National Nanotechnology Coordinated Infrastructure

NNCI Coordinating Office Annual Report (Year 1)

April 2016 – March 2017

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NNCI Coordinating Office Annual Report 2017

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1. NNCI Overview

1.1. Introduction

The National Nanotechnology Coordinated Infrastructure (NNCI) is an NSF-funded network of academic nanofabrication and characterization sites and their partners, formed to advance research in nanoscale science, engineering and technology. The NNCI site awards were the culmination of a competition conducted by NSF, under Program Solicitation NSF 15-519, which was generated as a result of input from the science and engineering community following the completion of the National Nanotechnology Infrastructure Network (NNIN, 2004-2015). Over 50 proposals from potential NNCI sites were submitted, resulting in 16 awards. The NNCI network is funded by the NSF through cooperative agreements with the individual sites, with the initial site awards being made around September 15, 2015 with an initial award period of 5 years. The Coordinating Office for the network was awarded to the Georgia Institute of Technology on April 1st, 2016. The total NSF funding for the initial 5 years is $81 million.

The NNCI sites are located in 17 states and involve 29 universities and other partner organizations (see Figure 1) that provide researchers from academia, small and large companies, and government with access to university user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology.

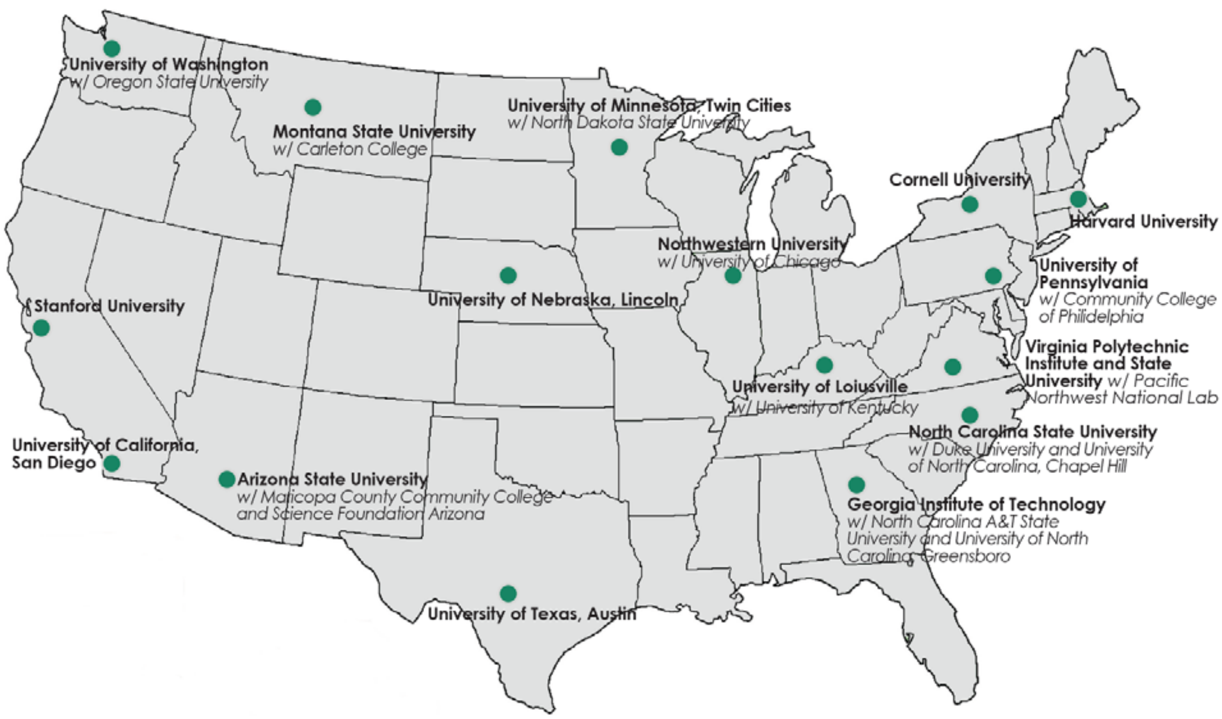


Figure 1: US Map with Locations of the 16 NNCI Sites

The goal of the NNCI network is (1) to provide open access to **state-of-the-art nano-fabrication & characterization facilities**, their tools and staff expertise across US, and (2) to use these resources to support **education & outreach (E&O)** as well as **societal & ethical implications (SEI) programs** in/of nanotechnology.

The 16 NNCI sites and their 13 partners (university, college, national lab, and non-profit foundation) provide access to more than 2,000 tools located in 66 distinct facilities. As will be detailed later in this report, these tools have been accessed by nearly 11,000 users including >2,500 external users, representing >200 academic institutions, almost 700 companies, >40 government and non-profit institutions, as well as >35 foreign entities. Overall, these users have amassed more than 900,000 tool hours. Over the first year, the network has trained >4,000 new users.

1.2. NNCI Organization

All of the NNCI facilities, most of which have partners and multiple locations, are available for use by students and professionals from around the country and globally. The sites and facilities within NNCI (Table 1) support research and development for academic education and research purposes, as well as product and process development for commercial purposes. Each site operates under its own procedures for user recruitment, user access, training, rates, billing, and other logistical details. However, each has agreed to provide open access, with as minimal a burden as possible, to their state-of-the-art nanofabrication and characterization facilities, their tools, and staff expertise. All sites use the resources provided by NSF to support a variety of education and outreach activities (see Section 4.1), and many also offer programs or research in societal and ethical implications (SEI) of nanotechnology (Section 4.2).

Table 1: NNCI Sites, Locations and Facilities

NNCI Sites and Locations	NNCI Facilities
Cornell Nanoscale Science and Technology Facility (CNF) Cornell University	Cornell Nanoscale Science and Technology Facility
Center for Nanoscale Systems (CNS) Harvard University	Center for Nanoscale Systems
Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY MMNIN) University of Louisville University of Kentucky	Micro/Nano Technology Center Center for Nanoscale Science and Engineering Huson Nanotechnolgy Core Facility Electron Microscopy Center Conn Center for Renewable Energy Research Center for Applied Energy Research Center for Advanced Materials Rapid Prototyping Center
Mid-Atlantic Nanotechnology Hub (MANTH) University of Pennsylvania Community College of Philadelphia	Singh Center for Nanotechnology Quattrone Nanofabrication Facility Singh Center for Nanotechnology Nanoscale Characterization Facility Singh Center for Nanotechnology Scanning Probe Facility
Midwest Nanotechnology	Minnesota Nano Center

Infrastructure Corridor (MINIC) University of Minnesota North Dakota State University	NDSU Packaging Center
Montana Nanotechnology Facility (MONT) Montana State University Carleton College	Montana Microfabrication Facility Imaging and Chemical Analysis Laboratory Center for Biofilm Engineering Proteomics, Metabolomics and Mass Spectroscopy Facility Center for Bioinspired Nanomaterials
Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth) Virginia Tech Pacific Northwest National Laboratory	Virginia Tech Center for Sustainable Nanotechnology Virginia Tech Nanoscale Characterization and Fabrication Laboratory PNNL Environmental Molecular Sciences Laboratory
Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) Arizona State University Maricopa County Community College District Science Foundation Arizona	ASU NanoFab LeRoy Eyring Center for Solid State Science Solar Power Lab Peptide Array Core Facility Nano in Society User Facility ASU Flexible Electronics and Display Center Center for the Life Cycle of Nanomaterials
Nebraska Nanoscale Facility (NNF) University of Nebraska-Lincoln	Nebraska Center for Materials and Nanoscience
Northwest Nanotechnology Infrastructure (NNI) University of Washington Oregon State University	Washington Nanofabrication Facility Molecular Analysis Facility Advanced Technology and Manufacturing Institute Materials Synthesis & Characterization Facility
Research Triangle Nanotechnology Network (RTNN) North Carolina State University Duke University University of North Carolina at Chapel Hill	Analytical Instrumentation Facility NCSU Nanofabrication Facility Shared Materials Instrumentation Facility Chapel Hill Analytical and Nanofabrication Laboratory Zeis Textiles Extension for Economic Development PULSTAR Reactor Public Communication of Science & Technology Project Center for the Environmental Implications of Nanotechnology Duke Magnetic Resonance Spectroscopy Center
San Diego Nanotechnology Infrastructure (SDNI) University of California - San Diego	Nano3 Cleanroom Microfluidic Medical Device Facility Chip-Scaled Photonics Testing Facility NanoMagnetic Material Processing Facility
Southeastern Nanotechnology Infrastructure Corridor (SENIC)	Institute for Electronics and Nanotechnology - Micro/Nano Fabrication Facility

Georgia Institute of Technology Joint School of Nanoscience and Nanoengineering	Materials Characterization Facility JSNN Cleanroom and Labs
Soft and Hybrid Nanotechnology Experimental (SHyNE)Resource Northwestern University University of Chicago	Northwestern University Atomic and Nanoscale Characterization Experimental Center Integrated Molecular Structure Education and Research Center Northwestern University Center for Atom Probe Tomography J.B. Cohen X-ray Diffraction Facility Northwestern University Micro/Nano Fabrication Facility Simpson Querrey Institute Pritzker Nanofabrication Facility
NNCI Site @ Stanford (nano@stanford) Stanford University	Stanford Nano Shared Facilities Stanford Nanofabrication Facility Stanford Mineral Analysis Facility Stanford Environmental Measurement Facility
Texas Nanofabrication Facility (TNF) University of Texas -Austin	Microelectronics Research Center Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies The Center for Nano and Molecular Sciences Texas Material Institute

Sites have identified nearly 250 staff that support the NNCI program (Table 2), although some individuals fulfill multiple roles within a site's operations. In general, Site Leadership includes Site Directors, Deputy Directors, and Associate/Assistant Directors. Some of these individuals also serve as project co-PIs. New User Contacts are those site staff responsible for coordinating access to facilities for external users. Program Managers are identified as those staff who most interact with the Coordinating Office, providing data as requested and communicating information to appropriate site staff. Facility Managers are responsible for the operations of site facilities, often assisted by Technical Staff when identified. Education/Outreach Coordinators handle the K-12 activities and sometimes the university student and professional education as well. SEI and Computation Coordinators are responsible for those aspects of site operations.

