, and images, is set to be carried to the Moon later this year aboard Astrobotic's Peregrine lunar lander.

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

The CNF technical staff worked with CAP to design the chip, starting with a computer-aided design (CAD) through using their photolithography, etching, and dicing tools to lay down an 80-nanometer thin film of silicon nitride on a standard silicon wafer. Details of the process — from start to finished chip, 0.5" across the hexagon, flat edge to flat edge — can be found in the Image Gallery online. https://cnf.cornell.edu/node/325



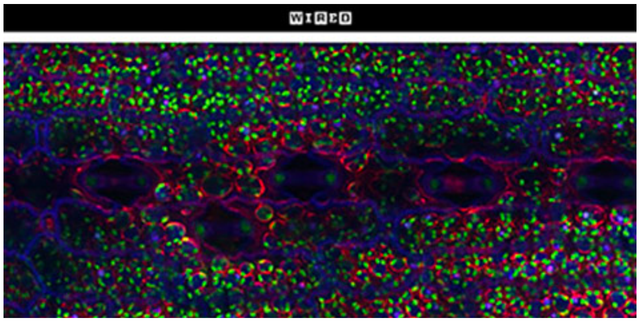
The CNF's Nano-Sized McGraw Tower

Once again the Cornell NanoScale Facility (CNF) makes a molehill out of a mountain — or in this case, the smallest rendition of Cornell's iconic McGraw Clock tower.

Twenty-four years ago, physics professor Harold Craighead and then-doctoral student Dustin Carr, Ph.D. '00, created the world's smallest guitar using cutting-edge technology in what was then the Cornell Nanofabrication Facility. They're at it again at the center – now known as the Cornell NanoScale Science and Technology Facility (CNF), in Duffield Hall. A team led by staff photolithographer Ed Camacho has created the world's smallest rendition of Cornell's iconic McGraw Tower – complete with its 161 interior steps, two sets of stairs and 21 bells.

"This is possibly the world's smallest bell tower," said Camacho, whose achievement of epic proportions was accomplished using one of CNF's newest tools: the NanoScribe GT2 Laser Lithography System, a two-photon polymerization volumetric 3D printer.

https://www.14850.com/051119827-mcgraw-tower-model/



Which Crops Can Survive Drought? Nanosensors May Offer Clues.

Abraham Stroock's technique can be used to track how water flows through plants, which could be key to breeding more resilient crops in an increasingly hot, dry climate. (This work was performed in part at the CNF)

https://www.wired.com/story/which-crops-can-survive-drought-nanosensors-may-offer-clues/

A Selection of 2020 Cornell NanoScale Facility Research-Related Patents, Presentations, and Publications

"A discrete interface in matrix stiffness creates an oscillatory pattern of endothelial monolayer disruption"; J.A. VanderBurgh, A.V. Potharazu, S.C. Schwager, C.A. Reinhart-King; J. of Cell Science 2020 133: jcs244533 doi: 10.1242/jcs.244533.

"A Highly Selective, Tunable High-Pass X-Ray Filter System and the Method of Fabrication"; D.Agyeman-Budu, A.Woll; 8827-02-US, United States, US from PRV, Filed, 8/3/20, 16/983,887.

"A minimally disruptive method for measuring water potential in-planta using hydrogel nanoreporters"; Jain, P.; Liu, W.; Zhu, S.; Melkonian, J.; Pauli, D.; Riha, S.; Gore, M.; Stroock, A.; bioRxiv, Posted May 30, 2020, doi: https://doi.org/10.1101/2020.05.29.122507.

"A Multiplexed Diagnostice Assay for Iron and Vitamin A Deficiency and Methods of Use Thereof"; D.Erickson, Z.Lu, S.Mehta; 7107-03-US Filed, US from PCT, 5/13/20, 16/763,707.

"A tissue engineering approach to metastatic colon cancer"; Sarvestani, SK, RK Dehaan, PG Miller, S Bose, X Shen, ML Shuler, and EH Huang; iScience 23:101719, Nov.20, 2020.

"a-axis YBa2Cu3O7-x/PrBa2Cu3O7-x/YBa2Cu3O7-x trilayers with subnanometer rms roughness"; Y. Eren Suyolcu, J.Sun, B.Goodge, J.Park, J.Schubert, L.Kourkoutis, D.Schlom; arXiv:2010.12624 [cond-mat.supr-con] [Submitted 23 Oct 2020].

"Absence of spin current generation in Ti/FeCoB bilayers with strong interfacial spin-orbit coupling"; L.Zhu, R.A. Buhrman; arXiv preprint arXiv:2010.13137, 2020 - arxiv.org.

"Acoustic Sensing Systems, Devices and Methods"; M.Abdelmejeed, J.Kuo, A.Lal; 7683-05-EP, Europe, EPC - European Patent Convention, Filed, 9/1/20, 19747141.

