Cornell NanoScale Science & Technology Facility

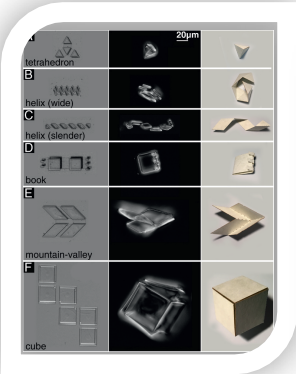
NNCI MEETING
October 23-25, 2019

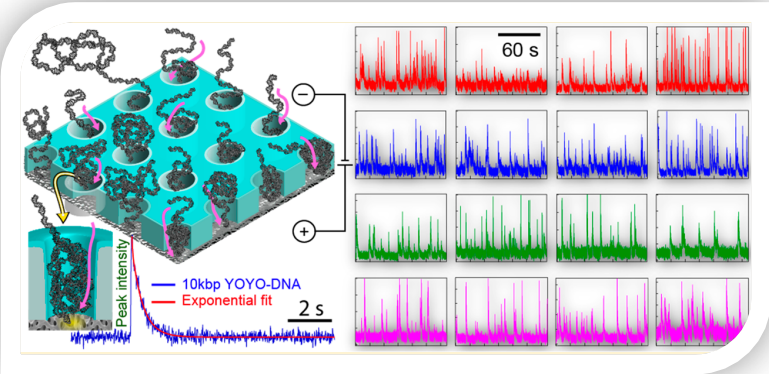
Chris Ober, Lester B. Knight Director
Ron Olson, Director of Operations
Lynn Rathbun, Laboratory Manager

CNF: Active Areas and Strategic Directions

Over 40 years of experience as a User Facility
Extensive facilities and processes to support:

Strategic Directions	NSF Big Idea
• Heterointegration	*Convergence*
• Quantum Materials and Devices	*Quantum Leap*
• 2D Materials	*Convergence*
• Life Sciences/Digital Ag	*Rules of Life*





Other Active Areas

- Electronics
- Organic and Flexible Electronics
- Spintronics and Magnetics
- MEMS/NEMS
- Optoelectronics
- Materials Characterization
- Nanophotonics
- Smart Textiles
- Nanomedicine
- Hard and Soft Materials

New website:
www.cnf.cornell.edu

Expertly-staffed user program providing rapid, affordable, hands-on 24/7 open access to advanced nanofabrication tools

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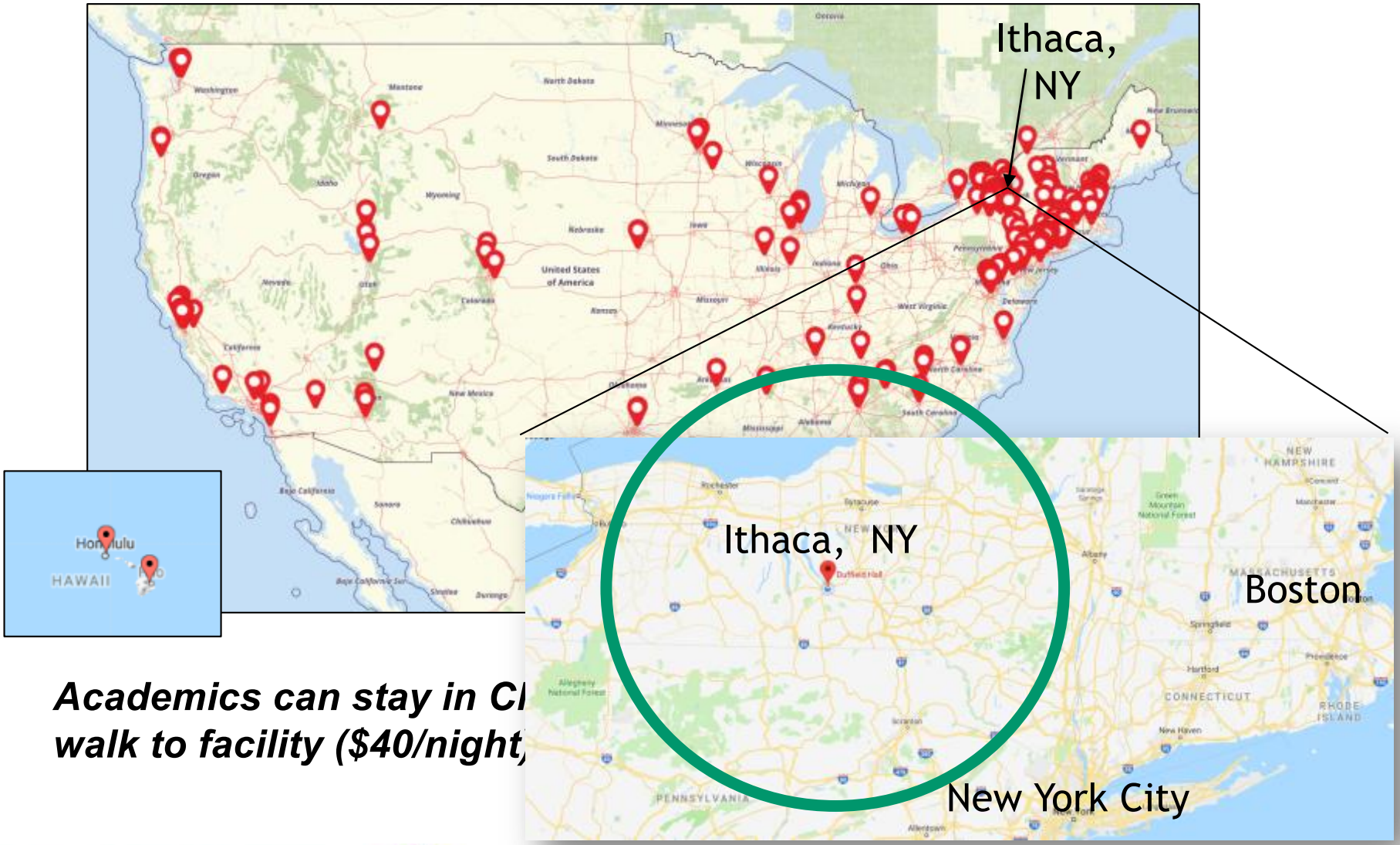
CNF: User Geography and Location