Table 2: NNCI Site Staff

NNCI Site Staff	
Site Directors	16
Other Site Leadership	39
New User Contacts	29
Program Managers	19

Facility Managers	58
Education/Outreach Coordinators	30
SEI Coordinators	8
Computation Coordinators	5
Safety/Facility Director/Technical Staff	29
Facility Administrative Staff	14

2. NNCI Coordinating Office

The NNCI Coordinating Office is led by Prof. Oliver Brand (Executive Director, Georgia Tech Institute for Electronics and Nanotechnology (IEN) and Director, SENIC) who serves as **Director**. Dr. David Gottfried (Senior Assistant Director, Georgia Tech IEN and Deputy Director, SENIC) serves as **Deputy Director** and oversees the Coordinating Office day-to-day operations, assisted by a **Program Assistant** (Amy Duke). Three **Associate Directors** manage the network activities in specific areas. Dr. Nancy Healy (Georgia Tech) coordinates the NNCI education and outreach programs. Dr. Healy was the Education Coordinator of the NNIN and in that role shaped the successful E&O program of the previous network. Prof. Jameson Wetmore (Arizona State University) coordinates the Societal and Ethical Implications (SEI) activities. Prof. Wetmore is an Associate Director within the Center for Nanotechnology in Society at ASU and has been coordinating SEI activities on a national level as Co-Director of the Center for Engagement and Training in Science & Society. Prof. Azad Naeemi (Georgia Tech) coordinates the computational activities and facilitates interactions with nanoHUB/NCN at Purdue University. Prof. Naeemi is currently responsible for SRC-funded benchmarking efforts for emerging "beyond-CMOS" devices and in that role already collaborates with nanoHUB/NCN to make computational tools for benchmarking widely available. This executive staff meets monthly by conference call. The originally proposed Web Developer has not been hired, as NNCI website design and creation used an external vendor (see more below).

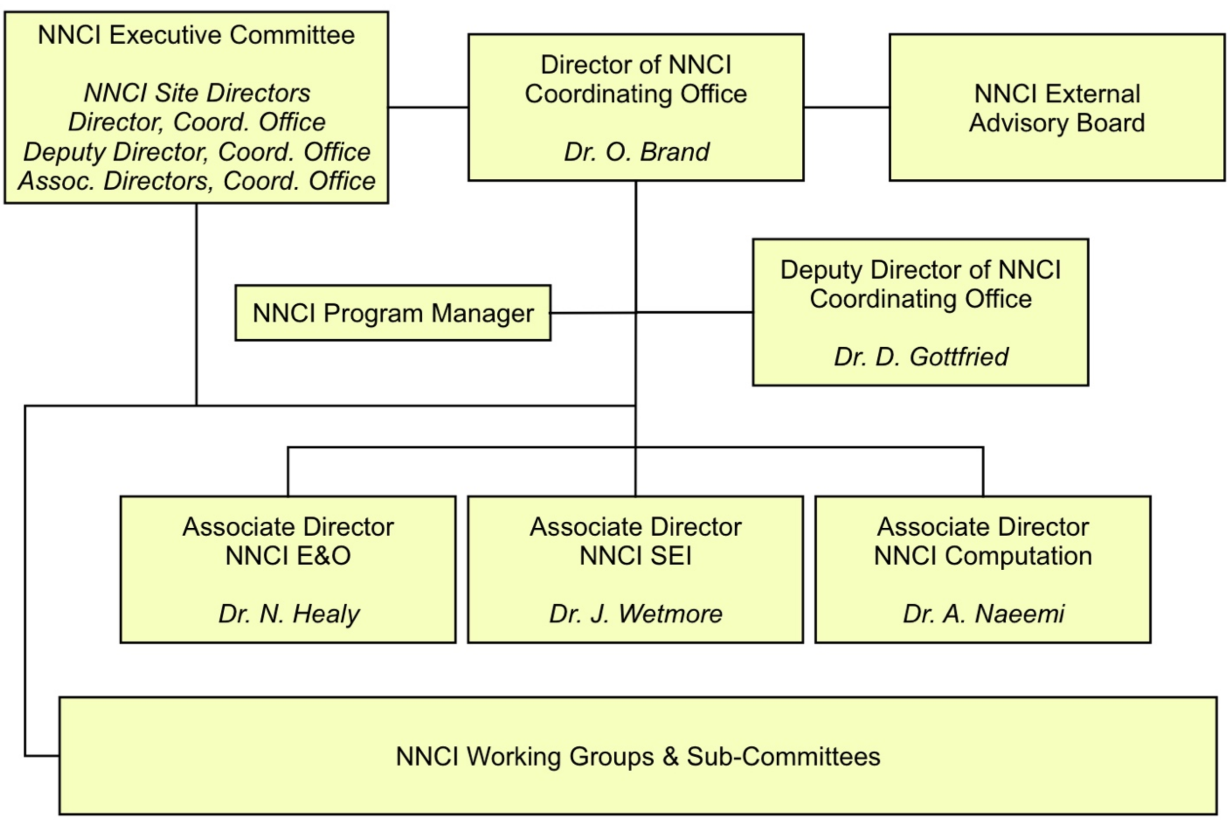


Figure 2: NNCI Coordinating Office Organizational Chart

The core staff is guided by an **Executive Committee** which includes the 16 NNCI site directors. The Executive Committee met every other month in the first year via teleconference/WebEx and annually in person at the NNCI Conference. Starting in April 2017, the Executive Committee will meet monthly. The Executive Committee and Coordinating Office are advised by an **External Advisory Board** (EAB, see Section 3) comprised of members representing industry, academia, government, education and outreach, SEI, computation and non-traditional disciplines in nanoscience and nanoengineering. The EAB meets in person as part of the NNCI Conference, with additional conference calls as determined by the EAB.

In addition to the work of the Associate Directors, several **subcommittees** of the Executive Committee have been formed to tackle high-level issues related to the NNCI network as a whole (see Section 5). Finally, leveraging the distributed expertise at the network level, several **working groups**, composed of staff members from the NNCI sites, have been formed to share and develop best practices for site and network operations, technical areas, research areas, and education and outreach (see Section 6).

To learn more about the NNCI sites and their partners, the Coordinating Office started visiting the individual NNCI sites, with initial priority given to NNCI sites that were not part of the NNIN network. The goal of these visits is to get to know site staff, learn about the facilities and programs, share success stories, and discuss challenges. Within the first year, the Coordinating Office visited the following sites and has several more planned for 2017:

- Montana Nanotechnology Facility (June 2016)
- Mid-Atlantic Nanotechnology Hub (Aug. 2016)
- Kentucky Multi-Scale Manufacturing and Nano Integration Node (Sept. 2016)
- Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (Nov. 2016)
- Research Triangle Nanotechnology Network (Nov. 2016)
- San Diego Nanotechnology Infrastructure (Feb. 2016)
- Nanotechnology Collaborative Infrastructure Southwest (Feb. 2016)
- Soft and Hybrid Nanotechnology Experimental Resource (planned for March 2017)
- NNCI Site @ Stanford (planned for April 2017)
- Nebraska Nanoscale Facility (planned for Aug. 2017)

Finally, Coordinating Office Director Oliver Brand was invited by the NNCO to discuss “Infrastructure Needs” at the 2016 NNI Strategic Planning Stakeholder Workshop (Washington DC, May 19-20, 2016). The findings from this workshop influenced the 2016 National Nanotechnology Strategic Plan (https://www.nano.gov/node/1676), released in October 2016.

3. External Advisory Board

During the NNCI first year, the Coordinating Office established an NNCI External Advisory Board. To this end, names for potential advisory board members were solicited from the 16 NNCI sites. The Coordinating Office then assembled the Advisory Board from the solicited list, ensuring a diverse board in terms of gender, ethnicity and disciplinary background. Table 3 shows the Advisory Board members and their affiliations.

Table 3: NNCI External Advisory Board

Name	Affiliation
Dr. Tina Bahadori	Director, National Center for Environmental Assessment US Environmental Protection Agency
Prof. Dionysios Dionysiou	Department of Biomedical, Chemical and Environmental Engineering University of Cincinnati
Prof. Reggie Farrow	Department of Physics New Jersey Institute of Technology
Dr. Andrew Greenberg	Associate Director, Institute for Chemical Education University of Wisconsin
Dr. Angelique Johnson	MEMSTIM Louisville, KY
Mr. Joe Magno	Executive Director The North Carolina Center of Innovation Network
Prof. Richard Osgood	Department of Electrical Engineering & Department of Applied Physics Columbia University
Dr. Kurt Petersen	Band of Angels Palo Alto, CA
Dr. Andreas Roelofs	Founding Director, Nano Design Works Argonne National Laboratory
Prof. Ken Wise	Department of Electrical Engineering and Computer Science University of Michigan

The Advisory Board meets at least twice per year, once in person during the annual NNCI Conference and once virtually via Webex or conference call. Ahead of the first NNCI

Conference in January 2017, the Coordinating Office asked the Advisory Board to take a critical look at what NNCI is doing well and areas where we can improve. In particular, the Advisory Board considered the following questions:

1. What activities can/should NNCI support to achieve the goal of the network surpassing the sum of the parts? This should involve not only research facilities aspects, but also consider support of education/outreach, computational tools, and societal and ethical implications activities.
2. The NSF considers increasing usage by external users as well as usage by "non-traditional" users of prime importance. Considering the current activities of the sites and the network, what can be improved to achieve this aim?
3. Since NNCI serves to support cutting-edge research in both academia and industry, what capabilities should sites begin to acquire to anticipate 5-10-year research trends?

From the feedback of the Advisory Board at the January 2017 NNCI Conference (see Appendix 11.1) it became clear that a more detailed "Charter Letter" with input from the NSF on what would constitute a successful network is needed. This document will be drafted in Spring 2017 and communicated to the Advisory Board.

4. Associate Director Reports

4.1. Education and Outreach

NNCI's Education and Outreach (E&O) mission seeks to: (1) Offer education and training to address the growing need for a skilled workforce and informed public; (2) Provide resources, programs, and materials to enhance knowledge of nanotechnology and its application to real-world issues; and (3) Support the US economy by enabling a STEM-literate workforce ready to meet the technological challenges of a nano-enabled economy as well as an informed citizenry that supports continued and safe growth of nanotechnologies. Towards these goals, the 16 sites of the NNCI have developed 16 individual E&O programs that have common themes, which lend themselves to collaboration and support. The Coordinating Office envisions a two-pronged approach to these efforts: (1) programs and activities that address local needs and interest and (2) programs and activities across the network that will have national reach.

The first year of the NNCI's E&O efforts demonstrate that it was a very productive year with over 295,000 individuals reached. Of that number, 245,000 were the result of NanoEarth's *Pulse on the Planet* radio broadcasts and NNF's traveling nano exhibit. This number does not include the 3-5 million who visit Disneyworld's Epcot Theme Park where the *Nanooze* exhibit is housed, nor the thousands of print editions of *Nanooze* that were distributed to schools and classrooms.

