Harvard University:
Center for Nanoscale Systems

NNCI Annual Meeting

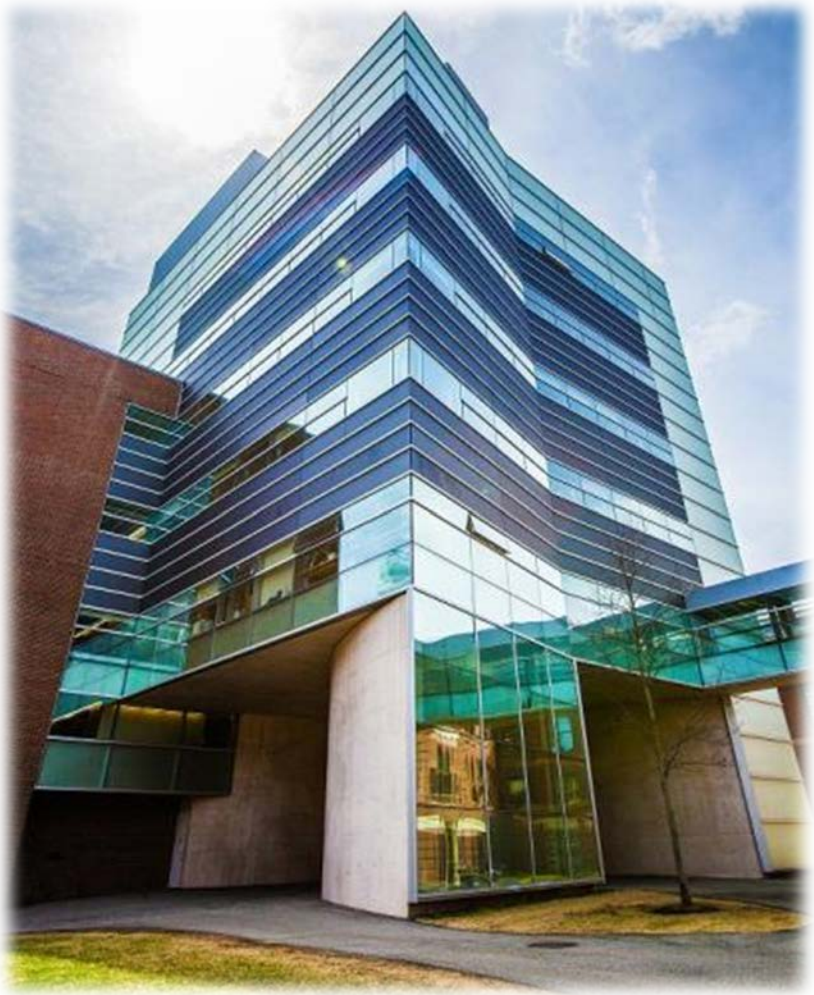
October 16, 2017

National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University
FAS • SEAS

The Epicenter for Interdisciplinary Nanoscience Research at Harvard:
LABORATORY FOR INTEGRATED SCIENCE AND ENGINEERING (LISE)



- ***CNS*** serves as a one-stop shop for all things "Nano" (almost fully self-use)
- ***CNS*** serves as a important regional, nanoscience community resource. (open access; mostly self-use)
- ***CNS*** is initiating new training and educational programs to engage larger numbers of undergraduates, non-traditional, and underserved external users, in nanofabrication, advanced characterization and advanced imaging techniques.
- ***CNS*** is developing a number of new experimental platforms expanding our experimental capabilities; (example, Scanning probe spectroscopy platforms.)
- ***CNS now*** offering support for new Start-up companies and is establishing alliances with local incubators technology.

Robert Westervelt
Director

William L. Wilson
Executive Director

National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University
FAS • SEAS

TWO PRIMARY CORES: Nanofabrication / Nanoscale Characterization

Enabling scientific excellence

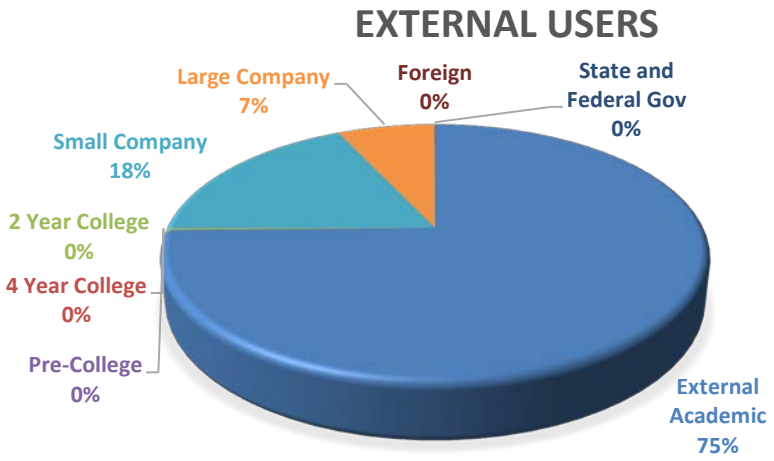
National Nanotechnology Coordinated Infrastructure