(under NNCI)



Academics can stay in Cl
walk to facility ($40/night)

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CNF: Extensive Fabrication Resources

Process Integration

Inspection

Thin Films

Instrumentation & Training

Deposition

Metrology

Process Characterization

Lithography

Plasma Etch

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CNF: A Leader in High Resolution Lithography

ASML Deep UV stepper

- 248 nm
- Sub 200nm resolution
- Backside alignment
- 3 inch to 200 mm wafer capability

JEOL JBX-9500FS

- Only one in US university
- 100 keV, 100 MHz
- Improved column optics
- 5.5 nm or less feature size
- 5 mm – 300 mm sample size

JEOL JBX-6300FS

- 100 keV, 50 MHz
- Sub – 10 nm features
- Up to 150 mm sample size
- Capable of writing on non-planar substrates
- Scripting Software

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CNF: New Facilities and Tools

Etch

Plasmatherm - Atomic Layer Etch (ALE) System

- Precise (atomic layer by layer) etching
- Joint development agreement with Plasma Therm
- **Supports our efforts in 2D materials**

Deposition

OEM AlN deposition system-

- Novel S-GUN design allows for high deposition rate of piezoelectric Aluminum Nitride
- Dedicated system
- Highly versatile in its ability to tune material properties
- **Supports our efforts in the Quantum Computing**

Additional new resources:
Flip Chip bonder, AJA sputtering system, Xallent Nanoprobes

New Director of Operations – **Ron Olson**

- 32+ years of progressive industrial experience
  - GE Global Research, Xanoptics, Lockheed Martin, Raytheon
- Former CNF user

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CNF Research Impact

- Use up 15% each year of NNCI
- Total 344 PPPs (underreported) for 2018
  - 178 Publications (25% High impact journals)
  - 87 Conference Papers
  - 79 Patent (Disclosures, Applications, Issued)
- Users: 30 small companies, 10 large Companies
- Leverage estimated $40M in grant funding per year
- 10 StartUps in first 4 Years (Xallent, Esper Biosciences, FloraPulse, Ultramend, Jan BioTech, Heat Inverse, JR2J, White Light Power, Odyssey Semiconductor, GeeGah)
- PRAXIS: Engineering and Physical Sciences Business Incubator, co-located in Duffield Hall
- Big Success Story: Pacific Biosciences – Illumina offers $1.2B for acquisition

- NNCI makes possible open doors at CNF, outreach and enables us to talk to Cornell administration in search for resources