"Acoustically Driving the Single-Quantum Spin Transition of Diamond Nitrogen-Vacancy Centers"; Chen, H. Y.; Bhave, S. A.; Fuchs, G. D.; Physical Review Applied, 13, 5, 54068.

"Acoustically-driven Quantum Spin Sensor"; H.Chen, G.Fuchs; 9329-01-US, United States, Filed, MPR 1/24/20, 62/965,533; 9329, Invention, Filed by Cornell.

"Adsorption-controlled growth of Ga2O3 by suboxide molecular-beam epitaxy"; P.Vogt, F.Hensling, K.Azizie, C.Chang, D.Turner, J.Park, J.McCandless, H.Paik, B.Bocklund, G.Hoffman, O.Bierwagen, D.Jena, H.Xing, S.Mou, D.Muller, S.Shang, Z.Liu, and D.Schlom; arXiv:2011.00084 [Oct 2020].

"All-Epitaxial Bulk Acoustic Wave Resonators"; J.Miller, J.Wright, H.Xing, D.Jena; physica status solidi (a), 217, 7, 1900786.

"An array microhabitat device with dual gradients revealed synergistic roles of nitrogen and phosphorous in the growth of microalgae"; Liu, F.; Yazdani, M.; Ahner, B.; Wu, M.; Lab on a Chip, 20, 4, 798-805.

"An automated controlled release device for livestock management"; D.Erickson, J.Giordano, Ma.Masello, Y.Ren; 9391-01-US, United States, Filed, MPP, 4/27/20, 63/016,235.

"An organotypic in vitro model of matured blood vessels"; J.Lee, E.Lee; bioRxiv, Posted August 04, 2020. doi: https://doi.org/10.1101/2020.08.03.234807.

"An unexplored MBE growth mode reveals new properties of superconducting NbN"; Wright, J.; Chang, C.; Waters, D.; Lüpke, F.; Raymond, L.; Koscica, R.; Khalsa, G.; Feenstra, R.; Muller, D.; Xing, H.G.; arXiv:2008.09596 [cond-mat.mtrl-sci] [Submitted on 21 Aug 2020 (v1), last revised 24 Dec 2020 (this version, v3)] DOI: 10.1103/PhysRevMaterials.5.024802.

"Antifouling urinary catheters with shape-memory topographic patterns"; D.Ren, H.Gu; US Patent App. 16/674,199, 2020.

"Applying uniaxial strain to graphene devices fabricated on flexible substrates"; Oh, J.; Schaefer, B.; Sunko, V.; Watanabe, K.; Taniguchi, T.; Hicks, C.; Mackenzie, A.P.; Nowack, K.; Bulletin of the American Physical Society, 65.

"Area-selective atomic layer deposition enabled by competitive adsorption"; Suh, T., Y.Yang, H.Sohn, R.DiStasio Jr., and J.Engstrom; Journal of Vacuum Science & Technology A 38, 062411 (2020) [Editor's Pick in JVST A].

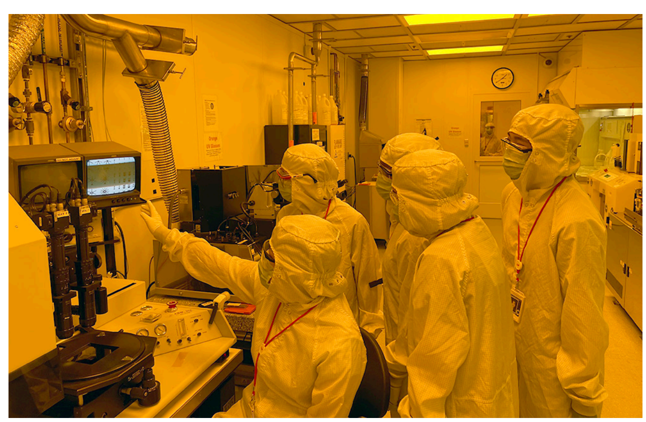
"Athermal lithium niobate microresonator"; Ling, Jingwei; He, Yang; Luo, Rui; Li, Mingxiao; Liang, Hanxiao; Lin, Qiang; Optics Express, 28, 15, 21682-21691.

"Atomic Layer Deposition for Mechanical, Magnetic, and Robotic Systems"; Dorsey, K.; Ph.D. Thesis, Cornell University, 2020. 28025674.

"Automated microfluidic Oocyte Denudation Module"; A.Abbaspourrad, A.Mokhtare, G.Palermo; 9534-01-US, United States, Filed, MPR - Manuscript Provisional, 7/6/20, 63/048,531; 9534, Invention, Filed by Cornell.