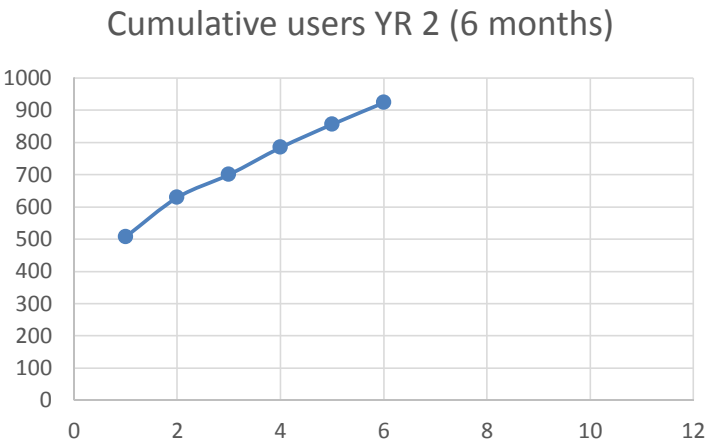
NSF

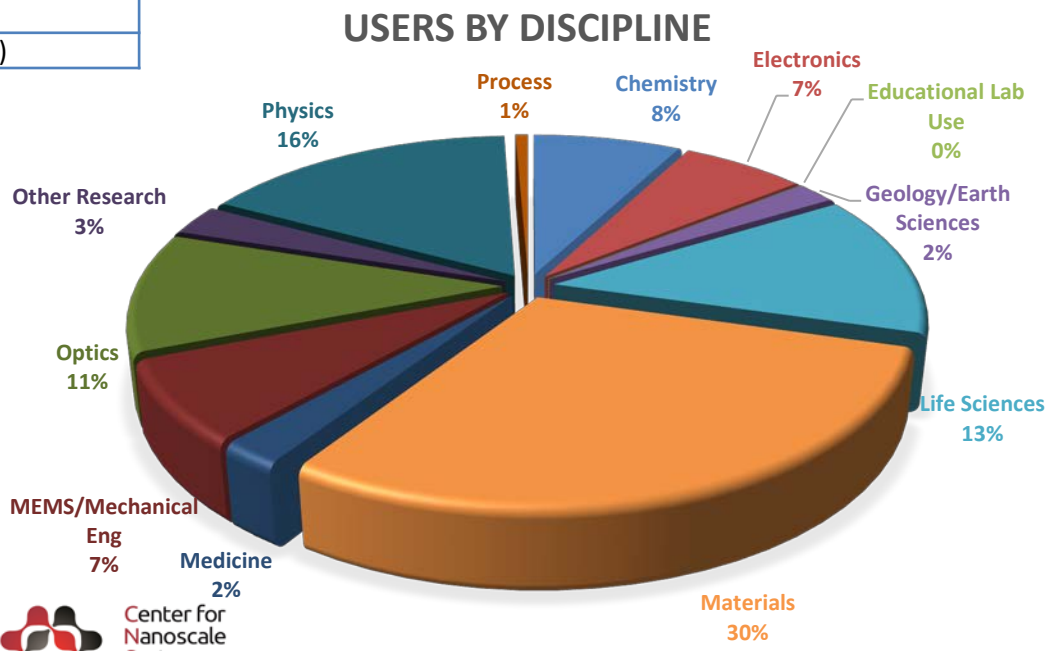
Center for Nanoscale Systems
Harvard University FAS • SEAS

Harvard CNS User Data

Yearly User Data Comparison		
	Year 1(12 months)	Year 2 (6 months)
Total Users	1246	923
Internal Users	673	516
External Users	573 (46%)	407 (44%)
Total Hours	174,710	83,222
Internal Hours	124,256	60,457
External Hours	50,454 (29%)	22,765 (27%)
Average Monthly Users	511	496.5
Average External Monthly Users	201 (39%)	185 (37%)
New Users	415	179
New External Users	199 (48%)	83 (46%)