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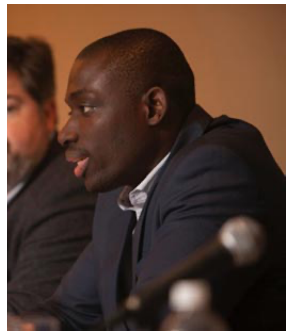
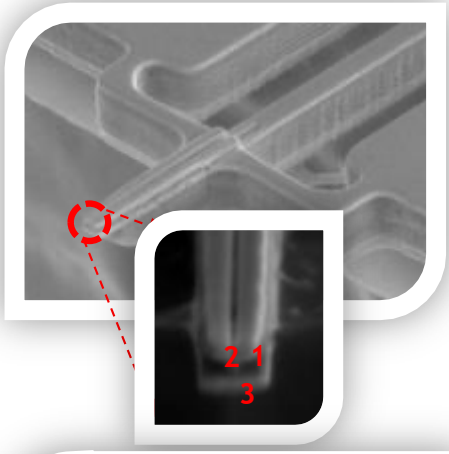
Startup Impact: Xallent

- MEMS based Nanoscale Multi-probing Solutions
  - SEM and Ambient probing solutions
- Founded in 2016, **Xallent** builds nanoscale testing solutions to enable customers to identify faults during the early stages of manufacturing.
- Products allow customers to perform tests that typically take days in minutes, translating to significant **cost savings** and **faster time-to-market**.
- Xallent nanomachine technology is based on trailblazing discoveries at **Cornell University** and follow-on subsequent innovations as CNF Users
- **Xallent nanoprobers are available in CNF (SEM and ambient)**



Kwame Amponsah,
Founder, PhD '13



FUNDING AGENCIES

NSF DARPA NIST United States Army NEW YORK STATE

National Nanotechnology Coordinated Infrastructure NSF CNF Cornell NanoScale Science and Technology Facility

Diversity – Essential Aspect of All We Do

- NNCI Diversity sub-committee
  - Diversity survey
- A key part of REU and iREU program since inception
- Work closely with Cornell Diversity Programs in Engineering
  - Diversity open house
  - Outreach to schools – New York inner city
  - Recruit diverse student and faculty community to Cornell and to nanoscience
  - Support to send students to NSBE and SHPE
  - LSAMP program activities with DPE
- **Nellie Whetten Award** – given to outstanding young women whose research was conducted in CNF, and whose lives exemplify Nellie's commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy and exuberance for life (since 1989)
  - **Cindy Harnett (U of L) 2019 speaker**

Big Idea

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Includes

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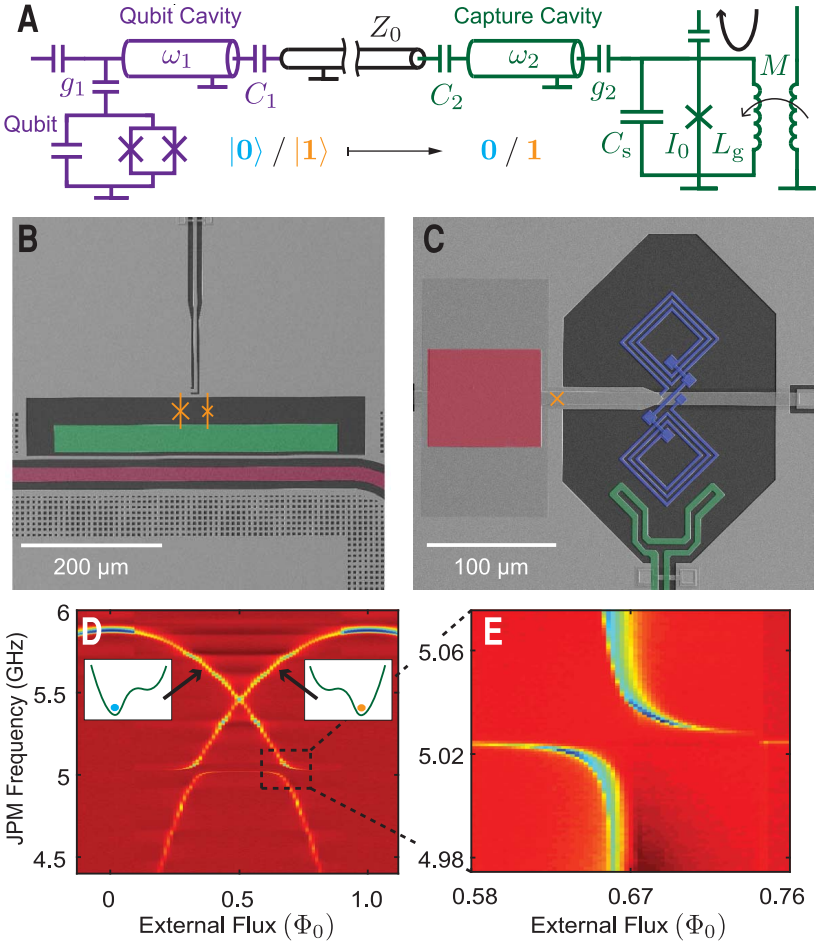
User Research: Measurement of a Superconducting Qubit with a Microwave Photon Counter

