

# NNCI @ Stanford

**BRUCE CLEMENS**

PROFESSOR OF MATERIALS SCIENCE  
& ENGINEERING

DIRECTOR OF STANFORD NANO SHARED  
FACILITIES (SNSF)



nano@stanford supported by NSF award ECCS-1542152



Stanford University

# NNCI @ STANFORD

Provide access to world-leading facilities and expertise in nanoscale science and engineering for internal users and for external users from academic, industrial, and government labs.

Develop and propagate a national model for educational practices that will help students and visitors become knowledgeable and proficient users of the facilities.

# Facilities

Stanford Nanofabrication Facility (SNF)  
~ 440 users/year

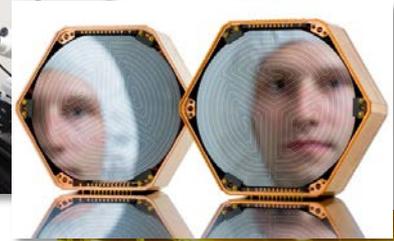
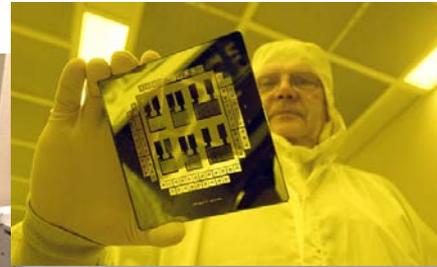
Stanford Nano Shared Facilities (SNSF)  
~940 users/year

Stanford Mineral Analysis Facility (MAF)  
~25 users/year

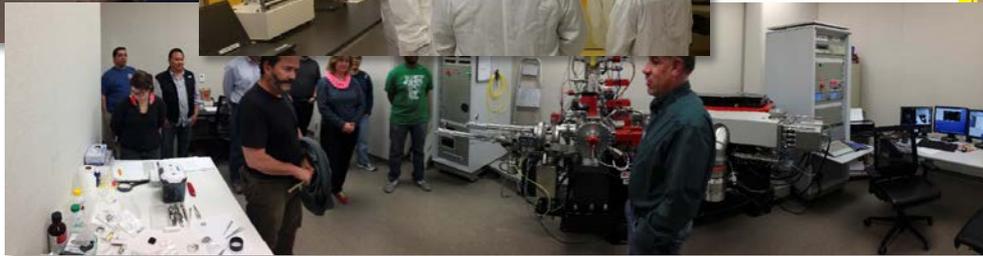
Environmental Measurement Facility (EMF)  
~160 users/year