"Automated, Ultra-Fast Laser-Drilling of Nanometer Scale Pores and Nanopore Arrays in Aqueous Solutions"; Gilboa, T.; Zvuloni, E.; Zrehen, A.; Squires, A.; Meller, A.; Advanced Functional Materials, 30, 18, 1900642.

"Bidirectional Self-Folding with Atomic Layer Deposition Nanofilms for Microscale Origami"; Bircan, B.; Miskin, M. Z.; Lang, R. J.; Cao, M. C.; Dorsey, K. J.; Salim, M. G.; Wang, W.; Muller, D. A.; McEuen, P. L.; Cohen, I.; Nano Letters, 2020, 20(7), 4850-4856.



"Biological Small-Molecule Assays Using Gradient-based Microfluidics"; A.Abbaspourrad, M.Azizi; 9495-01-US, United States, MPR, Filed, 12/23/20, 63/130,172.

"Block Copolymer Self-Assembly-Directed and Transient Laser Heating-Enabled Nanostructures toward Phononic and Photonic Quantum Materials"; F.Yu, Q.Zhang, R.P.Thedford, A.Singer, D.M. Smilgies, M.O. Thompson, and U.B. Wiesner; ACS Nano 2020, 14, 9, 11273-11282; Publication Date:August 11, 2020; https://doi.org/10.1021/acsnano.0c03150.

"Blood-immersed Bearing System for a Blood Pump"; J.Antaki; 9293, Invention, Filed - Ownership Determination - TBD.

"Body-on-a-Chip Microscale models for Drug Development"; Shuler, M.L.; SelectBio 2D to 3D Culture and organoids. Boston, MA March 23-25. (virtual talk).

"Body-on-a-Chip: Conception to Practical Applications"; Shuler, M.L.; EUROoCS Conf. 2020. Held virtually (originally scheduled for Uppsala Sweden), July 8-9.

"Body-on-a-Chip: Human Microscale Models for Drug Development"; Shuler, M.L.; Select Bio Organ-on-a-Chip 2020. San Diego, CA September 28-30. (virtual talk).

"Bottom Tunnel Junction Blue Light-emitting Field-effect Transistors"; S.Bharadwaj, A.Hickman, D.Jena, K.Lee, K.Nomoto, V.Protasenko, L.van Deurzen, H.G.Xing; 9544, Invention, Filed by Cornell 2020; APL 117, 031107 (2020); https://doi.org/10.1063/5.0009430.

"Breakdown of the Small-Polaron Hopping Model in Higher-Order Spinels"; A.Bhargava, R.Eppstein, J.Sun, M.Smeaton, H.Paik, L.Kourkoutis, D.Schlom, M.Toroker, R.Robinson; Advanced Materials Volume 32, Issue 49; December 10, 2020; https://doi.org/10.1002/adma.202004490.

"Broadband Ultrahigh-Resolution chip-scale Scanning Soliton Dual-Comb Spectroscopy"; Lin, T.; Dutt, A.; Joshi, C.; Phare, C.; Okawachi, Y.; Gaeta, A.; Lipson, M.; arXiv preprint arXiv:2001.00869.

"Characterization of AlScN on CMOS"; Y. Liu, J. Kuo, B. Davaji, V. Gund, J. Sharma, N. Singh and A. Lal; IEEE International Frequency Control Symposium (IFCS), 2020.

"Characterization of Metal Effect on Solidly Mounted AlScN on CMOS"; Y.Liu; J.Kuo; A.Lal; J.Sharma; N.Singh; 2020 IEEE International Ultrasonics Symposium (IUS), 7-11 Sept. 2020, DOI: 10.1109/IUS46767.2020.9251681.

"Characterization of topologically protected charge-parity qubits"; Y.Liu, K.Dodge, M.Senatore, B.Cole, J.Ku, S.Zhu, A.Shearrow, A.Klots, L.Faoro, L.Ioffe, R.McDermott, B.Plourde; Applied Superconductivity Conference, Nov. 2020 Invited poster.

"Chemical-Genetic Interrogation of Nuclear Size Control Reveals Cancer-Specific Effects on Cell Migration and Invasion"; Rizzotto, A.; Tollis, S.; Pham, N.; Wildenhain, J.; Zuleger, N.; Keys, J.; Batrakou, D.; Culley, J.; Zheng, S.; Lammerding, J.; bioRxiv, Posted January 11, 2020, doi: https://doi.org/10.1101/2020.01.10.902148.

"Chip-scale blue light phased array"; M.Shin, A.Mohanty, K.Watson, G.Bhatt, C.Phare, S.Miller, M.Zadka, B.Lee, X.Ji, I.Datta, and M.Lipson; Optics Letters 45 (7), 1934-1937 (2020).