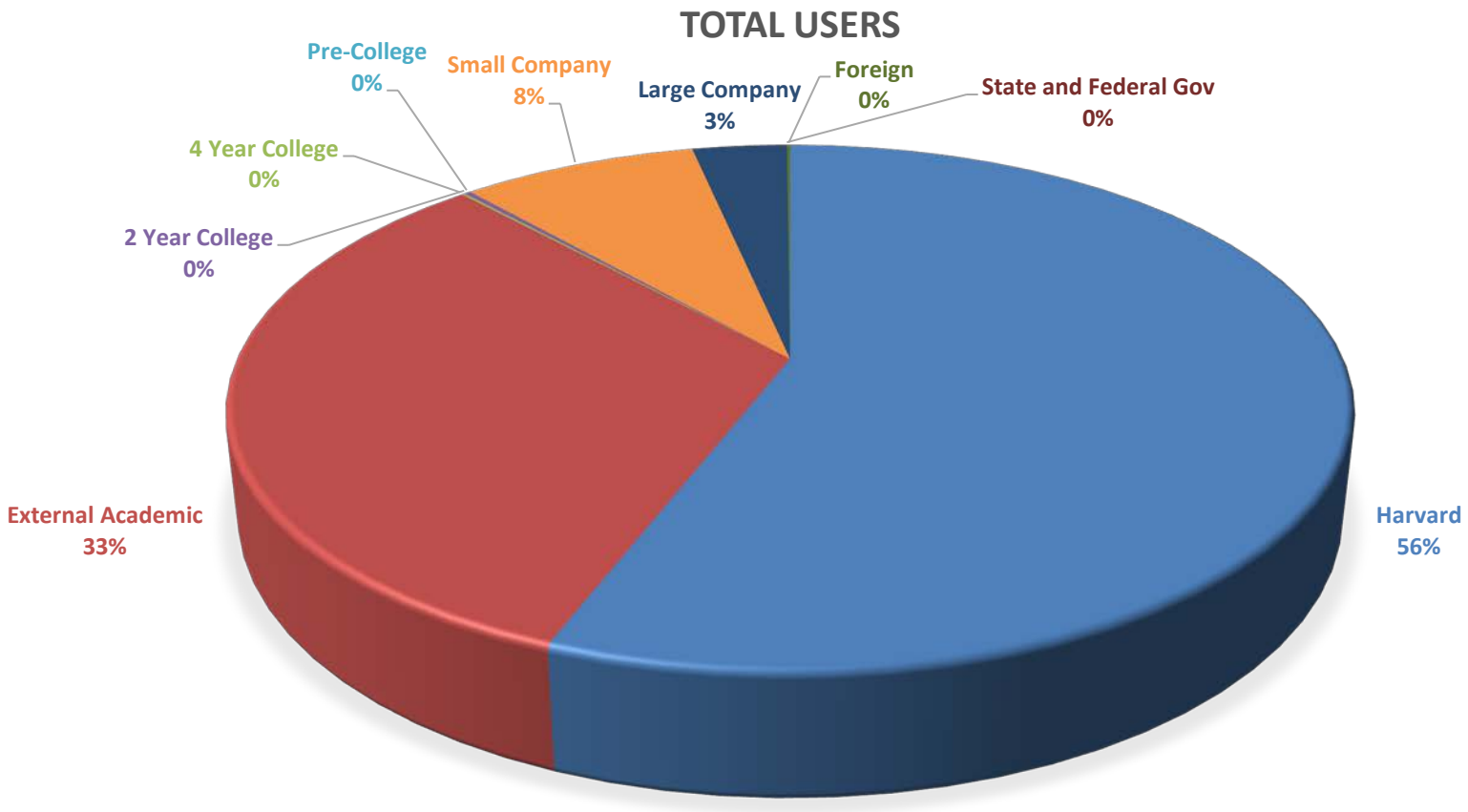


National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University FAS • SEAS

CNS Total User base Data*



*In General; ~47% of our userbase is external users

National Nanotechnology Coordinated Infrastructure

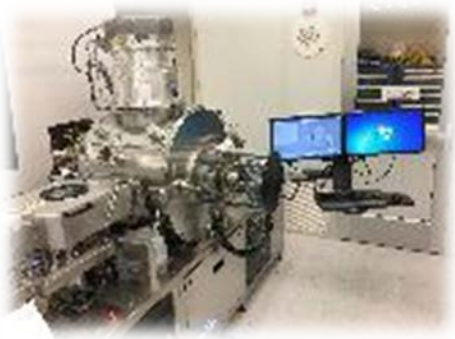
NSF

Center for Nanoscale Systems
Harvard University FAS • SEAS

CNS *(Nanofabrication)*: Expanding capabilities for one of the most comprehensive nanotechnology research communities in the world.

Nanofabrication Additions:

- Multi angle Ion Beam Etcher
- Deep Oxide Etcher
- Cleanroom SEM
- Mask-less aligner



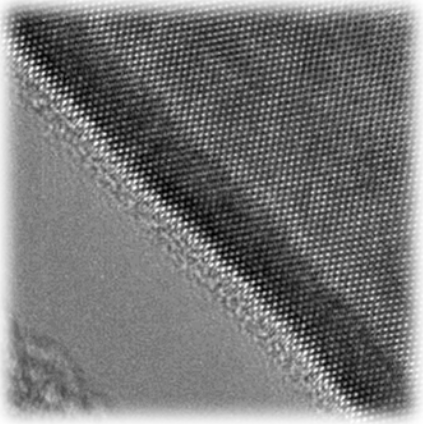
Operations Focus: *enhance process tools needed by our core basic science and engineering research programs. Adding training resources, tools, and staff to support transformative science and technology development;.*

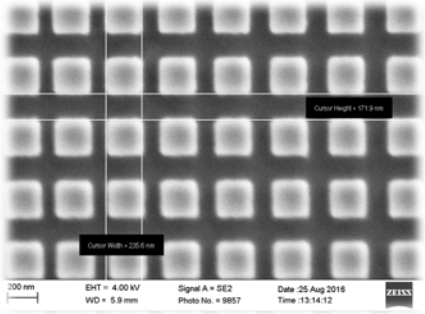
National Nanotechnology Coordinated Infrastructure

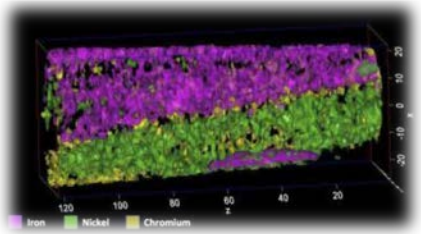
NSF

Center for Nanoscale Systems
Harvard University FAS • SEAS

CNS *(Imaging and Analysis)*: Revamping and expanded our Ion beam imaging and fabrication tools and added new instrumentation for nanoscale spectroscopy.