To coordinate the common efforts across the network and to determine efforts worthy of scaling up to other sites, the Coordinating Office developed E&O working groups (WG). The first groups organized in year one are: Research Experience for Undergraduates (REU), K-12 students and Community, K-12 Teachers and Research Experience for Teachers (RET), and Community College and Workforce Development. Due to common themes, the K-12 and Community WG merged with the K-12 Teachers WG. Working groups for Evaluation and Assessment, Diversity, and Online courses working groups are planned for the near future.

The REU WG, led by Dr. Lynn Rathbun of CNF, determined that 12 of the 16 sites have REU programs. This group gathered REU program descriptions to populate the NNCI REU web page so that interested students would have a common site to search nano-focused REU programs. The NSF REU program office was contacted to post our link on its REU page to provide greater visibility of the programs (https://www.nsf.gov/crssprgm/reu/list_result.jsp). Georgia Tech will host the first NNCI REU Convocation August 6-8, 2017. Seven of the twelve REU sites have committed to the event. The NNCI Coordinating Office gathered contact information for interns, faculty, and mentors from all sites offering an REU program in order to conduct a post survey. These results provided important information: 1. Assessment of programs across the network; 2. Contact information to continue the NNIN longitudinal study of REU participants (Healy and Rathbun, 2016; http://www.springer.com/us/book/9783319318325); and 3. Assessment data from faculty and mentors to assist in the selection of participants in CNF's international REU in Japan. CNF's pool of applicants for its 2017 summer internship at the National Institute for Materials Science in Tsukuba Japan will come from NNCI's REU participants for summer 2016.

The K-12 and Community WG, led by Dr. James Marti of MINIC, identified and reviewed NNCI E&O programs. From these, they created a list of programs recommended for possible scale up by sites. This list includes NanoDays; NNCI RET, teacher-training videos, NanoCamps, remote access to tools, and activity kits for schools. In year two, these will be topics of discussion for ways to implement recommendations with the sites.

NNCI workshops and symposia were offered by most sites. These technical workshops reach undergraduates, graduate students, post-docs, faculty, and industry and government professionals. They serve to not only educate individuals about particular aspects of nanoscale science and engineering but also serve as a means to introduce NNCI capabilities to current and potential users. Three NNCI sites (MONT, NanoEarth, SENIC) submitted an abstract to offer a two-day workshop at the Goldschmidt 2017 conference, the largest international geochemistry conference. The abstract was accepted for the August 2017 meeting.

The E&O Coordinating Office has been active in collaborating with other groups that are focused on nano-education and outreach. The goals are to promote our programs, share resources, make lasting connections with other E&O efforts, and raise the visibility of NNCI E&O. We jointly exhibited with the NNCO at the March 2016 National Science Teachers Association annual conference (also with nanoHub). We have promoted NNCO's NanoDay 2016 with sites contributing events and submitting videos for the NanoNuggets (https://www.nano.gov/node/41). NSF's *Generation Nano* is a contest for high school students. NNCI advertised the contest across the network and requested that site directors submit video responses for the "Ask a Nano Expert" questions submitted by students (https://www.nsf.gov/news/special_reports/gennano/ask.jsp). We have created a NNCI Education group on nanoHub where we are uploading the approximate 100 NNIN curriculum units. Having such a page on nanoHub will expand the reach of these K-16 instructional materials. We have had discussions with the Nanotechnology Applications and Career Knowledge Network (NACK at Penn State) about enlarging their Remotely Accessible Instruments for in Nanotechnology (RAIN) network to include NNCI sites. Collaboration with RAIN addresses the remote access recommendation of the K-12 and Community WG. The Coordinating Office will work with the WG to expand RAIN across the network.

The Community College/Workforce Development WG was formed and it proposes to assist the Workforce Development Subcommittee in its endeavor to determine needs and current site plans. There is overlap between these two groups and the coordinating office recommends that they work together and support common areas of interest.

Finally, the "Learn" page of the NNCI website was launched. In phase one, we created a network REU page with a link to all site applications http://www.nnci.net/research-experience-undergraduates) as well as an information page concerning E&O programs at each site including contact information (http://www.nnci.net/site-education-programs). We successfully migrated *Nanooze* from the NNIN site so all 14 issues are available on NNCI.net. Education articles have been posted and more will be developed during phase two of the website launch.

4.2. Societal and Ethical Implications

Nanotechnology holds great promise, but the NNCI CO recognizes that the introduction of any new technology can have significant societal and ethical consequences. We believe it is important to think about the impacts of nanotechnologies as we conceive them, develop them, and implement them. To that end, the Coordinating Office is working to help all of the NNCI sites develop Societal and Ethical Implication (SEI) research and engagement programs. Associate Director Jameson Wetmore (also part of the NCI-SW site) is leading these activities.

There are a wide variety of activities that could be part of an SEI effort. Scholars affiliated with the NNIN and the two NSF funded Centers for Nanotechnology in Society developed a suite of research projects and programs that sought to address SEI issues. These included historical research, engagement programs for scientists and engineers, workshops to develop expert scenarios of possible nano-enabled futures, and bringing together members of the public to develop robust and considered advice to policymakers. The NNCI looks to take inspiration from these efforts and blaze new paths to conduct SEI and technical research side by side.

Of the 16 NNCI sites, seven originally proposed some level of SEI activity. Many of these efforts are already underway. At the Montana Nanotechnology Facility, David Mogk and his colleagues are working to develop a series of case studies related to nanoscience to be embedded in a variety of STEM curricula. Daniel Ratner at the Northwest Nanotechnology Infrastructure is engaged in a number of outreach and workforce development efforts that overlap with SEI. The San Diego Nanotechnology Infrastructure's Michael Kalichman runs a monthly forum at the Fleet Science Center in conjunction with UCSD-TV and will be integrating nanotechnology ethics into that program. LeeAnn Kahlor at the Texas Nanofabrication Facility has worked on integrating SEI into labs in the past. Under NNCI she will be finding ways to overcome the barriers to integration into the corporate workplace. Jan Youtie at SENIC will continue the work on nanotechnology publication and patent databases that she did as part of the Center for Nanotechnology in Society at ASU and is also looking for ways to do an SEI component of the I-Corps Program. David Berube is bringing his variety of nano SEI research projects and activities to the Research Triangle Nanotechnology Network, including training, outreach, and the development of resources for the general public, including his Nano Hype blog.

The Nanotechnology Collaborative Infrastructure Southwest is coordinating two large efforts. First, it is running a yearly policy workshop in Washington, DC for graduate student scientists and engineers. In May 2016, 14 students from the NNCI met with over 25 policymakers, funders, regulators, lobbyists, and judges in the first nano "Science Outside the Lab." The second annual event has already been advertised to all the NNCI sites and will be held in June 2017. The NCI-SW also hosts an SEI user facility – a place where researchers from around the world can work with social scientists to learn new tools and methods for analyzing and better understanding the social aspects of emerging technologies. Thus far over 50 researchers and practitioners from academia, industry, and government have participated in the user facility.

The NNCI CO is working to promote and expand these SEI efforts through two primary mechanisms. First, it sponsors an annual "Winter School on Responsible Innovation and Social Studies of Emerging Technologies" every January. The goal of this program is to train the next generation of SEI scholars. The Winter School brings together fifteen early career social science researchers for a week of learning a variety of research tools from around a dozen social scientists and other scholars. The first four iterations of the Winter School were sponsored by the Center for Nanotechnology in Society-ASU. During that time the program built up a respected reputation amongst SEI scholars around the world and a healthy alumni network. The NNCI is building upon this success and will continue the tradition. From January 3-10, 2017 the NNCI hosted the fifth Winter School at Saguaro Lake Ranch, just west of Phoenix. The student and young faculty participants unanimously agreed that it was an important opportunity to reflect on and build their career. In the follow up survey one noted: "This was one of the most informative training sessions I've ever been to. The intellectual diversity is astounding and helps you to think about what you want to research." The next iteration will be held on January 3-10, 2018.

Second, the NNCI CO is working to foster the development and improve the quality of SEI programs across the NNCI. Thus far we have done this by bringing together the SEI coordinators of the active sites to discuss their programs and best practices via conference calls. We are looking to extend the exchanges face to face during a short pre or post workshop in conjunction with the Fall 2017 NNCI annual meeting.

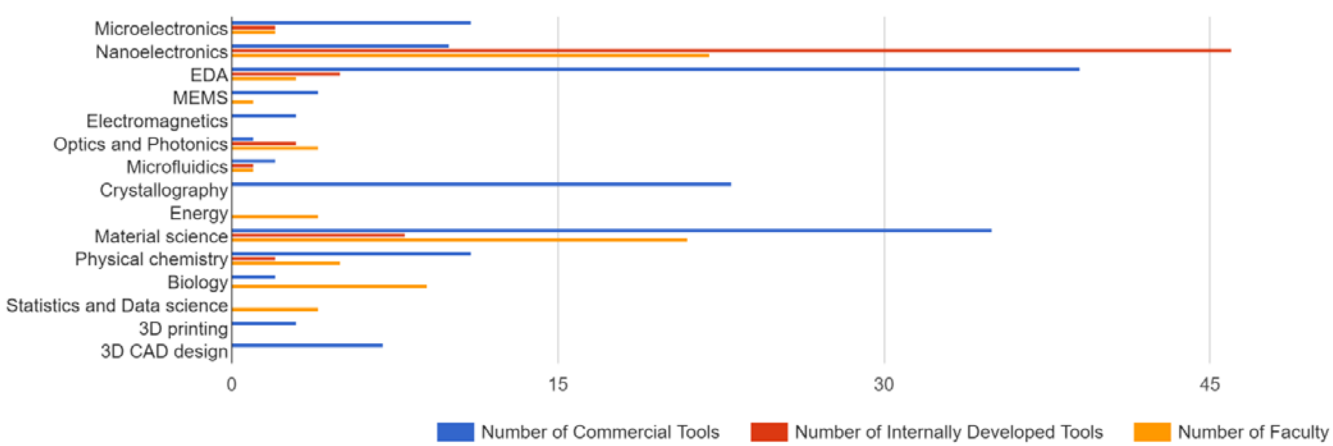
We also took advantage of the recent annual meeting to begin to work with sites that currently do not have SEI efforts. In addition to the original 7 SEI participating sites, there is now interest in developing SEI programs at the Midwest Nanotechnology Infrastructure Corridor, nano@Stanford, the Soft and Hybrid Nanotechnology Experimental Resource, and the Virginia Tech Center for Earth and Environmental Nanotechnology Infrastructure. The NNCI CO has arranged a visit to the University of Minnesota in March to run a half day SEI program for graduate students and discuss future collaborations and is currently in talks with Stanford and Virginia Tech to offer similar SEI building exercises.