**~30,000 ft<sup>2</sup>**

# Expertise

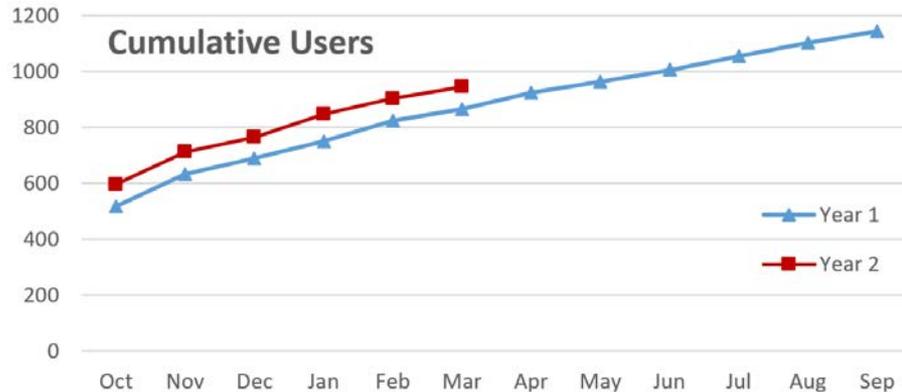


**35 expert staff members**  
**~170 faculty members**  
**5 deans**



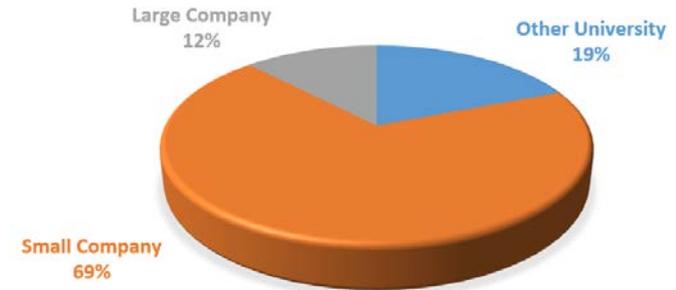
# Stanford Site User Data

Yearly User Data Comparison		
	Year 1(12 months)	Year 2 (6 months)
<b>Total Users</b>	1142	945
<b>Internal Users</b>	952	791
<b>External Users</b>	190 (17%)	154 (16%)
<b>Total Hours</b>	113,089	52,288
<b>Internal Hours</b>	94,996	41,963
<b>External Hours</b>	18,093 (16%)	10,325 (19%)
<b>Average Monthly Users</b>	520	549
<b>Average External Monthly Users</b>	74 (14%)	82 (12%)
<b>New Users</b>	542	232
<b>New External Users</b>	89 (16%)	42 (18%)