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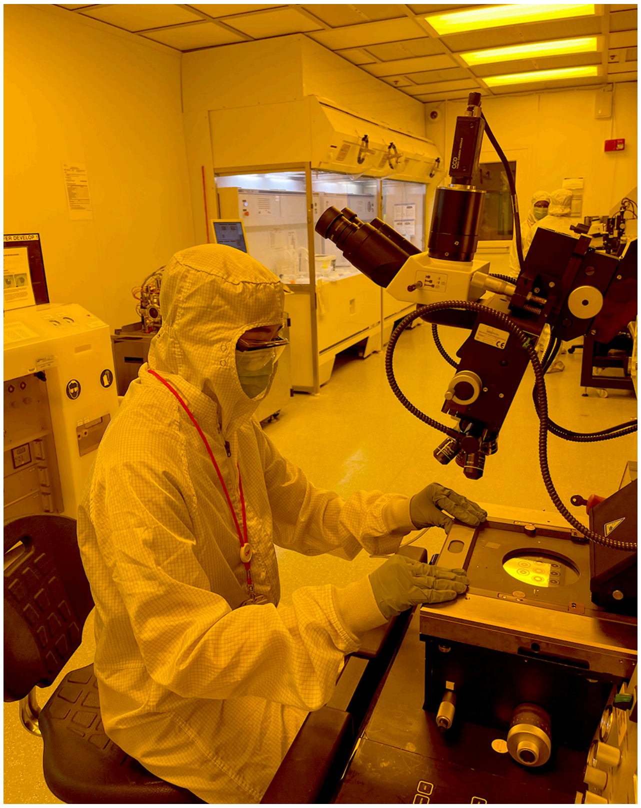

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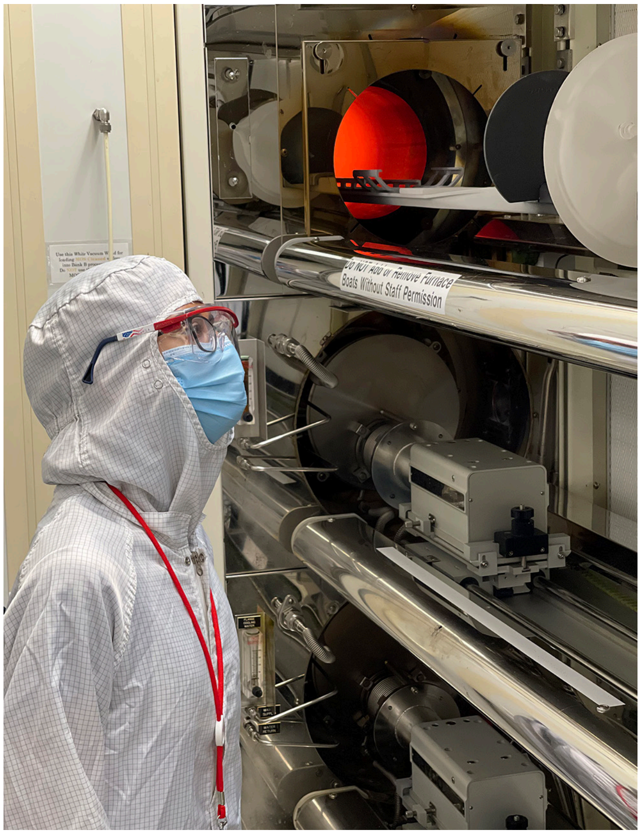

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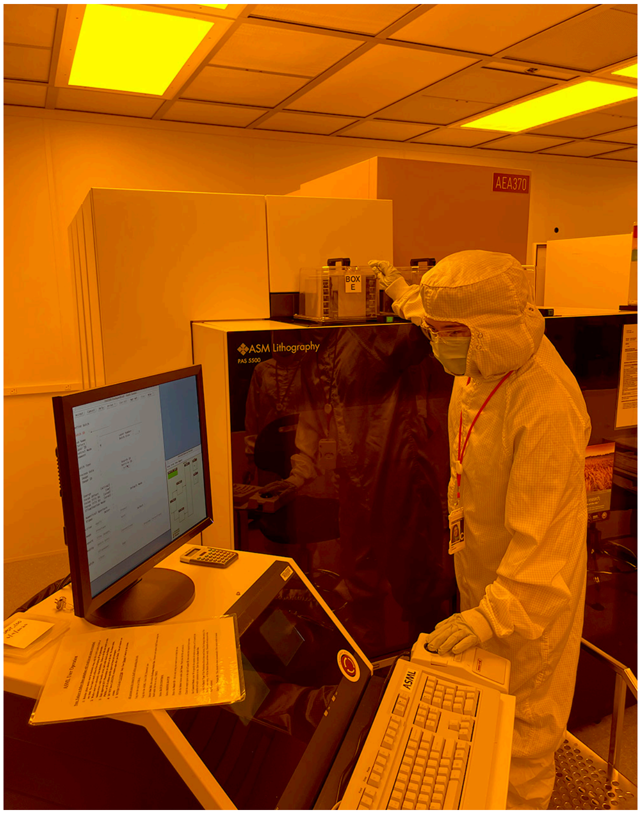