4.3. Computation

Modeling and simulation play a key role in enhancing nanoscale fabrication and characterization as they can guide experimental research, drastically reduce the required number of trial and error iterations, and enable more in depth interpretation of the characterization results. While only a few sites have proposed activities in the area of computation, a diverse set of software and hardware resources are available at the NNCI sites that, if made more readily accessible, can greatly help and even expand the NNCI user community. Furthermore, the NSF-supported Network for Computational Nanotechnology (NCN) has been developing a virtual society that shares simulation software, data, and educational materials covering all areas of nanotechnology. Hence, the two networks (NNCI and NCN) and their user communities have many common interests, needs, and goals and can benefit enormously if their efforts are harmonized and coordinated together.

Collecting an accurate and detailed inventory of resources available in various NNCI sites is an important contribution as it can facilitate access to these resources, provides awareness about the strengths and potential shortcoming of the existing tools and resources, and makes it possible to identify major gaps. Once the gaps and shortcomings are identified, the NNCI community can think about possible approaches to address them.

In the past year, an inventory of available modeling and simulation resources and expertise is being complied. The directory is hosted by nanoHub.org. So far, 10 sites have reported collectively more than 65 commercial simulation tools and 40 internally developed simulation tools available for internal and/or external users, as well as 8 supercomputers or major computing clusters available at various sites.



5. NNCI Subcommittees

In addition to the work of the Coordinating Office and specific topical areas of the Associate Directors, several subcommittees of the Executive Committee were formed to tackle high-level issues related to the NNCI network as a whole (Table 4). Positions on these committees were offered to each member of the Executive Committee (site PIs), along with any site co-PIs who wished to participate. Each Site Director serves on two of these subcommittees with a subcommittee chair selected by the Coordinating Office. Additional input may be sought from members of the External Advisory Board and other experts as needed. Members of the Coordinating Office serve on some of the subcommittees as ex-officio members. The first six topics were selected as part of the Coordinating Office proposal to NSF, while the last topic was added upon request of the Site Directors. As a starting point, the Coordinating Office created a number of guiding questions for each subcommittee. Reports of the subcommittees on current and future activities are presented below as provided by the subcommittee leads.

Table 4: NNCI Executive Committee Subcommittees

Subcommittee Topic	Subcommittee Lead
Diversity	Mike Hochella (NanoEarth)
Metrics and Assessment	Stephen Campbell (MINIC)
Global, Regional and Local Interactions	Vinayak Dravid (SHyNE)
New Equipment and Research Opportunities	Kevin Walsh (MMNIN)
Entrepreneurship and Commercialization	Mark Allen (MANTH)
Workforce Development	Trevor Thornton (NCI-SW)
Building the User Base	Nan Jokerst (RTNN)

5.1. Diversity Subcommittee

The following are two key questions concerning core diversity issues with which the NNCI sites wish to make progress. Our committee has discussed these issues online, and below are the key questions and our current collective wisdom to address them.

1) How can NNCI increase the diversity of users and participants in education and SEI activities? Remember that diversity can include both demographics (race and gender) as well as non-traditional research disciplines.

- Lower bar for entry for users classified as adding to diversity: Users classified as diverse can be given a simpler application process, and higher priority access.
- Offer cost assistance: Have mini-grants available for diverse users. Check out http://www.nanoearth.ictas.vt.edu/MUNI.html

- Offer internships: Sponsor internships of whatever form you wish, and target different levels as you wish, from high school, to undergraduates, grad students, postdocs, and/or beginning professors.
- Provide a Spanish homepage button to click: Have a button showing prominently on your site's homepage that one can click to get the page contents in Spanish, or, to provide the user with a page to post their name, contact information, and query in Spanish. For example, see https://www.rtnn.ncsu.edu/.
- Advertise on our homepages with videos: The NNCO website (and individual site websites) should highlight diversity of users and diversity in site leadership teams, including on their homepages. We could generate a series of 1 to 2 minute videos showing diverse users having success, and fun. Each video could be branded with a title/link that catches attention.
- Tap into gatherings on your campus like Engineering Discovery Days, NanoDays, etc: Lots of K12 students from diverse schools across your region bring students on these event days to learn about STEM. NNCO could provide a module for students at these fairs.

2) What forms of marketing and recruitment can we use to reach a diverse user population?

- Utilize personal visits to schools that provide diverse users, such as HBCUs: Some of us have done this, and it is exceptionally effective. Just one or two such visits can yield remarkable results. One spends an entire day talking with faculty, student groups, and giving an attractive and inviting seminar.
- Host targeted workshops: Sites could sponsor targeted workshops specifically to diverse user groups with nanofab, characterization, and/or imaging themes.
- Utilize societies that serve underrepresented demographic groups: If we could connect to the national levels of these organizations, we can reach a broader audience. We could include printed material, emails, web pages, etc. It may help to contact a few societies and ask them about their ideas for the best methods of reaching and engaging their members.

Plans for the coming year:

- Provide actual success stories: We will compile success stories from across the network and distribute them. Some of these could be highlighted on the NNCO site.
- Learn from our mistakes: We will compile descriptions of attempts that did not work out as well as anticipated, and share them with the network. The participants of the failures can be kept anonymous if desired.
- Be creative: We will continue to look for new ideas, and refine the best of the ideas/successes that we presently have.

Members: Mike Hochella (Virginia Tech, Chair), Jacob Jones (NC State), Chris Ober (Cornell), Jim Pfaendtner (Univ. of Washington), Beth Pruitt (Stanford), Bob Westervelt (Harvard).

5.2. Metrics and Assessment Subcommittee

The National Science Foundation has made a very substantial investment in the NNCI nodes. The measurement of the performance of these nodes is therefore essential, both to quantify performance to NSF and to incent the nodes to achieve the best possible results. Since this is not a typical research contract, the metrics are less obvious and may vary from node to node. It is essential however, that all nodes understand how the metrics are to be measured, which metrics are most crucial to NSF, and how to create metrics for network operations that involve multiple nodes. A comprehensive list of *potential* metrics was provided by the Georgia Tech coordinating office proposal to NSF:

Table 5: Possible NNCI Metrics

Site Usage	**Network Contributions**
✓ Numbers of internal and external users ✓ Amount of facility hours used ✓ Revenue from user fees ✓ User affiliations (academic, industry, government) and research discipline ✓ Numbers of new annual users ✓ Users at multiple partner sites	✓ Website contributions – news, events, videos, process information ✓ Participation in marketing efforts ✓ Staff participation in working groups and network committees ✓ Addition of new tools to the network ✓ Timely responses to information requests from the Coordinating Office
Site Productivity & Impact	**Education & Outreach/SEI**
✓ Publications, presentations, and patents ✓ Research grant funding enabled ✓ Graduate degrees supported ✓ Numbers of spin-off companies ✓ Economic impact of industry users by numbers of employees and investment amounts ✓ User and PI satisfaction survey	✓ Diversity of participants ✓ REU and community college internship outcomes ✓ Change in nanoscale knowledge due to curriculum and teacher training ✓ Development of SEI materials that inform users, policymakers, and the public

The committee was charged with an initial three questions:

- What is the definition of a "user" and what constitutes measured usage of a site?
- What are the best quantifiable metrics for measuring site performance, based on categories of site usage, site productivity and impact, education/outreach/SEI, and contributions to the network?
- What assessment methods can be used to indicate the combined impact of the NNCI network as "greater than the sum of its parts"?

The committee has met twice thus far. The discussion has centered on fact-finding, both from the Coordinating Office (12/5/16) and from Dr. Larry Goldberg of NSF (1/19/17). Detailed discussion including the charge questions are expected in 2017.

Members: Sanjay Banerjee (Texas), Stephen Campbell (Minnesota, Chair), David Gottfried (Ex-officio, Georgia Tech), Michael Hochella (Virgnia Tech), and David Sellmyer (Nebraska)

5.3. Global, Regional and Local Interactions Subcommittee

Preamble: There are complementary nanoscience/nanotechnology initiatives within the US from other Federal agencies (and foundations) that have been ongoing for more than a decade. These include, for example, DOE Nanoscale Science Research Centers (NSRCs) at five geographically distributed locations, among other nano-x institutes and initiatives. Several of these nano-initiatives are approaching a sense of maturity while some others are perhaps in soul-search mode as the nanoscale science and technology further diversifies and grows.

Looking outwards, with increasing physical and virtual connectivity across the world, nanoscience and nanotechnology continues to be a global enterprise. The broad societal challenges facing humanity encompassing energy, environment, water, food and health (to name the major ones) are not only global challenges but that they have a strong nanoscience/nanotechnology component, and would benefit immensely from a coordinated and collaborative effort across the globe.

Activities and Plans: The Global, Regional and Local Interactions subcommittee was formulated with the underpinning that NNCI should coordinate to leverage (and vice versa) other local, regional and global nano-initiatives, share good practices and feed off each other to enhance overall impact of nanoscience and nanotechnology.

The subcommittee is currently undertaking the key primary activity of "Taking Stock" in the first half of this academic year. "Taking Stock" includes documentation of internal NNCI node practices and interactions with local/regional nano-initiatives as well as international interactions. Several NNCI nodes are in close proximity to other nano-centers of DOE or other Federal/regional labs. Clearly, there is already considerable synergy between the NNCI nodes and other laboratory nano-initiatives. The documentation and collection of "taking stock" also extends to include global or international activities undertaken by NNCI nodes and their parent/lead department/institution.

Once we document and compile existing interactions, we will be in a better position to assess the local/regional synergies as well as global or international presence by individual NNCI nodes. Soon after we take the internal stock of regional/local and global interactions, the subcommittee will explore prospects for new activities and initiatives that may further strengthen the regional connectivity and enhance global interactions. Some tactical ideas for relatively rapid deployment of regional and global interactions include: challenging each NNCI node to undertake several (e.g. three) new activities related to some aspects of facility infrastructure, such as joint workshops or staff exchange visits to share good practices, to name a few.

We will also consider formal funding mechanism(s) to enhance NNCI international impact through global collaborative activities. The notable example of the International REU (NIMS, Japan) program championed by Lynn Rathbun (Cornell), provides the impetus to augment existing NNCI funding mechanism with other NSF programs/units, possible foundation and private philanthropic activities.