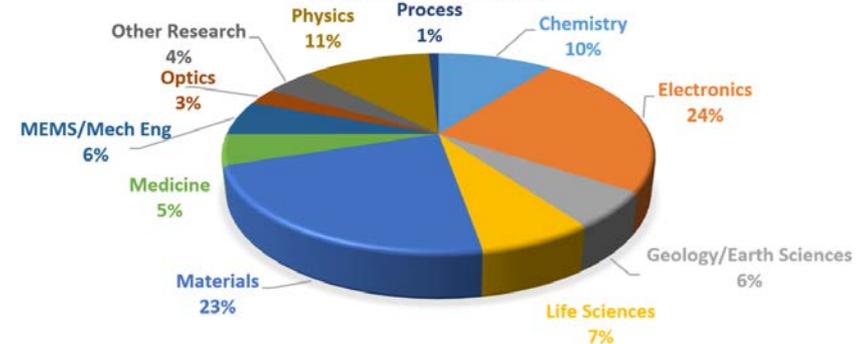
## External Users

Data: Oct 2015 - Sep 2016



## All Users

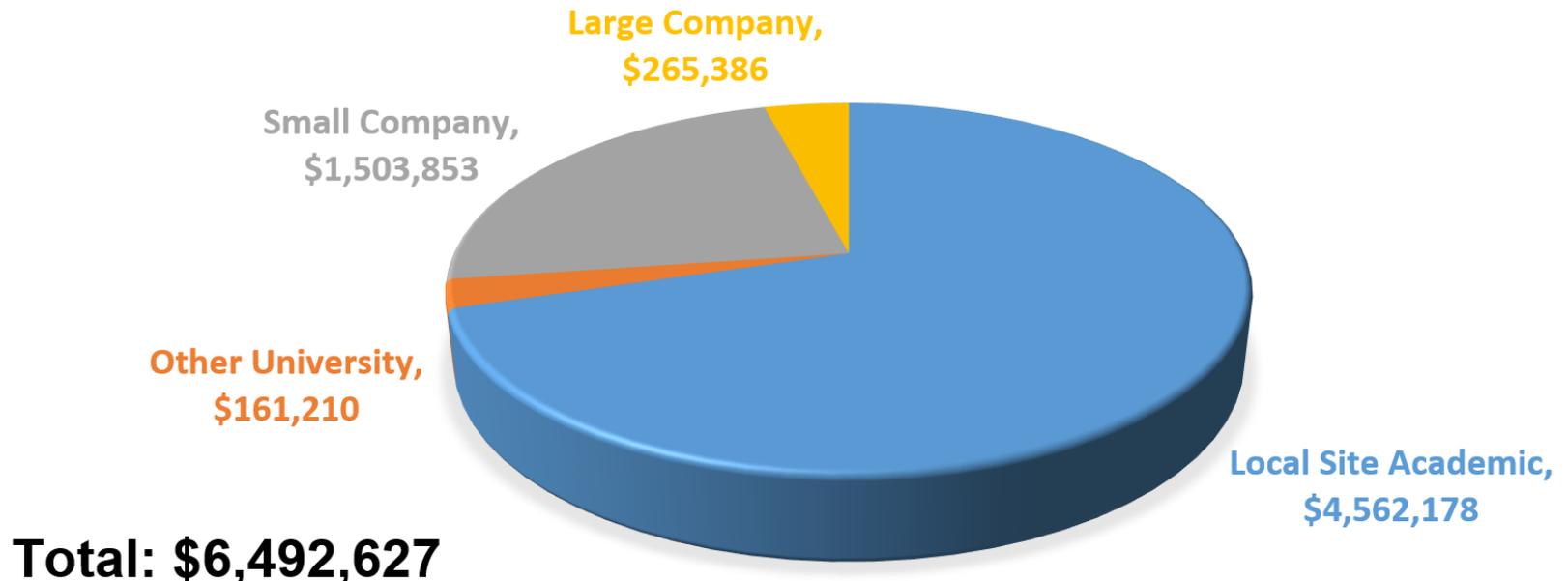
Data: Oct 2015 - Sep 2016



# Users: Lab Fees – 1st Full Year

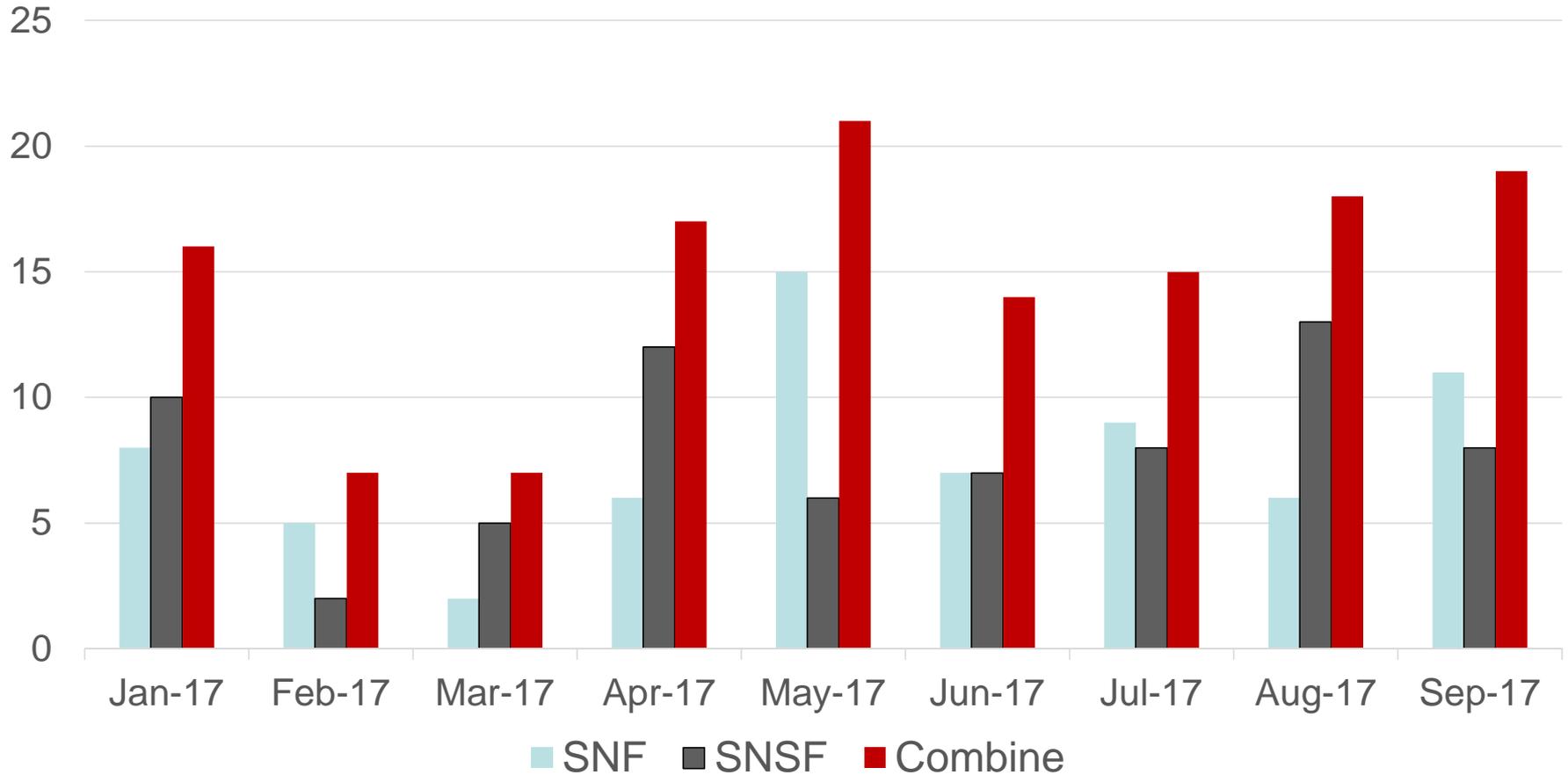