- In ***Science***, McDermott (Wisconsin), Plourde (Syracuse) and coworkers used the Cornell Nanoscale Facility to produce quantum devices.
- Fast, high-fidelity measurement is a key ingredient for quantum error correction.
- They introduce an approach to measurement based on a microwave photon counter demonstrating raw single-shot measurement fidelity of 92%.
- Their scheme provides access to the classical outcome of projective quantum measurement at the millikelvin stage and could form the basis for a scalable quantum-to-classical interface.



R. McDermott, B. L. T. Plourde *et al., Science*, 361, 1239–1242 (2018)

Funding: ARO grants W911NF-14-1-0080 and W911NF-15-1-0248. (CNF NNCI-1542081).

Big Idea NSF Quantum Leap

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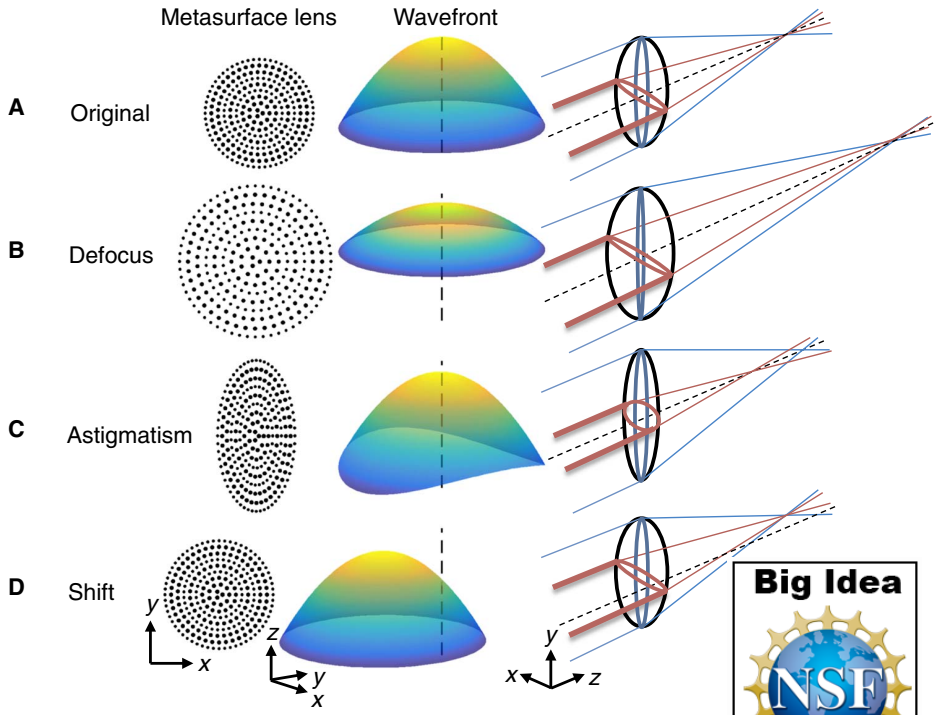
User Research: Adaptive Metalenses with Simultaneous Electrical Control of Focal Length, Astigmatism, and Shift

- In ***Science Advances***, Clarke, Capasso and coworkers (Harvard) and CNS collaborated with the Cornell Nanoscale Facility to fabricate adaptive metalenses.
- Focal adjustment and zooming are universal features of cameras and advanced optical systems. However, the recent advent of ultrathin planar lenses for mobile devices based on metasurfaces (metalenses) mandates fundamentally different forms of tuning based on lateral motion rather than longitudinal motion.
- They demonstrate electrically tunable large-area metalenses controlled by artificial muscles capable of simultaneously performing focal length tuning (>100%) as well as on-the-fly astigmatism and image shift corrections which until now were only possible in electron optics.
- Their results demonstrate the possibility of future optical microscopes that fully operate electronically, as well as compact optical systems that use the principles of adaptive optics to correct many orders of aberrations simultaneously.