The subcommittee will address the primary questions, such as:

- How should NNCI partner and collaborate with non-NNCI user facilities and national labs?
- How can we interact with similar nanotechnology infrastructure communities internationally?
- Can we find a funding mechanism for international programs (e.g., iREU, staff exchange, joint research programs) under NNCI auspices?
- Are there other synergy and leveraging opportunities with local/regional facilities that NNCI can play a leadership role?

We expect to attain a steady-state of interactions and periodic activities after the documentation and surveys are obtained, compiled and assessed. We look forward to constructive and vibrant contributions to local, regional and global nanoscience and nanotechnology infrastructure enterprise under the NNCI banner.

Members: Karl Bohringer (Wash), Vinayak Dravid (NU, Chair), Bob Westervelt (Harvard), Chris Ober (Cornell), Bruce Alphenaar (Louisville)

5.4. New Equipment and Research Opportunities Subcommittee

The New Equipment and Research Committee used email for their virtual meetings and discussions. We were asked by the Coordinating Office (CO) to discuss 4 areas related to NNCI new equipment and research. This report summarizes our ideas and discussion points for those 4 areas.

1) What new research areas will be significant in the next 5-10 years?

Nanotechnology will continue to expand beyond CMOS and play a significant role in several candidate research areas. The following fields were identified as potential targets: 1) Life Science including nano-medicine, personalized medicine, telemedicine, wearables for improving human health, point-of-care diagnostics, pharmaco-engineering, bio-integrated electronics, and bio-inspired nano devices and solutions, 2) Water, Energy and the Environment including desalination, purification, water splitting, energy efficiency, sustainability and renewability, 3) Internet of Things (IoT) including new sources of power, novel sensing modalities such as no power sensing, and advanced communication strategies, 4) Data/Computing including low power computing, quantum computing, high throughput tools for data processing, and cyber security, 5) Sustainable Agriculture including GMO crops and high tech agriculture, and 6) Novel Engineered Smart Materials for areas such as photonics and optics (meta-materials, cloaking technology, etc). To enable advances in the above areas and encourage low-cost solutions, the NNCI will need to expand both its user material base and its standard processing capabilities to include new offerings such as roll-to-roll, flexible electronics, 3D printing, and additive manufacturing, to name a few

2) What are the new tools and capabilities needed to enable these research areas?

From the characterization side, there is the need for studying materials and biological cells in-situ, in-operando, and in-vivo. From the fabrication side, many of the new tools identified by the committee were for non-traditional users or for the new emerging areas of nano-related research identified above. This includes high-resolution 3D printing tools capable of multiple materials, direct printing for flex circuits, high-resolution inkjet for complex non-planar geometries, next gen soft lithography, scalable manufacturing processes, roll-to-roll, and 3D AM tools capable of embedding nano-sensors and electronics. The need to conveniently locate wet labs and associated bio-facilities for the life science users was discussed.

3) Are there untapped research communities that NNCI can serve?

The committee felt that there are many untapped and partially tapped research communities. These include the following: biological sciences, agriculture, natural sciences such as forestry, environmental science, medical sciences, some aspects of chemistry and civil engineering, bio-medical can be expanded, geo-science, pharmaceutical, food and cosmetics. It is important to note that some NNCI sites are experiencing a dramatic growth in their "non-traditional" user numbers. While this presents a tremendous opportunity, it does not come without challenges. Challenges include: non-traditional users require significantly more training and hand-holding; contamination can be an issue due to their diversity of materials and processes, new equipment will need to be added to address their unique fabrication and characterization needs, many new users are not accustomed to paying for services, seed funds are not traditionally available for non-traditional users to experiment, and non-traditional users are not aware of what micro/nano can do for them.

4) Generate prioritized list of tool needs as justification for MRI or other equipment proposal efforts.

The committee expressed concerns how the NNCI sites will replace "workhorse" tools like sputtering systems and contact aligners, which are traditionally not appropriate for MRI funding. For next-generation emerging tools, it was suggested that sites might collaborate on joint proposals and the NNCI could help coordinate this activity. Some research tools that the committee identified included next generation 3D printing and AM equipment which merge nano/micro with meso using a diverse set of materials, new EBL and NIL technologies, nano-SIMS, the latest in FIB/SEM, high-speed EM camera (K2), and next gen LEAP.

Membership: Kevin Walsh (Louisville, Chair), Jacob Jones (NCSU), Yuhwa Lo (UCSD), Mark Allen (Penn), Stephen Campbell (Minn), David Dickensheets (Mont State), Karl Bohringer (Wash), Vinayak Dravid (NW), Oliver Brand (GaTech CO, ex officio)

5.5. Entrepreneurship and Commercialization Subcommittee

The commercialization subcommittee received its initial input and charge from the External Advisory Board at the NNCI Annual Meeting in January 2017. This charge included:

(i) Defining an appropriate method for counting commercial spinoffs and patent licenses as part of NNCI site reporting;

(ii) Defining a process to quantify as best as possible the commercial output and impact of NNCI site activities as well as overall network commercial impact.

The Entrepreneurship and Commercialization Subcommittee will be working this reporting period to act on the charge of the External Advisory Board.

Membership: Mark Allen (Penn, Chair), Bill Wilson (Harvard), David Dickensheets (MSU), Kevin Walsh (Louisville), Trevor Thornton (ASU), Yuhwa Lo (UCSD), Dan Herr (SENIC/JSNN)

5.6. Workforce Development Subcommittee

The NNCI Workforce Development Subcommittee (WDS) was established during the Fall of 2016. The WDS convened on 7th November, 2016, via an Adobe Connect on-line meeting. For this kick-off meeting we focused on introductions and summaries of workforce development activities at the committee members' home institutions. We also began to address the questions suggested by the NNCI CO.

Summary of Subcommittee Activities:

ASU is partnering with Rio Salado Community College to support the laboratory component of their two year AAS degree in Nanotechnology. The lab materials are based on the curriculum developed by the NACK Network, www.nano4me.org

UW is partnering with North Seattle Community College that currently has a two year nanotechnology degree program. The NSCC students will spend time at UW as part of a two semester internship.

Harvard is partnering with Bunker Hill Community College and Northeastern University to bring veterans onto campus for an REU internship program.

Questions from NNCI Coordinating Office:

- How can NNCI and its sites leverage their state-of-the-art facilities for workforce development besides the traditional undergraduate and graduate student training?

1) By partnering with community colleges to provide internship and REU opportunities to their students.

- How can we collaborate with 2-year colleges and industry to assist with their workforce development needs?

1) By providing laboratory access for AS/AAS degree programs based on the NACK Network curriculum.

2) Offering mini-course (certificate programs?) and seminar series to build links with industry.

3) Survey local industry needs perhaps using the ASU-MCCCD survey as a model.

- What can the network do along these lines in addition to activities by the individual sites?

Need to follow up with individual sites before we can answer this.

Outcomes and Action Items for the Coming year

By the end of the meeting it was clear that the NNCI needs to have a good understanding of the range of workforce development activities being conducted across the NNCI. To this end the WDS suggests contacting all of the NNCI sites with a short survey. The results from the survey can be used to identify activities common to a majority of sites that might benefit from network wide coordination. It will also serve to identify gaps in our activities.

A question raised by the WDS was how useful and/or valuable at the community college level is specific training in nanotechnology as compared to basic physics, chemistry or materials science? One way to address this would be to survey local industry needs to determine the level of interest. This data is helpful for community college administrators thinking of establishing a new AS/AAS degree because they are often required to demonstrate the local need for such programs before they can be approved. ASU worked with Maricopa County Community College District (MCCCD) to develop and distribute a survey that was shared with the other WDS members. The ASU-MCCCD survey will be shared amongst all the sites and those interested can use/modify the survey to suit their needs. The biggest challenge here is building a database of suitable industry contacts and following up to ensure a sufficient number of contacts respond to the survey.

Members: Trevor Thornton (ASU, Chair), Ray Tsui (ASU), Lara Gamble (Univ. Washington), Shamus McNamara (Univ. Louisville), David Sellmyer (Univ.Nebraska), Bill Wilson (Harvard), Nancy Healy (Ex-Officio, Georgia Tech)

5.7. Building the User Base (BUB) Subcommittee

The NNCI Building the User Base (BUB) Subcommittee had their first conference call on November 29, 2016. The goal of the BUB Subcommittee is to increase the user base, with particular emphasis on non-traditional users. The discussion focused around the following questions:

- What is the low hanging fruit? How can we leverage activities going on at our institutions already for marketing and/or for engagement of new users?
- What are the opportunities for leveraging national programs already in existence, developing content for these programs, beta testing programs for new users, and passing them on to the entire network?
- Decide on a strategy for information exchange- What is going where, how to categorize the interfaces with users, how to move BUB programs from beta testing at individual sites to the entire network.

Users:

What constitutes a user? A definition of a user is needed, and the BUB committee will propose some user classes and definitions.

Non-traditional users include the following:

- Demographic groups: women and under-represented minorities
- Research areas: those that do not typically use nanotechnology facilities
- Users from non-Research I educational institutions
- Small companies

- Students: K-12 students, community college students, and teachers (K-12 and community college)

Key Factors:

In building the user base there are key factors that have an impact on the growth of the user base, including awareness, cost and distance

- Awareness- the following are different strategies that can be used to bring awareness to the program to build the use base
    - Social media & websites
    - Targeted marketing thru Linked-in
    - Regional teaching seminars advertising
    - Workshops with vendors

Note: Assessment is key; need to collect data on how they heard about the program

- Cost- determine ways to make use cost effective for users
    - Time investment
    - Extensive training for Fabrication- does it make sense for users at a distance to travel to learn to do fabrication? Probably not.
    - Distance – remote usage will be important to implement large change, especially to reach rural areas
    - Remote usage by running equipment remotely – slowly emerging
    - Remote usage aided by facility Staff

Building the User Base:

Short term direct approaches being alpha/beta tested now in the NNCI:

- Awareness: Websites, Coursera course, workshops with vendors, REU programs, seminars, webinars
- Cost:
    - Many of the NNCI sites have internal seed grants and the RTNN free use funds;
    - Some sites are testing uses external free use funds, which can be used to increase the external user base
- Distance: Some sites are experimenting with remote use

Longer term, increasing the user base develops future users through programs such as

- Summer Camps at regional institutions;
- Integration of tours/demos/experiences into K-12 science curricula – target specific classes, grade levels
- Science Fair
- Girls/Boy Scouts, 4H Clubs
- Mobile STEM Bus

Members: Nan Jokerst (RTNN/Duke, Chair), Bill Wilson (Harvard), Todd Hastings (MMNIN/UK), Shyam Aravamudhan (SENIC/JSNN)

6. Working Groups

One of the greatest strengths of the NNCI network is the combined staff expertise of the individual sites. To leverage this expertise at the network level, the Coordinating Office has initiated the formation of working groups composed of staff members from the NNCI sites. While these working groups meet primarily via teleconferences and WebEX, they also have the ability to organize workshops and/or dedicated sessions at the annual NNCI Conference. We anticipate and are encouraging working groups (Table 6) in (1) important "network" responsibilities, such as environmental health & safety, vendor relations, or equipment maintenance and training, (2) particular process technologies, such as lithography or characterization (although these are only examples of possible topic areas), (3) research areas of nanoscience and nanoengineering, in particular those targeting "non-traditional" disciplines, such as bio, geo and environmental sciences, and (4) education and outreach activity. Not all of these working groups have been created in the first year, but rather certain priority topics (highlighted in bold below) have begun, with other groups added later on as interest and need arises. In addition, some topical areas (EBL, Etch, and ALD) have begun working groups through grass-roots efforts of NNCI staff, with support from the Coordinating Office. The outcomes of these working groups can have many forms, including process recipes, recommendations to vendors for future equipment development, maintenance and training videos/webinars, recommendations on how to evaluate the safety of new processes, or direct recommendations for new users. Each working group has one or more dedicated coordinators selected from one of the NNCI sites, and staff participation in the working groups can be one measure for site performance. Participation in these working groups can also be considered as a mechanism for staff growth and career development, which might be further supported through certificates earned when participating in related workshops, for example, and this is being explored. Reports of current working groups, as provided by the leads, are presented below.