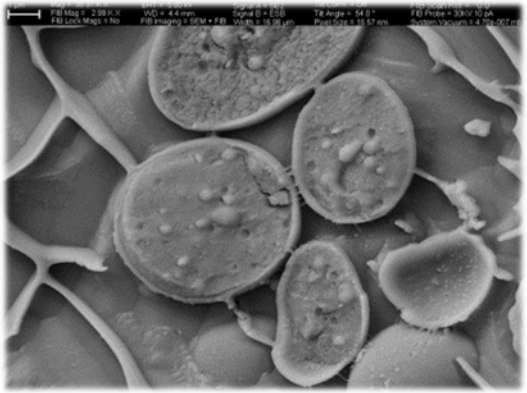




Imaging and Analysis Additions

- Park Instruments SICM
- Neospec s-SNOM
- Hitachi FIB*
- XPS/UPS System*

Imaging and Analysis Focus: *establishing a complete set of instrumental tools for interdisciplinary Quantum nanoscience ensuring we have the resources to support transformative science with nanoscale spectroscopy tools.*



National Nanotechnology Coordinated Infrastructure

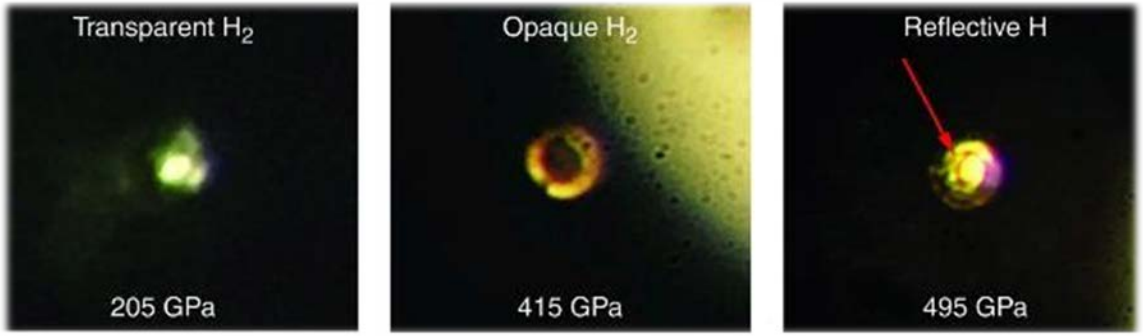
NSF

Center for Nanoscale Systems
Harvard University
FAS • SEAS

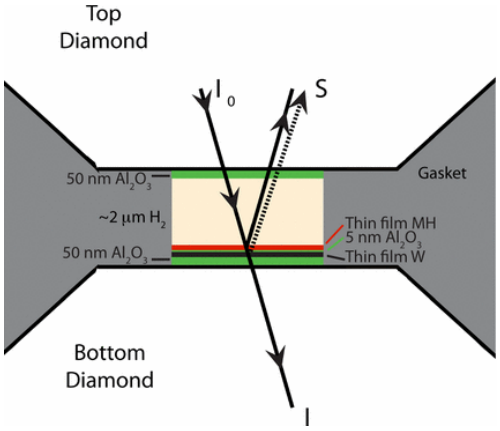
*Acquired via lease

ENABLED RESEARCH: *Observation of Metallic Hydrogen*

Silvera Group, *PHYSICS DEPARTMENT*, **HARVARD UNIVERSITY**



Microscopic images of the stages in the creation of atomic molecular hydrogen: Transparent molecular hydrogen (left) at about 200 GPa, which is converted into black molecular hydrogen, and finally reflective atomic metallic hydrogen at *495* GPa.



*SCIENCE, Volume: 355, Issue: 6326, Pages: 715-718
DOI: 10.1126/science.aal1579
Published: FEB 17 2017