Big Idea Convergence

She et al., *Sci. Adv.* 2018;4:eaap9957

Acknowledgement: J. Treichler, A. Windsor, G. Bordonaro, K. Musa, and D. Botsch thanked for their help in using CNF. Funding: AFOSR MURI: FA9550-12-1-0389. NSF CMMI-1333835; MRSEC DMR 1420570. CNS ECCS-0335765. (CNF NNCI-1542081).

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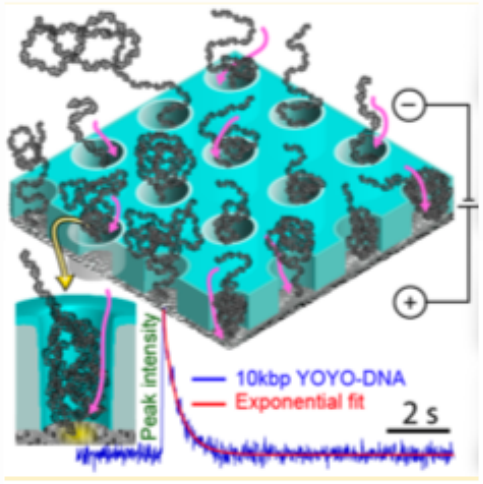
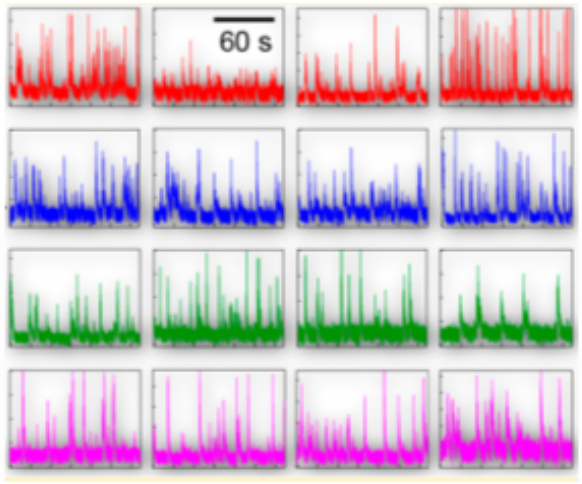
User Research: Porous Zero-Mode Waveguides for Picogram-Level DNA Capture

- In ***Nano Letters***, Wanunu and coworkers (Northeastern, NIST, Pacific Biosciences) used the Cornell Nanofabrication Facility to develop an approach for the wafer-scale fabrication of waveguide arrays for DNA sequencing.
- They have recently shown that nanopore zero-mode waveguides are effective tools for capturing picogram levels of long DNA fragments for single-molecule DNA sequencing.
- In a new design the membrane at each waveguide base contains a network of serpentine pores that allows for efficient electrophoretic DNA capture at picogram levels while eliminating the need for prohibitive serial pore milling.
- Here, they show that the loading efficiency of these porous waveguides is up to 2 orders of magnitude greater than their nanopore predecessors.





Big Idea
NSF
Rules of Life

Wanunu et al., *Nano Lett*. 2019, 19, 921−929

Funding: NIH: NHGRI 1R01 HG009186 (CNF NNCI-1542081).

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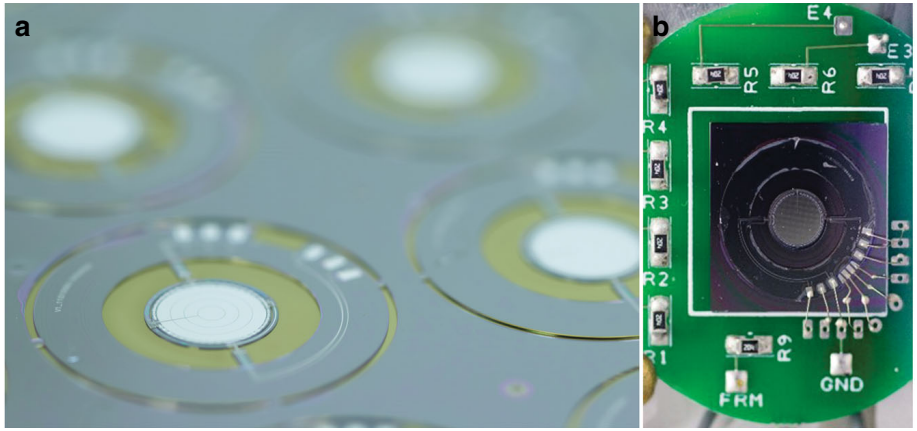
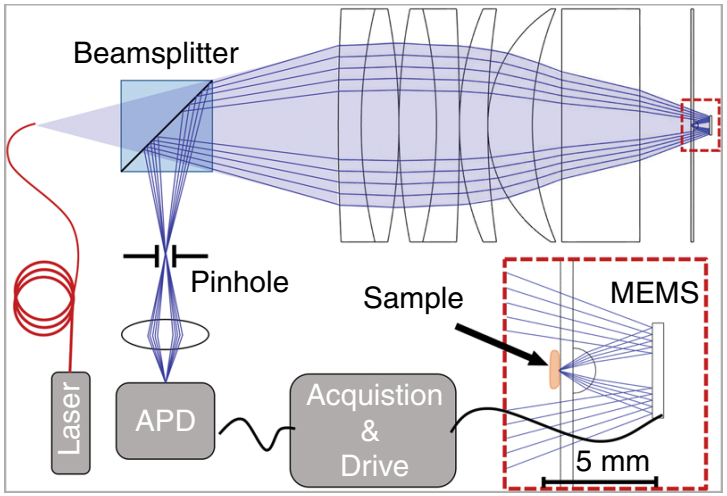
User Research: MEMS-in-the-lens architecture for a miniature high-NA laser scanning microscope