Table 6: NNCI Working Groups

Working Group Topic	Working Group Lead
Network Support Working Groups	
Equipment Maintenance & Training	Meredith Metzler (Univ. Pennsylvania)
Vendor Relations	Mike Khbeis (Univ. Washington)
Environmental Health & Safety	
Marketing, Admin, and Finance	
NNCI Website	
Technical Working Groups	
XPS/UPS	Carrie Donley (UNC), Walter Henderson (Georgia Tech)
E-Beam Lithography	Devin Brown (Georgia Tech)

Etch Processing	Vince Genova (Cornell)
Atomic Layer Deposition	
Photolithography	
Additive Manufacturing	
Metrology and Characterization	
Education and Outreach	
K-12 and Community	Jim Marti (Univ. Minnesota)
Research Experience for Undergraduates	Lynn Rathbun (Cornell)
Community College and Workforce Development	
Metrics and Assessment	Nancy Healy (Georgia Tech)
Diversity	
Online Course	
Research Area Working Groups	
Geo and Environmental Sciences	
Life Sciences	
Next Generation Electronics	
Optics and Photonics	
MEMS and Sensors	

Equipment, Maintenance, and Training

The working group is pleased with the opportunity to identify and address issues that affect member sites in the areas equipment, maintenance, and training. Early conversations have focused on cost saving measures related to equipment operations and upkeep. As an example, each facility faces financial constraints that require aging equipment to be kept operational rather than being replaced. Many facilities in the network have aging fleets of tools and systems that are becoming more resource intensive to maintain. By leveraging our experience and relationships, both within the network and with equipment vendors, we feel there is an opportunity to collectively address these challenges.

Each of the member sites possess in-depth knowledge encompassing many years of experience with respect to equipment manufacturers and service providers. To capitalize on this asset, the group seeks to identify a confidential means for sites to communicate and facilitate sharing this knowledge within the network. The availability of this information would aid facility staff in the decision making process with respect to the selection and acquisition of new equipment, as well as in the selection of service providers for tasks such as: vacuum pump rebuilds, RF component repairs, third-party on-site equipment service, and even the replacement of complete control systems for aging equipment.

The long term cost of ownership is not only affected by the cost of repairs but also impacted by the cost of routine facilities (electrical, nitrogen, process gas, etc.) and by the cost of preventative measures. To this end, we seek to compile and make public the information related to other cost saving investments made by individual sites including: the migration of aging computers to solid state hard drives, the use of compressed air in place of nitrogen for pump-purge applications where applicable, and any methods devised for idling process equipment and older model vacuum pumps when not in use. The sharing of these cost saving methods will enable network member sites to benefit and broaden the impact of their funding.

One other way to leverage our relationships with key suppliers is to obtain financial support in the form of discounts on service and parts for cleanroom equipment at NNCI member sites. With the end of the current fiscal year approaching, discussions are currently in progress with several vendors common to the NNCI to secure long term reductions in both the cost of annual service contracts and spare parts. We plan to pursue similar arrangements with other major vendors and also seek to include regional providers for repair services to help save on time and freight expenses.

The group plans to hold quarterly web teleconference meetings. We also plan to hold concurrent meetings with other NNCI functions and workshops to economize on travel costs. We see this as a first step in fulfilling one of the intended missions of the working group.

Members: Meredith Metzler (Penn), Weinan Leng (Virginia Tech), Bob Geil (UNC), Christos Malliakas (Northwestern), William James (UT), Mary Tang (Stanford), Al Bailey (UW)

XPS/UPS

Interest in a working group focused on x-ray and ultraviolet photoelectron spectroscopies (XPS and UPS) was expressed by some of the sites. With leadership from Carrie Donley (RTNN) and Walter Henderson (SENIC), a listserv/online forum is being established that will allow members of the working group to communicate with each other regarding issues related to instrument maintenance, interpretation of data, and other related issues. Currently 9 NNCI sites have XPS instruments, and staff from 7 sites have agreed to participate so far. We are also actively soliciting participation from people outside the NNCI in order to tap into a larger pool of expertise, and to also increase the impact of such an activity.

Members: Xinqi Chen (Northwestern), Carrie Donley (UNC), Gerry Hammer (Univ. Washington), Walter Henderson (Georgia Tech), Chuck Hitzman (Stanford), Timothy Karcher (ASU), Paul Lee (Univ. Arizona)*, Ben Meyers (Northwestern), Mitsuhiro Murayama (Virgnia Tech), Robert Opila (Univ. Delaware)*, Fred Stevie (NCSU), Mark Walters (Duke)

*Non-NNCI member

E-Beam Lithography

An “NNCI EBL meeting” has been established for all EBL tool owners in the NNCI network to participate. So far a meeting has been held twice via WebEx hosted by Georgia Tech. The first meeting was 7/18/2016 and the second was 11/14/2016. The next meeting has not yet been scheduled, but likely will occur in February or March 2017. It is difficult to set meeting times that work for everyone, so a best attempt is made to include maximum participation from EBL tool owners. The initial purpose and goal of having the meeting is very simple and modest. The purpose and goals include: 1) identifying what EBL tools exist in the network and at which NNCI sites, 2) identifying the staff that are responsible for these tools, 3) share information between tool owners including recent breakthroughs or any problems tool owners are having they would like help with. For now, that will continue to be the purpose and plan of the meeting. The chair of the meeting is Devin Brown from the Georgia Tech site. Questions may be directed to him at devin.brown@gatech.edu. All EBL tool owners are invited and considered members of the "working group" if they want to be. A separate Excel spreadsheet is available with all known EBL tools and owners.

Members: Devin Brown (Georgia Tech), Talmage Tyler (Duke), Rich Tiberios (Stanford), Alan Bleier (Cornell), Amrita Banerjee (Cornell), Kevin Roberts (U. Minn), Gerald Lopez (U. Penn), Kevin Nordquist (Arizona State), Brian Wajdyk (UK).

Etch Processing

The objective of the Etch Working Group is to provide an interactive forum for all etch personnel from all the NNCI participating sites. This interaction includes but is not limited to the sharing of information regarding etch capabilities, established etch processes, processes under development, maintenance issues, preventative maintenance, baselining efforts, equipment modification, and the acquisition of new etch tools. Identification of the broad and complementary etch tools within NNCI allows us to effectively process wafers within the network to meet the diverse specifications of individual projects.

This past year has been very productive and included an on-site two-day workshop at Cornell University held on May 24-25, 2016. Twelve of the NNCI sites participated in the workshop including:

- Cornell University
- Harvard University
- Stanford University
- Georgia Institute of Technology
- University of North Carolina
- University of Louisville
- University of Minnesota
- University of Nebraska
- University of Pennsylvania
- University of Texas-Austin
- University of Washington
- Arizona State University

Day 1 of the workshop consisted of site update presentations which included a current listing of all etch equipment types such as RIE, ICP, ECR, ion mill, ashing, and dry release systems. Specifics included gas chemistries, wafer size capabilities, and principal applications (i.e., established processes). Discussions on topics such as material restrictions, chamber conditioning strategies, user training, process development, maintenance practices, plans for equipment modification and acquisition led to a very enlightening exchange.

The activities of Day 2 consisted of invited and contributed presentations on a variety of advanced topics in etching. Suggested topics included nanoscale etching of silicon, silicon based dielectrics, high-k and low-k dielectrics, III-V materials, metals, and pattern transfer of those features defined by EBL, deep UV, and NIL using novel chemistries.

The specific topics presented were:

- "Silicon vs. Germanium Deep Reactive Ion Etching"-Vincent Genova, Cornell University
- "HBr Based Etching of Silicon"-Vincent Genova, Cornell University
- "Highly Selective Silicon Nitride to Silicon Oxide Etch Process"-Vincent Genova, Cornell University
- "Deep Reactive Ion Etching of Silicon"-Usha Ranghuran, Stanford University
- "Diamond Etching"-Ling Xie, Harvard University
- "Metal Etching Using the Bosch Process"-Bob Geil, University of North Carolina
- "Etching as an Undergraduate Teaching Tool"-Tony Whipple, University of Minnesota

The 2-day workshop was quite fruitful in producing many outcomes such as:

1. The creation of a new communication path for members of the NNCI etch community. A LinkedIn "NNCI Etch Group" has been created where etch equipment and process issues can be discussed.
2. The creation of a detailed database of NNCI etch tools and process capabilities listed by site and available on the NNCI website. This is an invaluable resource for user managers and etch personnel in the evaluation of new proposals and in the event of a "tool down" situation where network shared services can be implemented.
3. The identification of sites with niche capabilities especially for the processing of unconventional and exotic materials.

Future plans for the NNCI Etch Working group:

1. An on-site 1 or 2 day workshop to be held at an NNCI site on a rotating basis perhaps every 12-18 months, if possible. The format would be flexible to include possible equipment vendor participation, in addition to the routine site updates and presentations on advanced pattern transfer techniques. This in-person forum will encourage fellowship among the etch community fostered by discussions inside and outside the technical sessions.
2. A "WebEx" or "Zoom" teleconference to be held on a 6-month basis to collectively discuss any equipment or process issues, along with any new process developments.