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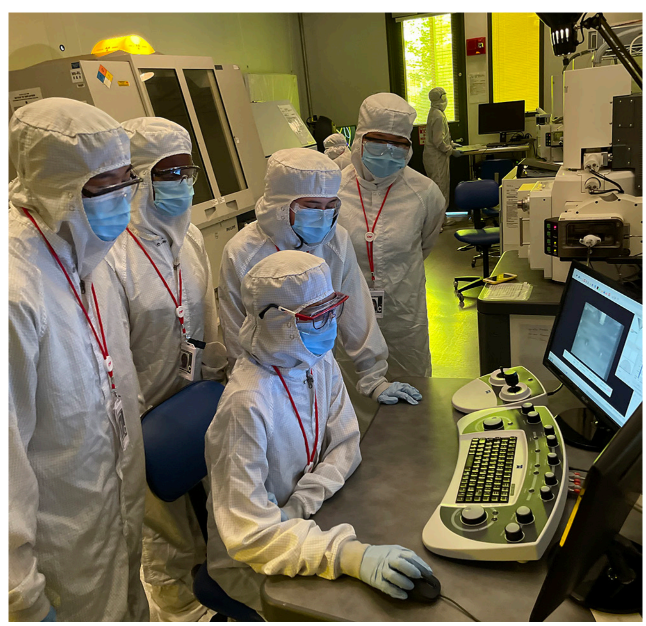

Common Abbreviations & Meanings

μl .. .. microliter
μm .. .. micron, micrometer
μN .. .. micro-Newtons
μs .. .. microsecond
Ω .. .. Ohm
< .. .. is less than
> .. .. is greater than
~ .. .. approximately
1D .. .. one-dimensional
2D .. .. two-dimensional
2DEG .. .. .. two-dimensional electron gas
3D .. .. three-dimensional
^{3}He helium-3
α-Al_2O_3 .. .. .. sapphire
a-Si .. .. amorphous silicon
AC .. .. alternating current
AFM .. .. atomic force microscopy/microscope
AFOSR .. .. .. Air Force Office of Scientific Research
Ag .. .. silver
Al .. .. aluminum
Al_2O_3 .. .. aluminum oxide
ALD .. .. atomic layer deposition
AlGaAs .. .. .. aluminum gallium arsenide
AlGaN .. .. .. aluminum gallium nitride
Ar .. .. argon
ARC .. .. anti-reflective coating
ArF .. .. argon fluoride
As .. .. arsenic
atm .. .. standard atmosphere (as a unit of pressure)
Au .. .. gold
AuNPs .. .. .. gold nanoparticles
B .. .. boron
B. subtilis .. .. .. *Bacillus subtilis*
Bi .. .. bismuth
BOE .. .. buffered oxide etch
Br .. .. bromine
C .. .. carbon
C .. .. centigrade
C-V .. .. capacitance-voltage
C_3N_4 .. .. carbon nitride
$CaCl_2$ .. .. calcium chloride
$CaCO_3$ .. .. .. calcium carbonate
CAD .. .. computer-aided design
CaF_2 .. .. calcium fluoride
CCMR .. .. .. Cornell Center for Materials Research
Cd .. .. cadmium
CdS .. .. cadmium sulfide
CdSe .. .. cadmium selenide
CDW .. .. charge-density-wave
Ce .. .. cerium
CF_4 .. .. carbon tetrafluoride or tetrafluoromethane
CFD .. .. computational fluid dynamics
CH_4 .. .. methane
CHESS .. .. .. Cornell High Energy Synchrotron Source
CHF_3 .. .. trifluoromethane
Cl .. .. chlorine
Cl_2 .. .. chlorine gas
Cl_2/SF_6 .. .. .. chlorine sulfur hexafluoride
cm .. .. centimeter
CMOS .. .. .. complementary metal oxide semiconductor
CMP .. .. chemical mechanical polishing
CNF .. .. Cornell NanoScale Science & Technology Facility
Co .. .. cobalt
CO_2 .. .. carbon dioxide
Co_3O_4 .. .. cobalt oxide
CoFeAl .. .. .. cobalt iron aluminum
CoFeB .. .. .. cobalt iron boron
CoP .. .. cobalt porphyrin
CPC .. .. colloidal photonic crystal
CPD .. .. contact potential difference
CpG .. .. cytosine-phosphate-guanine
Cr .. .. chromium
CRDS .. .. .. cavity ring-down spectrometer
cryoSAXS .. .. cryogenic small angle x-ray scattering
CTE .. .. coefficients of thermal expansion
CTL .. .. confinement tuning layer
Cu .. .. copper
CVD .. .. cardiovascular disease
CVD .. .. chemical vapor deposition
CW .. .. continuous wave
CXRF .. .. .. confocal x-ray fluorescence microscopy
DARPA .. .. .. Defense Advanced Research Projects Agency
DC .. .. direct current
DCB .. .. double cantilever beam
DCE 1,2-dichloroethane
DCM .. .. dichloromethane
DEP .. .. dielectrophoresis
DFT .. .. density functional theory
DFT .. .. discrete Fourier transform
DI .. .. de-ionized
DMF .. .. dimethyl formamide
DNA .. .. deoxyribonucleic acid
DNP .. .. dynamic nuclear polarization
DOE .. .. United States Department of Energy
DPPC 1,2-dipalmatoyl-sn-glycero-3-phosphocholine
DRAM .. .. .. dynamic random access memory
DRIE .. .. .. deep reactive ion etch
DSA .. .. directed self assembly
dsDNA .. .. .. double-stranded DNA
DUV .. .. deep ultraviolet
e-beam .. .. .. electron beam lithography
E. coli .. .. .. *Escherichia coli*
EBL .. .. electron-beam lithography
EDS .. .. energy dispersive spectroscopy
EELS .. .. electron energy loss spectroscopy
EG .. .. ethylene glycol