- In Light: Science & Applications, Dickensheets and colleagues at MONT collaborated with the Cornell Nanoscale Facility to develop MEMS-in-the-lens
- Laser scanning microscope was miniaturized for *in vivo* imaging by substituting optical microelectromechanical system (MEMS) devices in place of larger components.
- MEMS-in-the-lens architecture incorporates a reflective MEMS scanner between a low-numerical-aperture back lens group and an aplanatic hyperhemisphere front refractive element to support high-numerical-aperture imaging.
- Developed new optical system using a recently developed hybrid polymer/silicon MEMS 3D scan mirror that features an annular aperture.
- Imaging of hard targets and human cheek cells demonstrated with a confocal microscope that is based on the new objective lens design.





Big Idea Rules of Life

Dickensheets, Liu et al. Light: Science & Applications (2019)8:59

Funding: NIH:NIBIB 1R21EB018507; NIH: NCI P30CA008748. MNF ECCS-1542210 (CNF NNCI-1542081).

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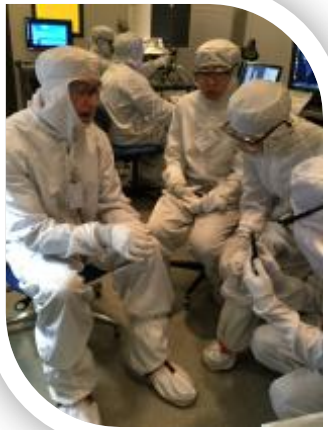
CNF: Education and Outreach Impact

Major CNF Activities	# events	# Participants (annual)
Nanooze Magazine		>100000
Nanooze Disney		>250000
Nanodays at Sciencenter	1	160
College/Community college events/visits	30	388
TCN Short course	2	36
FIRST Jr. Lego Event	1	300
4-H	4	149
Girl Scout Engineering Day -Graduate Society of Women in Engineering	1	240
International REU	1	6
REU	1	5
CNF Annual Meeting	1	154
K-12 visits to CNF	11	196
Visits to Schools	8	634
Nanometer Newsletter	2	2000
CNF Research Accomplishments	1	1000
Technical courses/workshops	6	153
Conference booths	2	352
General public events/tours	84	684
Evaluated Activities		
Total CNF		**>350,000**



All reported activities organized and conducted by CNF staff

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Nanooze – Outreach Impact

CNF's Science Magazine for Kids

- Produced by Prof. Carl Batt and distributed by CNF
- Distributed free to classrooms and other organizations
- 100,000 copies per issue printed (16 issues)
- >1.5 million copies distributed