3. The use of the LinkedIn NNCI Etch group to provide a vehicle where members can contact one another for any etch related issue on an as needed basis. This will also serve as a means to announce and plan upcoming etch related events.

Members:

Cornell University: Vince Genova, Jeremy Clark, Tom Pennell, Jerry Drumheller
Harvard University: Ling Xie, Kenlin Huang
Stanford University: Usha Ranghuram
Georgia Tech: Thomas Johnson-Averette, Hang Chen
University of Pennsylvania: Meredith Metzler
University of Texas at Austin: Ricardo Garcia, Marylene Pallard
University of North Carolina-Chapel Hill: Bob Geil
University of Nebraska-Lincoln: Jiong Hua
University of Louisville: Evgeniya Moiseeva, Xiaojin Wang
University of Washington: Mark Morgan
University of Minnesota: Tony Whipple
Arizona State University: Kevin Hilgers
Montana State University: Phil Himmer
University of California-San Diego: Yu-Hwa Lo
Virginia Tech: Donald Leber (invited)
University of Chicago: Peter Duda (invited)

K-12 Teachers/RET/Students/Community Outreach

Activities to Date: The initial K-12 Teachers and RET working group was organized and held two phone conferences in September and October of 2016. In November the group chair offered to absorb the roles and membership of the K-12 Students and Community Outreach working group, since a) the latter group had not yet met, and b) many of the programs our group was discussing were both K-12 and community outreach in nature, making it more efficient to address education and outreach efforts as a whole. The larger group held a phone conference in December to discuss common goals and current activities.

Current Effort: Identify and review education and outreach programs in place at NNCI institutions that have potential for network-wide application.

Members of the group have summarized the outreach programs and activities they have used successfully to reach K-12 teachers, students, and the general public. After some discussion, we have the following list of programs we believe are worthy of consideration for scale-up to the full (or partial) NNCI network.

1. NanoDay events. These have been popular across multiple sites, involving hands-on activities paired with short presentations, lab tours, cleanroom gowning demonstrations, and other activities.

   Now that the NISENet organization has sunsetted, new kits are no longer being distributed, so individual sites must re-supply kits. For outreach off-campus or bringing schools in for on-campus NanoDay programs, some additional funding will be needed.

2. RET and RET-like programs. This type of program would provide teachers with new skills and knowledge they could use to improve their science curriculum in their home institutions when they return. These connections could also lead to making a real impact in the school as we build on relationships made.

   RET programs have been popular at several schools, and could be applied across at least a portion of the NNCI. As one example, RET teachers from individual sites could come together for a sharing session after the summer experience is done. This will require supplemental funding, an issue we can raise during the First Year meeting in Atlanta.

3. Development of videos for equipment training that can be applied to teacher training and outreach. The working group has discussed how to make these videos using on-campus student effort. Videos are a great tool to build a variety of programs around once they are developed, including user training, teacher and student training, and community events.

4. Nano camps: partial or full day experiences for students to explore nanotech topics in depth. UNL has experience in setting these up in partnership with schools, summer camps, community groups, etc.

5. Remote Access and/or traveling tool programs. The group has discussed the pros and cons of remote access tool use. Some of the technical obstacles to remote tool access include bandwidth limitations at host schools, lack of hands-on experience for the students as they simply watch the tool being used elsewhere. One school (NCSU) has begun moving toward traveling tools (e.g., the benchtop SEM) and bringing groups to their facilities instead.

6. Activity kits distributed to schools for in-class use. These are available from several sources. Perhaps NNCI's role will be as a clearinghouse for nano-related classroom activities, rather than developing new activities.

Members: Dan Ratner (Washington), Maude Cuchiara (NCSU), Jaimie Ann Iuranich (Nebraska), Terese Janovec (Nebraska), Dominga Sanchez (UCSD), Kristin Field, (Penn), Jim Marti (Minnesota)

Research Experience for Undergraduates (REU)

The purpose of the NNCI REU Working Group is to bring value to the REU programs of participating NNCI sites by exchanging knowledge, experience, and best practices. Several members have had extensive experience with the former NNIN REU program allowing the group to benefit from that experience to some degree. Others bring fresh ideas and insight.

First order of business was to inventory the current and proposed REU activities at NNCI sites. Unlike NNIN where every site participated, under NNCI, a site REU program is optional, and cooperation with other sites is also optional. Nonetheless we believe there is considerable value in the REU program and that that value is enhanced by cooperating as a network as much as possible.

Table 7: REU Program Status at NNCI Sites

Site	Status	Number of Students	Funding Source/Status

CNF (Cornell)	Active	5	NNCI Site Funding
SENIC			
JSNN	Active	4	
Georgia Tech	Active	4+5 pending	NNCI Site Funding+pending
MANTH (Penn)	Active	6+	NNCI Site Funding
CNS (Harvard)	Active	5 REU+5 veterans	NNCI Site Funding
Stanford	No program	n/a	n/a
SDNI (UCSD)	Active	10-12	NNCI Site Funding
NanoEarth (Virginia Tech)			
TNF (Texas)	Active	5+5	NNCI site funding and NASCENT(NSF)
MINIC (Minnesota)	No program	n/a	Seeking future funding
NNI			
Oregon State	Pending	2 pending	Pending funding
U.Washington	Pending	5 pending	Pending funding
NNF (Nebraska)	Active	4	Mixed
MONT (Montana State)	Active	2	NNCI Site Funding ??
NCI-SW (ASU)	Active	5	NNCI Site Funding
KY-MMNIN			
U. Louisville	Active	8	NSF award
U. Kentucky	No program	n/a	n/a
SHyNE			
U. Chicago	No program	n/a	n/a
Northwestern	Active	4	NNCI Site Funding
RTNN			
UNC-Chapel Hill	Pending funding	5	Pending funding
NCSU	Pending funding	5	Pending funding
Duke	Pending funding	5	Pending funding

As noted, some sites support REU from their site budgets, others have external NSF funding, some sites have applied for external funding.

Actual activity for 2017 is still unknown as a number of sites have outstanding REU proposals under review. The total participation in 2017 will likely be between 65 and 90 students. This is similar in size to the former NNIN REU program.

A conference call was held in October to review the inventory and solicit ideas for interaction. Areas of potential cooperation were defined, and included:

- Advertising and recruitment (joint effort or best practices)
- Evaluation and assessment (joint effort or best practices)
- Convocation (see below) (joint effort)
- Inter-site presentation/seminars/presentation skills workshops, etc (Joint effort)
- Mentor training (joint effort or best practices)

Given the timing that REU recruitment would begin in November, the first order of business was to establish an NNCI gateway for posting site REU program information. A temporary directory of sites and application links was established on the temporary NNCI web site, and later transferred to the permanent NNCI web site. This page provided a central gateway to the individual site REU applications.

NNIN had a single REU application and applications were processed centrally. This was well liked by students as it eliminated a lot of duplicate effort. Under NNCI this is not likely possible. This required considerable expense by the managing node, funds which are not available. And under NNCI, sites have established a variety of niche populations (regional, etc.) that they wish to target. And at this point, each site has already set up its own process/software/etc. to handle this process. Overall, it is likely less efficient but under the circumstances is not likely to be changed by NNCI.

A signature part of the NNIN REU program was the end of program joint REU convocation. REU participants from each site traveled to a common site to a three day technical symposium where the students presented their results to their peers. The conference consists of student presentation, student posters, plenary sessions of general interest, and networking. Georgia Tech has budgeted funds in the coordinating budget to support hosting a 2-day convocation. This will be held at Georgia Tech, August 6-8, 2017. The coordination budget pays for local expenses, but travel to and from the conference is paid by each site.

To date, nine sites have committed to participate: Cornell, SENIC (GT+JSNN), Harvard, Penn (optional for students), U. Louisville, Montana State, RTNN, ASU and U. Texas. Nebraska, UCSD, and Northwestern will not be participating due to scheduling issues. Nonetheless, we expect to have a group of at least 40 participants in the joint NNCI REU Convocation. We hope that other NNCI sites will recognize the value and reconsider participation in the future.

For 8 years, NNIN conducted an international REU program directed to delivering a formative experience in nanotechnology research in an international context, particularly as related to how research is communicated and managed in other cultures. This program used the NNIN REU program as its sole feeder program. There are no funds for this program in NNCI. Cornell University has, however, secured independent NSF funds to continue this activity with the National Institute for Materials Science in Tsukuba, Japan. Cornell has chosen to continue with the established recruitment method, that is selecting students only from the participating NNCI REU programs. Six students were selected (from former NNIN REU site programs) for the summer 2016, and six more students (from 5 different NNCI REU site programs) have just been selected for the summer 2017 program from the participants in the 2016 NNCI site REU programs. We refer to this program by the NNIN name, iREU.

As *quid pro quo* for hosting out iREU students, NIMS sends a small number of graduate students from the Japanese Nanotechnology Platform program to the US (i.e. to NNCI sites) each summer. In 2016, NNCI hosted three students, one at U.Texas and two at U.Louisville. These students are fully funded by Japan. Potential projects for summer 2017 have been solicited and applications will be collected in February. Participation by NNCI sites in this program is voluntary but Cornell is appreciative of the support it has received from NNCI sites.

The NNCI REU working group will continue to meet and work together particularly as the details for the site REU programs for summer 2017 become more defined.

Members: Lynn Rathbun (Cornell), Marylene Palard (Texas), Kristen Fields (Penn), Dominaga Sanchez, (UCSD), Raymond Bailey (Northwestern), Melanie-Claire Mallison (Cornell), David Mogk (Montana State)

7. User Recruitment

7.1. Marketing

Marketing and user recruitment strategies vary widely across the NNCI network, based on particular site local and regional needs and situations. During the January 2017 NNCI Conference, a breakout session on marketing and user recruitment identified these strategies as a way to help sites develop their plans to increase facility usage. While much of the focus is on recruiting new external users, many of the approaches and best practices apply to internal users, particularly non-traditional users, as well. Some sites have staff with external user engagement as a primary job responsibility, while other sites do this on a more ad hoc basis. Previous NNIN sites generally seem to have a more mature marketing strategy based on previous trial and error, although most new sites have significant pre-NNCI experience with external users as well. Challenges to any marketing strategy include the often significant lag time between when a certain marketing tactic is employed and when actual usage may happen. This can make it particularly difficult to gauge the effectiveness of various approaches. Certain NNCI sites also possess geographic advantages and a built-in clientele of tech companies, start-ups, and other academic users, while other sites need to work hard to engage non-traditional users. Finally, IP concerns and overly burdensome access agreements can often discourage new users.