EIS.. .. .. electrochemical impedance spectroscopy
ELISA .. .. enzyme-linked immunosorbent assays
EO .. .. electro-optic
EOT .. .. equivalent oxide thickness
EPICs .. .. electronic photonic integrated circuits
Er. .. .. erbium
ErAs .. .. erbium arsenide
ESM .. .. effective screening medium
EUV .. .. extreme ultraviolet
ex situ .. .. Latin phrase which translated literally as 'off-site' -- to examine the phenomenon in another setting than where it naturally occurs
ex vivo .. .. Latin for "out of the living" -- that which takes place outside an organism
F .. .. fluorine
FDA .. .. United States Food & Drug Administration
FDMA .. .. fluorinated perfluorodecyl methacrylate
Fe. .. .. iron
Fe_2O_3 . .. . iron oxide
$FeCl_3$.. .. .. iron(III) chloride, aka ferric chloride
FeGe .. .. iron germanium
FEM .. .. finite element method
FET. .. .. field-effect transistor
FFTs .. .. fast Fourier transforms
fg . .. . femto gram
FIB . .. . focused ion beam
FIR . .. . far infrared
fJ.. .. .. femto Joules
FM .. .. frequency modulation
FMR .. .. ferromagnetic resonance
FOTS. .. .. fluorosilane, tridecafluoro-1,1,2,2-tetrahydrooctyltrichlorosilane
FTIR .. .. Fourier transform infrared spectroscopy
Ga .. .. gallium
Ga_2O_3. .. .. gallium(III) trioxide
GaAs . .. . gallium arsenide
GaAsN.. .. .. .. gallium arsenide nitride
GaInNAs . .. .. gallium indium nitride arsenide
GaN .. .. gallium nitride
GaP. .. .. gallium phosphide
GaSb.. .. .. gallium antimonide
Gd .. .. gadolinium
Ge .. .. germanium
GFET. .. .. graphene field effect transistor
GHz .. .. gigahertz
GI .. .. gastrointestinal
GMR . .. . giant magnetoresistance
GPa. .. .. gigapascal
GPS .. .. global positioning system
h .. .. hours
H.. .. .. hydrogen
H_2O_2 .. .. hydrogen peroxide
HBAR .. .. high-overtone bulk acoustic resonator
hBN .. .. hexagonal boron nitride
HBr. .. .. hydrogen bromide
hcp.. .. .. hexagonal close packing
He .. .. helium
HEMTs . .. . high electron mobility transistors