National Nanotechnology Coordinated Infrastructure

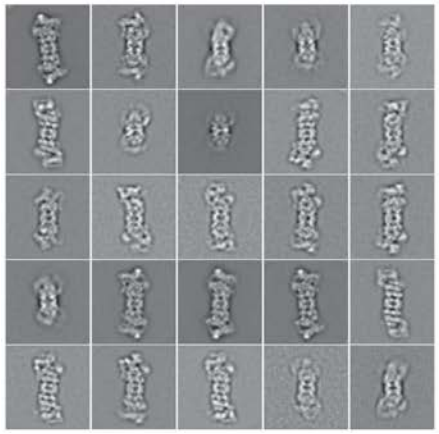
NSF

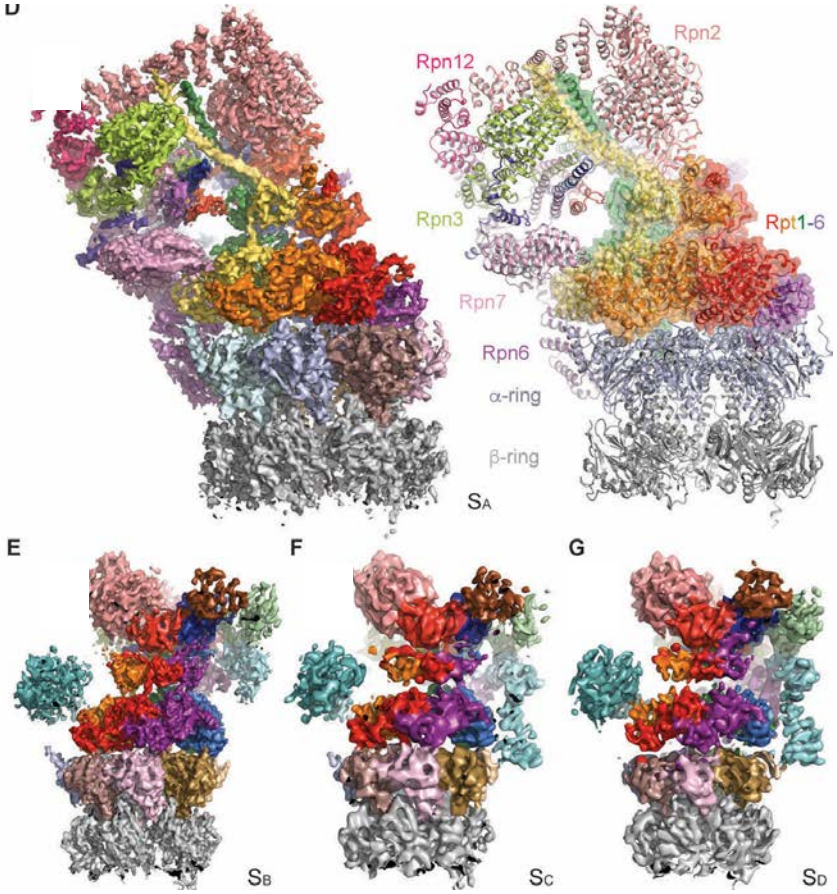
Center for Nanoscale Systems
Harvard University FAS • SEAS

Dynamic regulation of human **26S** proteasome

Cryo-EM was used to analyze four conformations of the human 26S proteasome holoenzyme, which provides significant insights into the dynamic regulation of the human 26S functions.

Using **FEI** Tecnai Arctica equipped with Gatan **K2** Summit camera, the 26S structure in the resting state was determined at near-atomic resolution, with three alternative conformations at subnanometre resolutions, for the first time.





S. Chen, J. Wu, Y. Lu, …, M. Kirschner, Y. Mao; Dana-Farber Cancer Institute, Department of Microbiology and Immunobiology, Department of Systems Biology, Harvard Medical School

Reference: Proc. Natl. Acad. Sci. U S A **2016**, 113, 12991-12996

- ✓ Unique Expertise
- ✓ Pending NIH Center Proposal

CNS SUMMER PROGRAMS: Educational Initiatives / NNCI Enabled

REU – conventional program : *but with project offerings from entire userbase, both internal and external*



***Conventional REU PROGRAM** – Advanced research opportunities for Ugrads from external, 2 and 4yr institutions

Research **E**xperienc**e** **V**eterans – *staff served as mentors*

(some interns carried through school year)


***Bunker Hill CC based** – Advanced training for returning Vets; research opportunities with Harvard Faculty

National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University FAS • SEAS

CNS 2017 REV / REU Student Cohort

Demographics:

- 5 military veterans
- 5 female, 5 male
- 2 underrepresented minority
- 3 from primarily undergraduate institutions, 2 community college, 1 MS granting institution, and 4 PhD granting institutions

National Nanotechnology Coordinated Infrastructure

NSF

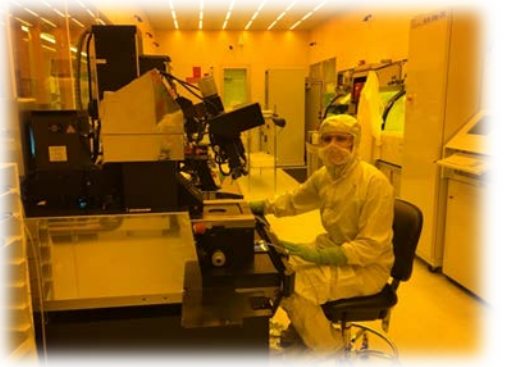
Center for Nanoscale Systems
Harvard University
FAS • SEAS

Mentors–Students Worked Closely Together

Daryl Vulis
2010 NNIN,
2011 NNIN iREU
Now NNCI
mentor

Sarah McDonald and her mentor Daryl Vulis are fabricating zero-index metamaterials using RIE.

Mike Hoeft and Dr. Andrew Gross are crafting 3D nanostructures using NanoScribe



Isabel Castillo is doing photolithography for fabricating microfluidics devices.