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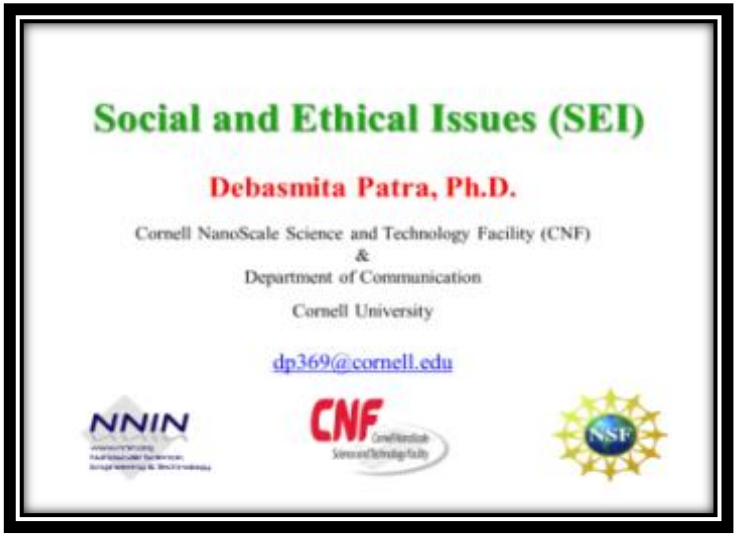
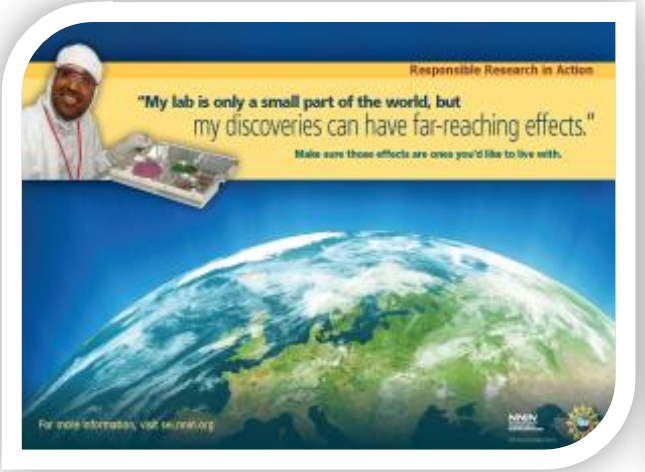
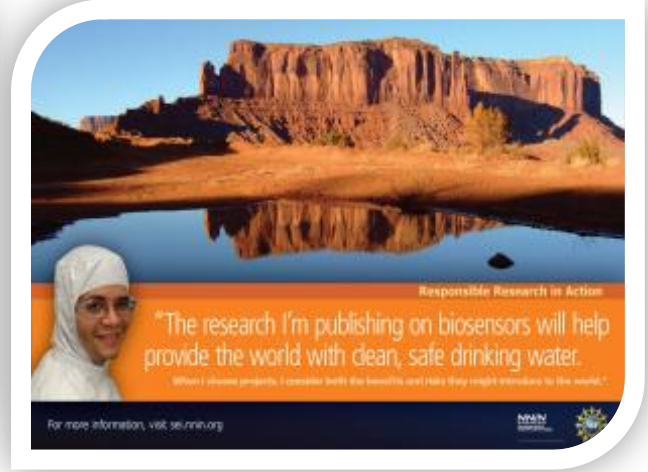
Societal and Ethical Implications

Responsible Research in Action

- Introduced during new user training
- ~1 hr interactive discussion
- Provides an overview of the
  - Importance of SEI
  - Examples and scenarios
- Perception of nano-ethics







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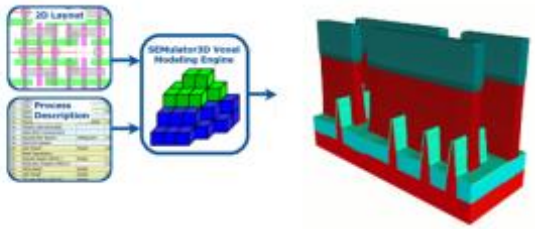
Computation Support of CNF Users

- **Nanostructure modeling**
  - Cluster with open source molecular dynamics and electronic structure modeling
- **Fabrication support**
  - **Cadence**
    - Chip design to chip packaging
    - Circuit simulation, GDS layout
  - **Coventor SEMulator**
    - 3D process simulation/modeling
  - **L-Edit**- CAD/GDS layout and design,
  - **PROLITH** – Modeling for resist exposures
  - **GenIsys** – BEAMER, TRACER, LABopc (litho simulation), ProSEM --CAD to exposure optimization and conversion
  - **JetStream**—JEOL conversion program for CAD file to exposure file.

cadence

COVENTOR
A Lam Research Company



GenISys

JEOL

PROLITH™

Real Virtual Patterning

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Network Collaboration: Intra-network projects

- **Intra-Network Interactions**
- Standing open accounts for other facilities
- Expedited access for intra-network cooperation
- Proof of concepts are explored Intra network
- Tool sharing - 2nd source for specialized tools

- **Etch Working Group** is one of the most active in NNCI (V. Genova-Cornell)
  - Most sites have at least one participant
- Interactive forum sharing information
  - Processes under development
  - Maintenance
  - Equipment Modifications
- Identification of complementary tools
  - Effective use of resources to meet user needs.