## Lab Fees

Data: Oct 2015 - Sep 2016

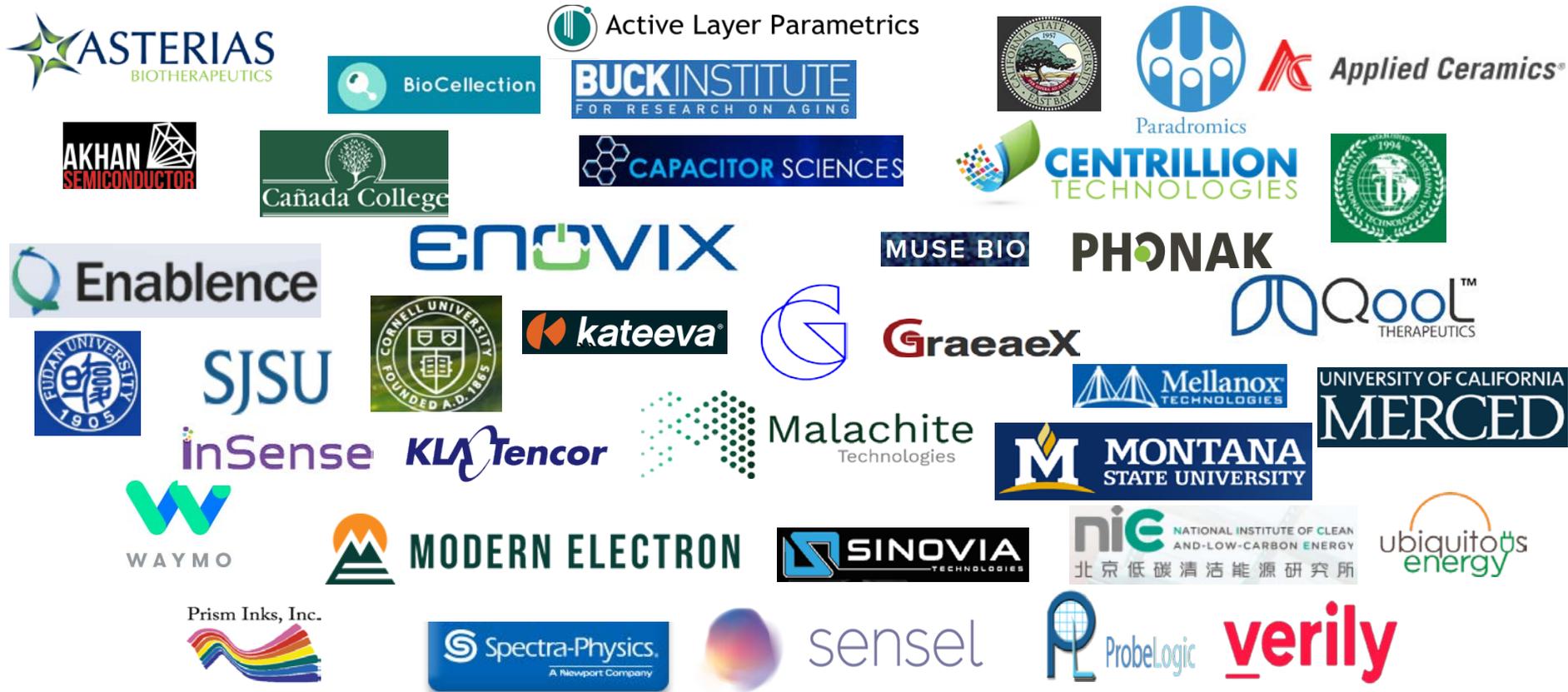




# New External Users 2017



# Sampling of new external user affiliations in 2017

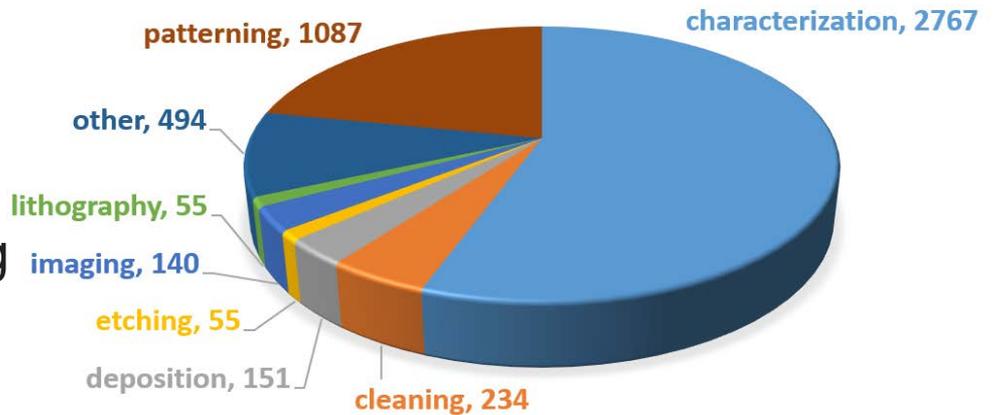


~ 51 new active organizations!