Interns-mentors are waiting for presentations at CNS staff meeting

National Nanotechnology Coordinated Infrastructure

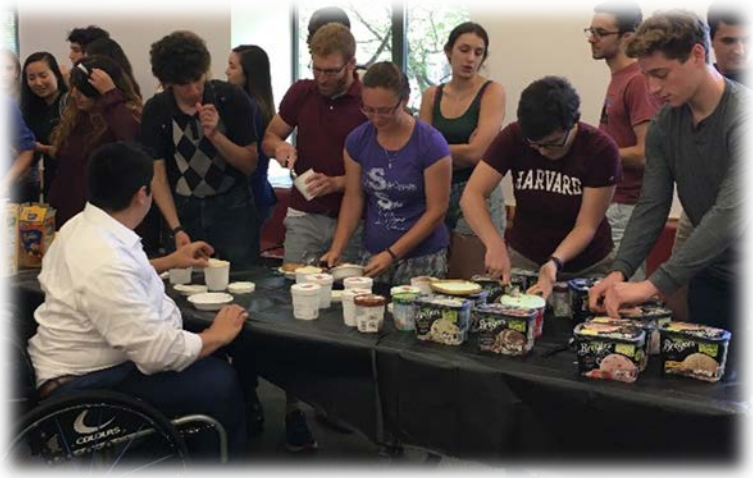
NSF

Center for Nanoscale Systems
Harvard University
FAS • SEAS

Joint Professional Development Activities

Students lived with a larger community of visiting undergraduates and participated in joint professional development activities

- Weekly Writing Workshop
- Responsible Conduct in Research
- Materials in the Environment Seminar
- Weekly CNS Technical Seminars
- Faculty Seminars
- Industry Careers,
- Graduate School Seminars
- Social Activities



Students submitted technical abstracts, NSF-style highlights, final presentations, and a final report

National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University
FAS • SEAS

CNS : Summer Training Programs, Workshops

Basic Nanofabrication Process Training

The 7th CNS-Nanofabrication Summer School –(2015)

Harvard University Center for Nanoscale Systems

CNS Nanofabrication Team will continue offering a series of tutorials on nanofabrication technologies in this summer. In these tutorials, fundamentals of each nanofabrication technology will be introduced; operation principles, process tips/tricks will be discussed. All CNS users are eligible to attend.

Agenda

Jun 5	Introduction of Nanofabrication	*JD Deng*
Jun 12	Photolithography	*Ameha/Guixiong*
Jun 19	*Maskless Laser Aligner (MLA) workshop**	*Heidelberg*
Jun 26	E-beam Lithography (EBL)	*Yuan Lu*
July 10	Reactive Ion Etch (RIE)	*Ling Xie*
July 17	Advanced RIE	*Kenlin/Ling*
July 24	Chemical Vapor Deposition (CVD)	*Philippe/John*
July 31	Metrology for Nanofabrication	*Jason Tresback*
Aug 5-7	*JAWoollam Ellipsometry Workshop**	*JAWoollam*
Aug 7	MEMS process and Packaging	*Guixiong Zhong*
Aug 14	Advanced AFM workshop	*Jason/JD*
Aug 21	Atomic Layer Deposition (ALD)	*Mac/Philippe*
Aug 28	Physical Vapor Deposition (PVD)	*Ed Macomber*
Sep 4	Cleanroom Facility	*Steve Paolini/David*

10 µm WD = 5.3 mm EHT = 5.00 kV Mag = 1.45 K X Width = 206.9 µm Signal A = SE2 Cycle Time = 10.1 Secs

Location and Time: 100 Geological Lecture Hall, 24 Oxford St., Cambridge MA, 02138, Friday, 12:00-1:30pm, Pizza lunch is available.

- *Workshops are 1-4 day long event, please see the additional announcement.
- The agenda may be changed according to staff's availability.

Contact Ling Xie: lxie@cns.fas.harvard.edu; Jiangdong Deng: jdeng@cns.fas.harvard.edu

Fundamental and Advanced Materials Characterization

CNS Imaging and Analysis Group

Harvard University Center for Nanoscale Systems

2015 Introductory Summer Seminar Series

June 4th	Energy Dispersive Spectroscopy (EDS)
June 11th	*In Situ* Transmission Electron Microscopy
June 18th	Focused Ion Beam (FIB)
June 25th	Sample Preparation for Electron Microscopy
July 2nd	Aberration Corrected Electron Microscopy (ACEM)
July 9th	Cryogenic Scanning Electron Microscopy (Cryo-SEM)
July 16th	Aberration Corrected Scanning Transmission Electron Microscopy (AC-STEM)
July 23rd	Single Particle Analysis in Cryogenic Transmission Electron Microscopy (Cryo-TEM)
July 30th	Environmental Scanning Electron Microscopy (ESEM)
August 6th	Micro-Computed Tomography (uCT)
August 13th	Micro-Raman and Micro-Photoluminescence
August 20th	Surface Analysis Techniques
August 27th	Atom Probe Tomography (APT)

100 Geological Lecture Hall
24 Oxford St. Cambridge, MA
Every Thursday 12-1pm

Contact: Dr. Arthur McClelland (amcclelland@cns.fas.harvard.edu)