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Network Collaboration: Etch Working Group

- Etch Working is one of the most active in NNCI (V. Genova-Cornell)
  - Most sites have at least one participant
- Interactive forum sharing information
  - Established Processes
  - Processes under development
  - Maintenance
  - Baselining
  - Equipment Modifications
  - Acquisitions
  - New Technologies
- Identification of complementary tools
  - Effective use of resources to meet user needs.

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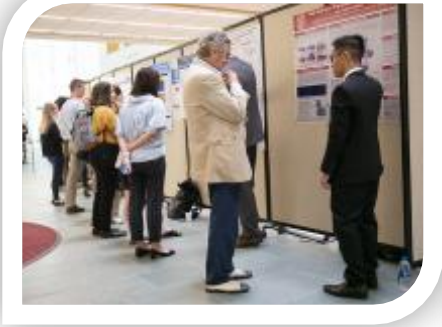
Network Collaboration: 2019 NNCI REU Convocation

Hosted By CNF

- Aug. 11-13, 2019 at Cornell
- 72 interns from across the NNCI sites attended the convocation and presented their research to their peers
  - Student talks
  - Student posters
  - Networking activities
  - Plenary sessions and panels

Historically (via longitudinal tracking since 1997) , >50% of NNUN/NNIN/NNCI REU students go on to receive a Ph.D.



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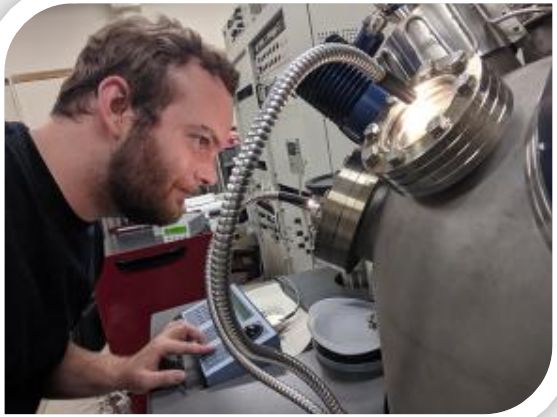
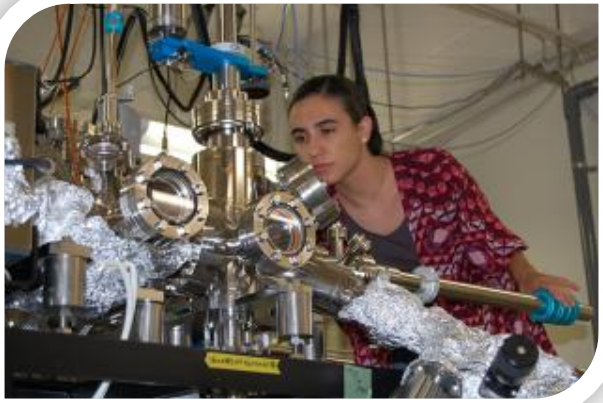
Network Collaboration: International REU

Co-funded by CNF and NNCI Coordination Office in 2019

National Institute for Materials Science , Tsukuba, Japan

- Conducted by CNF on behalf of the network
  - Participants drawn from prior year NNCI REU program
- 10 week international summer research experience
- 81 students since 2008; 6 students in 2019
  - 57 of the 81 are enrolled/completed Ph.D.
  - 22 of those 57 (38%) have NSF Graduate Fellowships
- Formative experience in developing the intercultural research skills necessary in the 21st century.





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Previous support from NSF OISE

Future Network Collaboration?: Reducing Chemical Waste

- FOR DISCUSSION OFFLINE
- CNF is among the largest chemical waste producers on campus
- Recently Cornell asked CNF to increase its financial contribution to and responsibility for handling chemical waste
- As part of this change we are evaluating the waste we produce and how we can cut back
- We are also looking at how we can induce better, less wasteful behavior among our users (e.g. we do not charge for photoresists - should we?)
- A best practice discussion among sites would be helpful

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CNF: Collaborations Beyond NNCI

- AI in the Clean Room
  - Supported by SEMI as a pilot to introduce AI into cleanroom
  - Wanted non-commercial cleanroom to identify data roadblocks
  - If successful may reduce downtime for new user developing CNF process chain
- Working with Morgan State University
  - Through our former colleague and Ext Adv Bd member, Prof. M. Spencer
  - Providing advice on cleanroom upgrade
  - Teaching NNCI culture to Morgan State students
- iREU Program
  - Supported by Cornell and coordinating office
  - Was not renewed last year – recommended to resubmit
  - Renewal submitted to NSF

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