# Facility Upgrades and New Tool Capabilities

- Since start of NNCI:
  - ~\$5M equipment
- Source
  - ~\$0.7Mk NSF MRI (XCT)
  - ~\$4.3M University funding

Total Equipment Purchases (\$k)



Heidelberg MLA150 Direct Write System



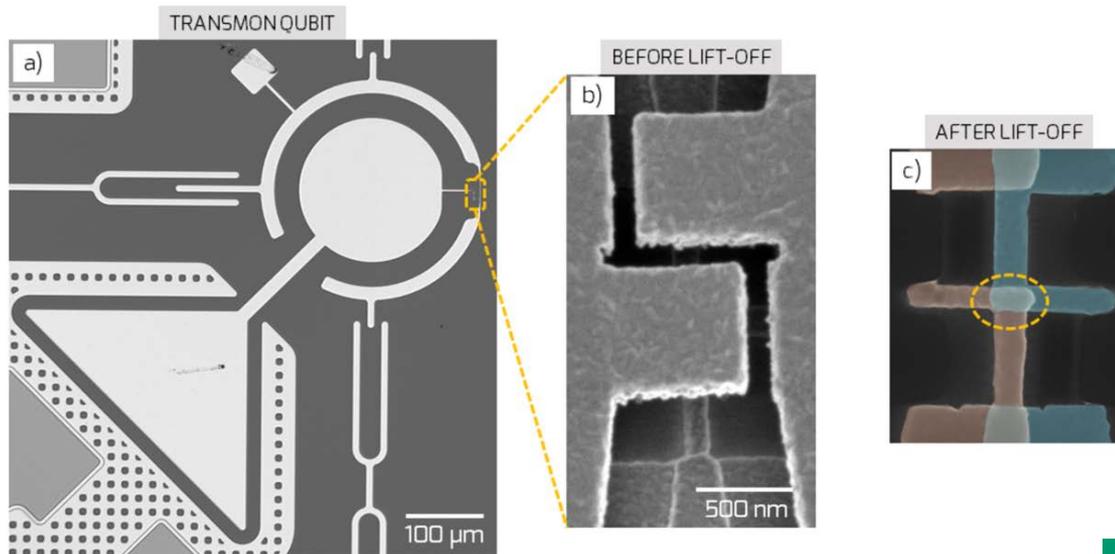
Leybold RF/DC sputter station



Nanoscribe 3D printing system

# Research Highlight: Rigetti Computing

- Motivation: develop a scalable quantum computing platform for artificial intelligence and computational chemistry
- Technique: fabrication of Josephson junctions, comprised of aluminum electrodes separated by a thin insulating barrier

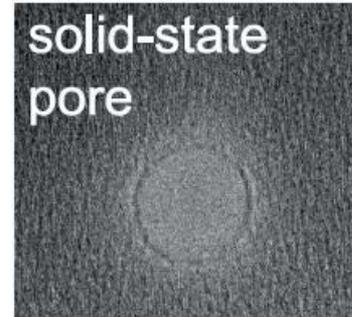


a) Fabricated transmon qubit. b) Bilayer e-beam resist stack after JEOL 6300FS e-beam patterning and double-angle aluminum evaporation. c) False color image of the Josephson junction at the end of the fabrication process.

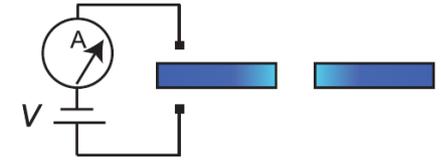
Rigetti Computing is a leading quantum computing start-up which recently raised \$64M in Series A and B funding. The company was founded in 2013 and has currently about 50 employees. <http://www.rigetti.com>

# Research Highlight: Two Pore Guys

- Motivation: single molecule detection platform based solid-state nanopore technology
- Technique: fabrication of nanopore using e-beam lithography



Single-molecule sensing with a nanopore device.