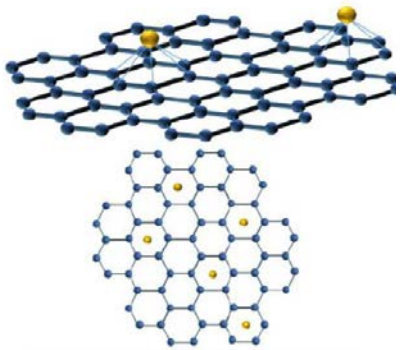
**Extensive training by workshop: enabled by CNS Staff*

National Nanotechnology Coordinated Infrastructure

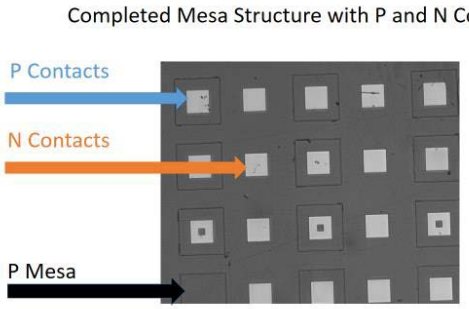
NSF

Center for Nanoscale Systems Harvard University FAS • SEAS

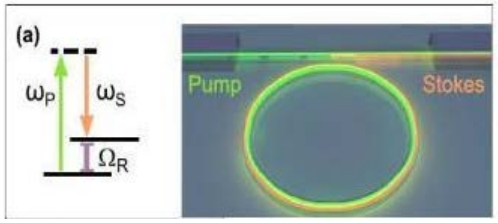
Educational Initiatives: **CNS** Scholars



Characterization of Quantum Materials



Development of Conventional Nanoelectronics
with nonconventional materials



Diamond NanoPhotonics

***CNS SCHOLARS PROGRAM** – Wide range of topics (above):

Advanced research opportunities
for Grads, Post Docs, and Junior
faculty from 2 and 4yr institutions

**The goal of Scholars is more "advanced" training and sophisticated research opportunities for researchers at other institutions*

National Nanotechnology Coordinated Infrastructure

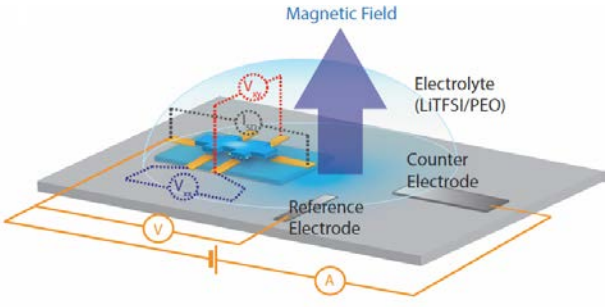
National Nanotechnology Coordinated Infrastructure

Center for Nanoscale Systems
Harvard University
FAS • SEAS

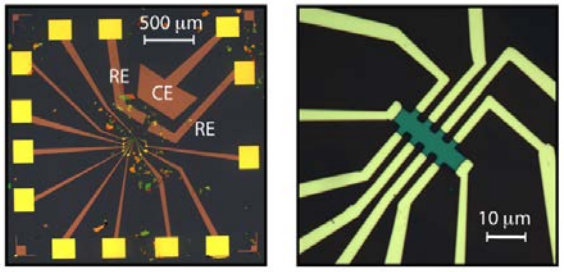
Electrochemical intercalation of discrete van der Waals heterostructures

Introduction: Two-dimensional (2D) materials can be assembled into hetero structure, creating artificial interface that can host intercalated species such alkali ions. This property makes them promising building blocks for innovative energy conversion/storage and electronic technologies. We have been studying graphene / Molybdenum disulfide(MoS_2) hetero structure to explore mechanism of charge transfer and intercalation process in 2D hereto layers.

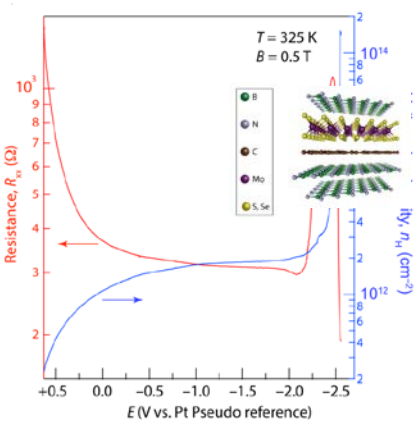
Goal: Maximize charge storage in interface of layered materials, Developing a technique for exploring of intercalation process in 2D van der Waals hereto structures



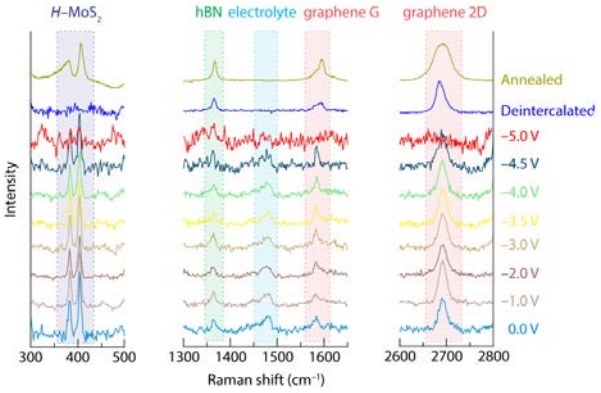
a) Schematic electrochemical cell for Hall voltammetry



b) on-chip electrochemical cell for charge transport and optical measurements



c) Transport measurement recorded at 325 K for a graphene–$MoSe_2$ device



d) Raman spectra of an hBN–graphene–MoS_2 over the course of electrochemical intercalation