Hf .. .. hafnium
HF .. .. hydrofluoric acid
HfB_2 .. .. hafnium diboride
HFEs . .. . hydrofluoroethers
HfO_2 .. .. hafnium dioxide
Hg .. .. mercury
high-κ .. .. high dielectric constant
HMDS.. .. .. .. hexamethyldisilazane
HRS .. .. high resistance state
HSQ .. .. hydrogen silsesquioxane
HSQ/FOx .. .. negative electron beam resist hydrogen silsesquioxane
Hz .. .. Hertz
I-V .. .. current-voltage
I/O .. .. input/output
IARPA.. .. .. .. Intelligence Advanced Research Projects Activity
IC. .. .. integrated circuit
ICP . .. . inductively coupled plasma
ICP-MS .. .. .. inductively coupled plasma mass spectroscopy
ICP-RIE .. .. .. inductively coupled plasma reactive ion etcher
IFVD . .. . impurity free vacancy diffusion
IID .. .. impurity induced disordering
IIEI . .. . ion implant enhanced interdiffusion
In . .. . indium
in situ. .. .. Latin phrase which translated literally as 'in position' -- to examine the phenomenon exactly in place where it occurs
in vitro .. .. Latin for "within glass" -- refers to studies in experimental biology that are conducted using components of an organism that have been isolated from their usual biological context in order to permit a more detailed or more convenient analysis than can be done with whole organisms
in vivo .. .. Latin for "within the living" -- experimentation using a whole, living organism
InAlN .. .. indium aluminum nitride
InAs .. .. indium arsenide
InAs NWs .. .. indium arsenide nanowires
INDEX . .. . Institute for Nanoelectronics Discovery and Exploration
InGaAsN . .. .. indium gallium arsenide nitride
$InGaZnO_4$ .. .. indium gallium zinc oxide
InP .. .. indium phosphide
IPA.. .. .. isopropyl alcohol
IR. .. .. infrared
IrO_2 or IrO_x. .. iridium oxide
ITO . .. . indium tin oxide
JP-8 .. .. Jet Propellant 8
κ .. .. dielectric constant
K.. .. .. Kelvin (a unit of measurement for temperature)
K.. .. .. potassium
KFM .. .. Kelvin force microscopy
kg. .. .. kilogram
kHz. .. .. kilohertz
KOH .. .. potassium hydroxide
La .. .. lanthanum
LED .. .. light-emitting diode
LER .. .. line edge roughness
Li . .. . lithium

low-κ . .. . low dielectric constant
LPCVD .. .. .. low pressure chemical vapor deposition
lpm . .. . liter per minute
LRS .. .. low resistance state
Lu .. .. lutetium
LWR .. .. line width roughness
MBE .. .. molecular beam epitaxy
MEMs .. .. microelectromechanical systems
MFMR.. .. .. .. microfabricated micro-reactors
MgO .. .. magnesium oxide
MGs .. .. molecular glasses
MHz .. .. megahertz
micron .. .. micrometer, aka μm
min . .. . minutes
ml .. .. milliliter
mm . .. . millimeter
mM . .. . millimolar
Mo .. .. molybdenum
MOCVD.. .. .. metal oxide chemical vapor deposition
MOS .. .. metal oxide semiconductor
MoS_2.. .. .. molybdenum disulfide
$MoSe_2$ .. .. molybdenum diselenide
MOSFET. .. .. metal oxide semiconductor field effect transistor
MRAM . .. . magnetic random access memory
MRFM.. .. .. .. magnetic resonance force microscopy
MRI .. .. magnetic resonance imaging
ms .. .. millisecond
MSM . .. . metal-semiconductor-metal
mTorr. .. .. millitorr
mV.. .. .. millivolt
MVD . .. . molecular vapor deposition
MΩ. .. .. megaohms
N.. .. .. nitrogen
N_2 .. .. nitrous oxide
nA .. .. nanoAmperes
NaCl . .. . sodium chloride
NASA .. .. National Aeronautics & Space Administration
Nb .. .. niobium
Nb_3Sn .. .. triniobium-tin
NCs .. .. nanocrystals
Nd .. .. neodymium
NEMs .. .. nanoelectromechanical systems
NH_4F . .. . ammonium fluoride
Ni. .. .. nickel
NIH .. .. National Institutes of Health
NIR. .. .. near-infrared
nL .. .. nanoliter
nm .. .. nanometer
NMP n-methyl-2-pyrrolidone
NNCI. .. .. National Nanotechnology Coordinated Infrastructure
NPs . .. . nanoparticles
NPs . .. . nanopores
ns . .. . nanosecond
NSF .. .. National Science Foundation
NV.. .. .. nitrogen-vacancy
NVM . .. . non-volatile memory
NW FETs. .. .. nanowire field-effect transistors
O.. .. .. oxygen
O_3 .. .. trioxygen
OFET. .. .. organic field effect transistor
OLED .. .. organic light-emitting diode
ONO .. .. oxide/nitride/oxide
ONR-MURI .. Office of Naval Research Multidisciplinary University Research Initiative
OPV .. .. organic photovoltaic cells
OTFT. .. .. organic thin-film transistor
Pa. .. .. Pascals
PAB .. .. post-apply bake
PaC . .. . Parylene-C
PAG .. .. photoacid generator
Pb .. .. lead
PBG .. .. photonic bandgap
PbS . .. . lead sulfide
PBS .. .. phosphate-buffered saline
PbSe .. .. lead selenide
PC .. .. persistent current
PC .. .. photocurrent
PCN .. .. photonic crystal nanocavity
Pd .. .. palladium
PD .. .. photodetector
PDMS .. .. polydimethylsiloxane
PEB .. .. post-exposure bake
PEC .. .. photoelectrochemical
PECVD .. .. .. plasma enhanced chemical vapor deposition
PEDOT:PSS .. poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate)
PEG .. .. polyethylene glycol
PEI.. .. .. polyethyleneimine
pFET.. .. .. p-channel field-effect transistor
PFM .. .. piezo-response force microscopy
PGMA .. .. poly(glycidyl methacrylate)
pH .. .. a measure of the activity of hydrogen ions (H+) in a solution and, therefore, its acidity
Ph.D. . .. . doctorate of philosophy
PhC. .. .. photonic crystal
PL .. .. photoluminescence
pL .. .. picoliter
PLD .. .. pulsed laser deposition
PMMA.. .. .. .. poly(methyl methacrylate)
poly-Si .. .. polycrystalline silicon
PS .. .. polystyrene
PS-*b*-PMMA polystyrene-*block*-poly(methyl methacrylate)
Pt . .. . platinum
Pt/Ir .. .. platinum/iridium
$PtSe_2$ .. .. platinum diselenide
PV .. .. photovoltaic
PVD .. .. physical vapor deposition
Py .. .. permalloy, $Ni_{81}Fe_{19}$
Q.. .. .. quality factor
QD.. .. .. quantum dots
QW . .. . quantum well
RA .. .. resistance-area
REU .. .. Research Experiences for Undergraduates Program
RF .. .. radio frequency