Voltage  $V$  applied across a single 27nm diameter nanopore, while measuring current through the pore




**Business Wire**  
A Berkshire Hathaway Company

HOME SERVICES NEWS EDUCATION ABOUT US

**Two Pore Guys Announces Global Licensing Agreement With Monsanto for Its Rapid Detection Technology Platform**

*Announcement marks 2PG's first agriculture agreement; Initial assays will target biomolecule detection in crops, pests and pathogens to improve lab and in-field testing efficiencies*

Two Pore Guys makes a digital, hand-held, testing platforms. Closed a \$24.5 million Series A round in April 2017. The company was founded in 2011 and has currently about 50 employees.  
<http://twoporeguys.com>

# Education and Outreach Activities

# Nanoscience Summer Institute for Middle School Teachers (SIMST)

- SIMST: 3 day workshop
- Emphasis on hands-on and experiments like ferrofluid, self-assembly, and dye-sensitized solar cells
- Follow-up workshops and support throughout the year
- Plans:
  - extend program with an Research Experience for Teachers (RET)



# Partnerships: Cal State University - East Bay

- **Fall 2015:** Prof. Ryan Smith joins proposal for NNCI, CSUEB's first field trip to nanofacilities
- **Fall 2016:** Prof. James Tandon visits with computer science class
- **Spring 2017:** Prof. Smith brings class to perform fabrication & characterization methods in SNF. Highlighted in [Stanford Report](#)
- **Summer 2017:** Prof. Smith prepares educational journal article for submission with Stanford
- **Fall 2017:** Prof. Smith is onboarding as a user to utilize more instruments



Professor Ryan Smith and his students are gowned up and prepared to enter the Stanford Nanofabrication Facility.



Staff member Uli Thumser performs an oxide etch on photovoltaic cells samples students brought to Stanford Nanofabrication Facility (SNF).

# Researcher Education

- Motivation
  - educational practices that will help researchers become knowledgeable and proficient users of the facilities
- Developed pilot modules on an edX-based platform
  - plasma etching and wafer handling
  - Under development: lithography and light microscopy content development
  - includes resource research, media production, and lab-specific training
- Coordinating to utilize network resources for content development and deployment

Stanford University

Engineering: nano@stanford | nano@stanford

View this course as: Student

Home Course

Bookmarks

Introduction to nano@stanford

1. Platform walkthrough

2. What Are These Materials and For Whom Are They Intended

3. How These Materials Are Organized

4. How to Use These Materials

Dry Etching

Substrates and Wafer Handling

Feedback

Terms of Use

Introduction to nano@stanford > 2. What Are These Materials and For Whom Are They Intended > What Are These Materials and For Whom Are They Intended

Bookmarks

Dry Etching

1. Introduction to the Dry Etching Section

2. Introduction to Dry Etching, and Basics of Plasmas and Types of Dry Etching Tools

3. Dry Etching Mechanisms and Choosing a Dry Etching Process and Tool

4. Choosing a Dry Etch Tool and Process at SNF

5. Tools

5a. Plasma-Therm Metal Dry Etcher (SNF)

Substrates and Wafer Handling

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Bookmarks

Introduction to Dry Etching, and Basics of Plasmas and Types of Dry Etching Tools

This and the next subsection contain presentations given by Dr. James McVittie of SNF, split up into 4 short videos, or 4 "parts," on the basics of dry etching in nanofabrication. The first two parts are in this subsection, and present an introduction to dry etching and the basics of plasmas and etching tools, particularly for those new to the field of plasma etching.

"Part 1: Introduction to Dry Etching" presents the basics of patterning a film, and discusses etch selectivity and the degree of anisotropy, as well as why we use plasmas for etching and the advantages over wet etching.

"Part 2: Basics of Plasmas and Types of Dry Etching Tools" presents the fundamentals of plasmas and different dry etch tool configurations.

Parts 3 and 4 are in the following section.

Part 1: Introduction to Dry Etching

Etch Profile Control - Definitions

- Etch profile often critical for structure application
  - Minimum edge loss for narrow structures
  - Sloped edge for step coverage

Isotropic etches equally in all directions

Plasma

Film

Substrate

get all the way through the film I'm etching. The second selectivity is when I go all the way through the material, and I hit the substrate material. And then the selectivity can also be very important, such as if I'm etching a gate over a gate oxide, a thin gate oxide, I have to stop immediately before going through that the oxide. So therefore I want a very high selectivity to the material I remove to my underlying gate oxide. So normally we want a high selectivity. We want to have—we want the rate of removal of my film to be much greater than the removal rate of my mask layer.

6:57 / 13:11

Speed 1.0x

Download videos

Download transcripts

# Network Activities

- Nanodays
- Workshops
- Webinars
- Teacher Development
- User Education & Training
- ...