D. Kwabena Bediako[1], Mehdi Rezaee[2], Tina L. Brower-Thomas[3] and Philip Kim[1]

1 Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
2 Department of Electrical Engineering, Howard University, Washington, DC 20059, USA
3 Department of Chemical Engineering, Howard University, Washington, DC 20059, USA

Biomimetic Microsystems for investigating Cardiovascular Diseases

The cardiovascular tissue engineering laboratory (CTEL) at Mississippi State University investigates cardiovascular related diseases.

The CETL team uses biomimetic microdevices to investigate the role of various biomolecules to determine the roles of specific chemical cues in disease onset and progression.

Specifically we are using microfluidic devices (Figure 1) to examine vasculopathies such as sickle cell disease. We also use biomimetic systems to understand the microenvironmental cues that influence cardiac performance.

The ultimate goal for the CTEL team is to improve patient outcomes by improving our understanding mechanisms that contribute to these disease.

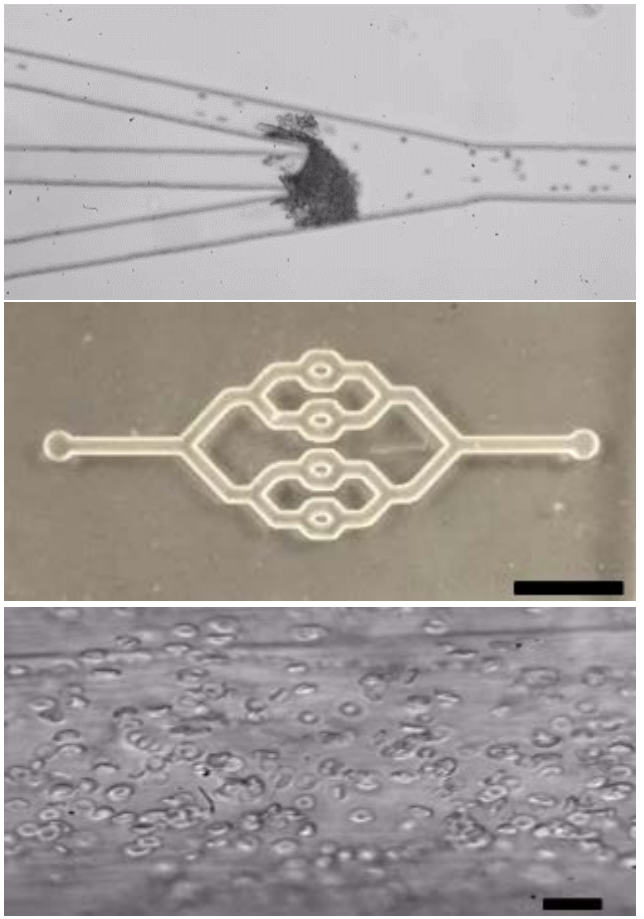


Figure 1: Example of the microdevice platforms used by CTEL.. Scale bar: 50 µm

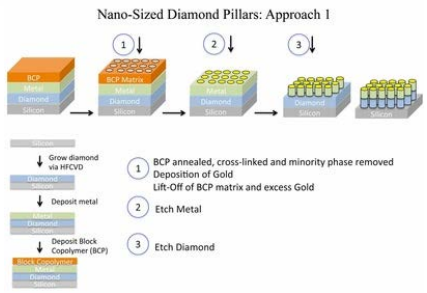
Kristen Hubbard, Allison Healey, Renita E. Horton, ; Department of Agricultural and Biological Engineering, College of Agricultural and Life Sciences, Bagley College of Engineering, Mississippi State University

NSF Center and other Scientific SYNERGIES

Programs to engage life science users: Partnership with Catalyst offering instrumentation/ fabrication funding for Translational Bioscience Research using CNS

Partnership with NSF STC: CQIM, offering instrumentation/ complex fabrication expertise.

CQIM CENTER for INTEGRATED QUANTUM MATERIALS



National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University
FAS • SEAS

Start-up Industry Outreach

"Still visiting local incubators"
(Defined incubator rate)

CNS Incubator activity initiated! added Harvard IP based Start-up Support rate

National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University FAS • SEAS

Defining Technological Sustainability

How do you maintain *state-of-the-art* tools and instrumentation?

- ✓ Direct support of capital purchases
- ✓ Equipment acquisition via funded grants
- ✓ Corporate gifts
- ✓ Instrumentation leases

How do you ensure Technological flexibility / Scientific nimbleness

- ✓ Direct dialog with the user-base / faculty
- ✓ Forums on technology evolution
- ✓ Modest funding for preliminary work / process development

National Nanotechnology Coordinated Infrastructure

NSF

Center for Nanoscale Systems
Harvard University
FAS • SEAS