RF MEMS .. .. radio frequency microelectromechanical systems
RIE . .. . reactive ion etch
RMS or rms .. root mean square
RNA .. .. ribonucleic acid
RTA .. .. rapid thermal anneal
RTD .. .. resistance temperature device
RTD .. .. resonant tunneling diodes
Ru .. .. ruthenium
s .. .. seconds
S .. .. sulfur
SAMs .. .. self-assembled monolayers
SAXS .. .. small angle x-ray scattering
Sb .. .. antimony
Sc. .. .. scandium
sccm .. .. standard cubic centimeters per minute
$scCO_2$ .. .. supercritical carbon dioxide
SDS .. .. sodium dodecyl sulfate
Se. .. .. selenium
sec .. .. seconds
SEM .. .. scanning electron microscopy/microscope
SERS . .. . surface enhanced Raman spectroscopy
SF_6 .. .. sulfur hexafluoride
Si . .. . silicon
Si_3N_4 .. .. silicon nitride
SiC.. .. .. silicon carbide
SiH_4 .. .. silane
SiN . .. . silicon nitride
SiO_2 .. .. silicon dioxide, silica
Sn .. .. tin
SnO_2 .. .. tin oxide
$SnSe_2$ . .. . tin selenide or stannous selenide
SOI . .. . silicon-on-insulator
SPR .. .. surface plasmon resonance
SQUID . .. . superconducting quantum interference device
Sr_2RuO_4 .. .. .. strontium ruthenate
SRC .. .. Semiconductor Research Corporation
$SrTiO_3$ .. .. strontium titanate
STEM .. .. scanning transmission electron microscopy/microscope
t-BOC .. .. *tert*-butoxycarbonyl
Ta. .. .. tantalum
Ta_2O_5 . .. . tantalum pentoxide
TaN. .. .. tantalum nitride
TAO_x . .. . tantalum oxide
Te. .. .. tellurium
TEM .. .. transmission electron microscopy/microscope
TFET . .. . tunnel field effect transistor
TFT. .. .. thin-film transistor
Tg .. .. glass transition temperature
THz .. .. terahertz
Ti . .. . titanium
TiN . .. . titanium nitride
TiO_2 .. .. titanium dioxide
TM.. .. .. transverse magnetic
TXM.. .. .. transmission x-ray microscopy
UHV .. .. ultra-high vacuum
USDA .. .. United States Department of Agriculture
UV.. .. .. ultraviolet
UV-Vis . .. . ultraviolet-visible
V.. .. .. vanadium
V.. .. .. voltage
vdW .. .. van der Waals
VLS .. .. vapor-liquid-solid
VRMs .. .. voltage regulator modules
VSM .. .. vibrating sample magnetometry
W. .. .. tungsten
WDM .. .. wavelength-division multiplexing
WSe_2.. .. .. tungsten diselenide
XeF_2 .. .. xenon difluoride
XPM .. .. cross-phase modulation
XPS .. .. x-ray photoelectron spectroscopy
XRD .. .. x-ray diffraction
XRR .. .. x-ray reflectivity
ZMW. .. .. zero-mode waveguide
Zn .. .. zinc
$ZnCl_2$ . .. . zinc chloride
ZnO .. .. zinc oxide
ZnO:Al . .. . zinc aluminum oxide
ZnS. .. .. zinc sulfide or zinc-blende
Zr. .. .. zirconium
ZrO_2 .. .. zirconium dioxide
ZTO .. .. zinc tin oxide

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