## How the National Nanotechnology Coordinated Infrastructure Nodes Support Environmental Research: Examples from the Field.

Thursday July 27<sup>th</sup> 2017 1:00-2:00 pm (Eastern)

### Speakers:



**Dr. Bruce Clemens** (Walter B. Reinhold Professor in the School of Engineering and Professor of Photon Science and, by courtesy, of Applied Physics, Stanford University)

Dr. Clemens studies growth and structure of thin film, interface and nanostructured materials for catalytic, electronic and photovoltaic applications. He and his group investigate phase transitions and kinetics in nanostructured materials, and perform nanoparticle engineering for hydrogen storage and catalysis. Recently he and his collaborators have developed nano-portals for efficient injection of hydrogen into storage media, dual-phase nanoparticles for catalysis, amorphous metal electrodes for semiconductor devices, and a lift-off process for forming free-standing, single-crystal films of compound semiconductors.



**Dr. Michael Hochella** (University Distinguished Professor, Geosciences, Virginia Tech).

Michael Hochella is University Distinguished Professor at Virginia Tech, concentrating on the area of nanogeoscience. His research interests include nanoscience and mineral surface geochemistry, and elucidating the role that these play in earth science, with particular interest in environmental issues. In addition to this, Dr. Hochella's team work on mineral-microbe interactions from both a geochemical and biochemical perspective and characterize aqueous partitioning reactions at oxide and silicate surfaces.

### Moderator:



**Dr. Larry Goldberg** (Senior Engineering Advisor in the Division of Electrical, Communications and Cyber Systems, Directorate for Engineering, National Science Foundation).

Dr. Goldberg is lead program officer and guided the competition for the National Nanotechnology Coordinated Infrastructure (NNCI). He has coordinated joint activities on nanoelectronics with the Semiconductor Research Corporation, conducted under NSF's emphasis area on Nanoscale Science and Engineering. He led federal agency funding for the 2012 National Academies study on Optics and Photonics: Essential Technologies for Our Nation. He serves as NSF member of the interagency Wireless Spectrum Research and Development Senior Steering Group, and represents the Engineering Directorate on the NSF program Enhancing Access to the Radio Spectrum (EARS). He also coordinates the Major Research Instrumentation (MRI) program for the Engineering Directorate.

# Network Activity Highlight: 2017 NNCI ALD/MOCVD Symposium

- Stanford and Harvard co-hosted symposium in April, 2017 at Stanford University.
- build networks between university shared labs
- Technical & research talks
- Participation:
  - 13 Universities, including
  - 9 NNCI sites
  - 100 researchers, including
  - 46 industry participants



# National Nanotechnology Day – October 9th, 2017

- 100 billion nanometer race
- Remote tours
- Classroom visits with hands-on activities
  - Staff and students visited local middle schools, utilizing SIMST teacher connection



# Panel discussion topic: Future Research Directions

- In-situ or in-operando techniques
- Integration of soft, bio and hard materials and approaches
  - Attract users from new communities
  - Integrate users across facilities
  - Brochure
    - Focus on unique capabilities for non-traditional users
- Cross-platform, multi-technique data blending

### OUR FACILITIES

**STANFORD NANOFABRICATION FACILITY (SNF)**  
SNF consists of a cleanroom equipped to support conventional device fabrication, the MOCVD lab for Molecular-Organic Chemical Vapor Deposition, and the SHELIX for Experimental Fabrication methods beyond silicon electronics.

**STANFORD NANO SHARED FACILITIES (NSNF)**  
NSNF is comprised of four core facilities: Nanofabrication, Electron & Ion Microscopy, X-Ray & Surface Analysis, and Soft & Hybrid Materials that encompass high-level fabrication and characterization methods.

**STANFORD MATERIALS ANALYSIS FACILITY (MAF)**  
MAF has several instruments used to characterize materials, metals, and the solid products of laboratory experiments on a range of materials of interest to geoscientists, materials scientists, and applied physicists.

**STANFORD ENVIRONMENTAL MEASUREMENT FACILITY (EMF)**  
EMF provides quantitative analysis and technical expertise to members of the Stanford community wanting to conduct soil, gas, and water measurements.

**EDUCATION & OUTREACH**  
nano@stanford supports the education of students, interns, and postgraduates through intern, professional, doctoral, master programs, online courses, formal lectures, and outreach programs serving the local community and beyond.

For a complete listing of facilities & capabilities, visit <http://nanofab.stanford.edu>

### CAPABILITIES & RESEARCH EXAMPLES

**JEOL 88X-6300P'S ELECTRON BEAM LITHOGRAPHY**  
The JEOL 88X-6300P is a 100 kV high-throughput field emission electron beam lithography system capable of a 12 nm patterning. Image: 100 kV image of a porous silicon membrane structure. Photo: Fabrice Druon.

**CAMECA RIBO SECONDARY ION MASS SPECTROMETER**  
The Cameca RIBO-1000 is a secondary ion mass spectrometer that measures elemental composition from films to 100 nm spatial resolution with ppm sensitivity. Image: Secondary image of a porous silicon membrane structure. Photo: Fabrice Druon.

**FEL TRANSMISSION ELECTRON MICROSCOPE**  
The FEL-FEM is an aberration-minimized environmental TEM featuring high image (1.7 nm) and energy resolution (0.1 eV). The instrument can operate in various modes with unique capabilities to study materials through a variety of excitation modes. Image: High-resolution TEM image of carbon nanotubes. Photo: Fabrice Druon.

**ASTRON METAL ORGANIC CHEMICAL VAPOR DEPOSITION**  
The MOCVD Lab has equipment and expertise for growing films of III-V and II-VI materials, nitrides, phosphides, and oxides used in electronics with applications ranging from microelectronics and optics to biology and space. Image: SEM image of a porous silicon membrane structure. Photo: Fabrice Druon.

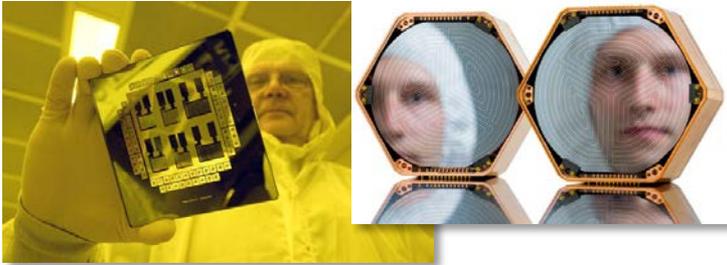
At nano@stanford, we, as well as our expertise in materials science and engineering. Every year, more than 1,200 lab members participate in a rich research culture where staff offer specialized expertise in energy, electronics, earth sciences, civil and environmental sciences, life sciences, and medicine. More than a lab, it's a vibrant community that enables multidisciplinary research and education to our scientists and engineers.

nano@stanford is supported by the National Science Foundation as part of the National Nanotechnology Coordinated Infrastructure under award ECCS-1041552.

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# Thank you!

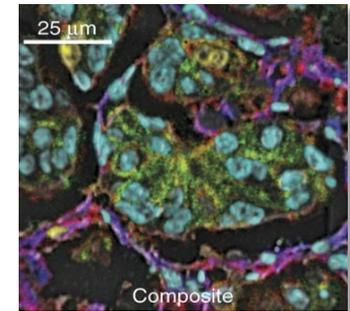
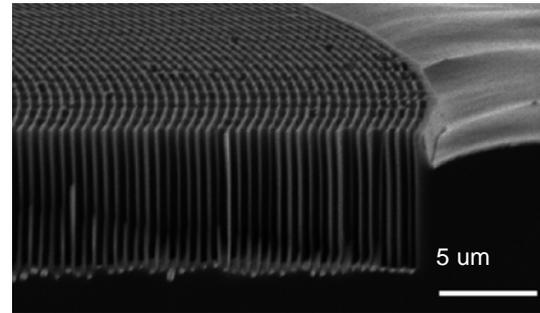
***nano@stanford* provides access to world-leading facilities and expertise in nanoscale science and engineering for internal users and for external users from academic, industrial, and government labs.**



~1,200 annual users take advantage of a comprehensive array of advanced nanofabrication and nanocharacterization tools available within the Stanford Nano Shared Facilities (SNSF), the Stanford Nanofabrication Facility (SNF), the Mineral Analysis Facility (MAF), and the Environmental Measurement Facility (EMF).

## Facilities feature:

- ~16,000 sqft fully equipped cleanroom facilities, including resources that are not routinely available, such as an MOCVD and advanced e-beam lithography
- ~15,000 sqft of characterization facilities, including SEM, TEM, FIB, XRD, SPM, XPS and unique tools such as a NanoSIMS, and a scanning SQUID microscope.



Broad research portfolio spanning traditional nano areas as well as life science, medicine, and earth and environmental science. Education and outreach programs, including a library of just-in-time educational materials, seminars, public events and tours.



<http://nanolabs.stanford.edu>