A number of marketing strategies and their relative success are summarized below, along with some best practices in external user engagement and challenges with recruiting new users.

Marketing Strategies:

1. Engage former users – either internal users moving on to industry or external users that change jobs.
2. Word of mouth advertising.
3. Connect with regional (county) economic development offices – this was seen as something easy to do, but not necessarily very successful.
4. Find start-up companies that have SBIR funding, particularly those outside the university community that may not be aware of resources.
5. Build a good web site. The group noted that typical site websites list equipment, but that potential users would be better served by an applications-focused site.
6. Hold open houses. This approach has been met with mixed success from different sites, but it helps build awareness of capabilities.
7. Exhibit as a vendor at conferences/tradeshows. This approach has also been met with varying degrees of success. Choosing an appropriate conference seems to be a key here to connect with the right audience.
8. Cold calls. Generally seen as ineffective.
9. Produce a single summary slide of your site for faculty to present at meetings and conferences.
10. Print advertisement. One site tried this without success.
11. To increase internal users, work with departments to recruit faculty that will take most advantage of the shared facility infrastructure.

12. Post SOP documents online. These show up in internet searches as people are trying to learn about a technique and provide simultaneous advertisement for your facility.
13. Assemble a database of current/potential users to track contact/usage.
14. Coordinate with other non-NNCI core facilities. This casts a wider net for potential users who are already using facilities in your university.
15. Hold vendor workshops. This helps build relationships with your vendors while leveraging their contacts to help promote your facilities.
16. Work with other research centers on campus. Many research centers may have sponsored research activities with companies and they may also be interested in core facilities access, but aren't aware of what is available.
17. Provide user grants to promote initial usage. Small grants (~$1000 seemed to be a common number) are provided with a simple application to get small companies and startups in the door.
18. Use social media. Many sites seem to recognize the importance of social media, but are just beginning to explore.
19. Develop webinars. This is a good way to fulfill an educational/outreach component while advertising your capabilities.
20. Evening classes/short courses.
21. Interact with less well-equipped universities/colleges in your area and make sure they know they can leverage your site's equipment in grant proposals, etc.
22. Prepare industry-specific marketing materials. Not all of the tools and techniques at your site are applicable for all potential users, so target your capabilities to the potential customer.

Best Practices:

1. Provide excellent customer service.
2. Make a personal connection with users and be sure to follow up.
3. Make usage/access easy. Try to minimize the bureaucratic red tape associated with onboarding a new user.
4. Provide quick turnaround times.
5. Provide users with a single point of contact for your site.

The consensus of the sites is that the role of the Coordinating Office in marketing and user recruitment efforts should include the following:

1. Represent the network at national conferences. In August 2016, a booth was hosted at the Hilton Head MEMS Conference, and a booth will also be staffed at the May 2017 TechConnect conference. Suggestions for additional conferences for national attention will be solicited from the sites. An NNCI flyer prepared for distribution is provided in Appendix 11.3. In addition, the Coordinating Office commissioned the design of an NNCI logo which is used on the website, in collateral materials, and was provided (in several different formats) to the sites for use in print and online materials.

National Nanotechnology Coordinated Infrastructure

National Nanotechnology Coordinated Infrastructure

2. Provide an NNCI website with tools and expert databases. At the January 2017 NNCI Conference, there was significant discussion about the website and a desire to present a more applications-focused user experience. More discussion of the website is provided below.
3. Establish a YouTube channel with educational materials, webinars, etc. The utility of an NNCI social media presence is currently under discussion.

7.2. NNCI Website

During the first year of the NNCI Coordinating Office, one of the main activities was the creation of a web portal to provide a comprehensive list of tools and experts available within the network for both user recruitment and support. An initial website at www.nnci.net was created by Lynn Rathbun (Cornell) as a placeholder when NNCI was initiated, and this site provided basic content on the NNCI program and the sites. When the current website was created, this same URL and some of the content was used in order to provide continuity

The design of a new, comprehensive website was predicated on the desire to accommodate the different needs of users, potential users, the public, and NNCI staff.

New User Support: Experience under NNIN indicates that the majority of NNCI external users will learn of individual site capabilities through each site's own marketing, the researcher's previous knowledge or use of the site, and/or word-of-mouth from a colleague. However, an NNCI web presence must provide an entry for new potential users without any prior connection to an NNCI site to make an informed decision about which site will best serve their needs. In many cases, when all else is equal, the primary factor for consideration is geographical, that is how close the site is to their own institution. To aid the first contact with individual sites, the NNCI network web presence should provide appropriate contact information for first time users as well as an overview of each site.

New users can generally be categorized into two groups: advanced and beginning users. The information that each of these groups of users require to make an informed decision can be distinctly different. *Advanced users* typically know exactly what tool or process they are looking for. Thus, it is crucial to provide for this user group comprehensive information on each site's shared tool set, process capabilities, usage rates, conditions for use, and contact information. Much of this information was incorporated into the NNIN website, and certain design elements and content that was successful under NNIN are repeated for the NNCI website. In particular, a complete and consolidated equipment list (tool database) that is regularly updated through the coordinating office and has basic and advanced search capabilities is a fundamental aspect of the site. While external users can use the website information to identify one or more NNCI sites based on technical needs and geographic convenience, contact information for each facility (new user, administrative, and technical contacts) allow a user to communicate directly with sites of interest. These individuals can then provide specific guidance to help evaluate the feasibility of accomplishing project goals successfully, identifying a project plan and tool needs, and estimating the cost and timescale. With combined staff expertise being one of the major NNCI assets, a staff expertise database, through which a user can find NNCI staff members with particular expertise in specific process or application areas, such as e-beam lithography or soft lithography, for example, was also created.

For the second class of users, the *beginning user*, a tool (or staff) database with advanced search functions may not be helpful enough. Novice users may have little background in nanotechnology, perhaps originating from one of the non-traditional research areas such as geo, environmental or life sciences. These users might want to find out how nano-/micro-scale fabrication and characterization can help them with their research, i.e., they need to be educated adequately before being able to make a decision on what site, tool or process to use. Significant effort will go towards helping these users. One way to educate beginning users is to provide technical resources such as example process flows or example devices fabricated at the different sites on the network webpage. However, in many cases these novice users ultimately need to communicate directly with NNCI staff. Thus, we plan to create a group of 3-5 technical personnel from NNCI sites who will serve rotating terms on a *New User Gateway Committee*. Potential users will be able to contact members of this team via an online ticketing system, which tracks the communication trail, and the team will be empowered to assist them with choosing an appropriate site for their needs, taking geographic distribution (east, central, and west regions) and technical capability into account. Currently, the contact form is available, but the committee is awaiting formation.

Existing User Support: The NNCI web portal will also support existing and continuing users by providing technical information and reports, a calendar of events across the network, best practices and process recipes, user research highlights, and publication lists. Some of this content will be implemented in Phase 2 of the development (see below). The website also provides links to other national nanotechnology and fabrication facilities at organizations run or supported by NIST, DOE, and NSF, and to scale-up facilities and business incubators at the individual sites.

K-12 Students and Teachers: The NNCI website serves as a resource for K-12 students and teachers, the general public, as well as the larger research community. News, events, videos, commercialization information, and technical resources (content collected from the individual sites) will be collated on the website. We have begun the process of migrating the nearly 100 teaching modules that are on the current NNIN website to the NNCI education page. These lessons were primarily written by teachers for teachers and represent an important resource that should be maintained, updated, and continually disseminated across the nation and internationally.

NNCI Staff: One approach to user support, as well as staff support across the network, includes the creation of working groups comprised of NNCI site staff members (see above). These groups may be formed for specific processes (lithography, etching, ALD, etc.) or for specific applications (MEMS, bio/life sciences, photonics, etc.). It is planned that such groups could have private pages on the NNCI website. Existing users and site staff will also be encouraged to post process recipes on the NNCI web portal. These process recipes should be appropriately verified by an individual site's technical staff before posting. In addition, we envision a mechanism for gathering and incorporating user feedback on these process recipes, similar to Yelp or TripAdvisor services.

While initial plans were to hire an in-house website developer, this proved difficult due to university restrictions on salary. Instead, the coordinating office hired a web development vendor, Cool Blue Interactive, which is based in Atlanta. There was a strong desire by the coordinating office team to create a more visual and graphic oriented website, compared to the previous NNIN website. One source for inspiration was the nanohub.org website.

The following indicates the current status of the NNCI Website, with content completed in 2016 and plans for 2017 improvements and additional content. Specific additions to the website will depend on consultation with the web developer. The website sitemap, listing all pages with links, is also provided below.

<u>NNCI Website Phase 1 (Completed December, 2016):</u>

1. Basic NNCI information
    a. About NNCI
    b. Coordinating office
    c. Advisory board
2. Individual site pages
    a. Contacts
    b. Map
    c. Getting started information
    d. Links to tools database
    e. Images
3. Tool database (>2000 tools) - searchable by site, taxonomy, or plain text
4. Experts database (>200 experts) - searchable by site, name, or plain text
5. Contact forms
    a. General information
    b. New user gateway
6. Education and outreach
    a. REU information
    b. Individual site information
    c. Teaching modules (in progess)
7. Societal and ethical implications
    a. Winter School
    b. Science outside the Lab
    c. Site information
8. Additional resources
    a. Other nanotechnology infrastructure
    b. Link to computation content at nanoHub
9. NNCI news blog

<u>NNCI Website Phase 2 (Beginning March 2017):</u>

1. Add application and fabrication proficiencies, with links to sites possessing that experience and capabilities.
2. Improvements to contact forms
    a. Multiple email recipients
    b. Ticket tracking system
3. Improvements to tools/experts databases
    a. Capability for site-specific editing
    b. Changes in taxonomy
    c. Small design refinements

4. Improvements to site pages
    a. Longer site description
    b. Editable site contacts
    c. Improved map
    d. Site-specific spotlights and news items
5. Possible changes to NNCI sites map
6. Additional resources content
    a. Recipes with rating system
    b. More technical reports and content
7. Private pages for working group activity
8. Private page for user statistics uploading by sites

NNCI.net Sitemap

Front page

Front page of *NNCI*

Main navigation

- About
    - Get Started
    - Becoming a User
    - Coordinating Office Contacts
    - NNCI Advisory Board
- Sites
- Tools
- Experts
- Resources
    - Computation Resources
    - Other Nanotechnology Resources
    - Commercialization Resources
    - NNCI News
- Learn
    - What is Nano?
    - Education and Outreach
        - Site Education and Outreach
        - Research Experience for Undergraduates (REU)
        - Educators (K-16)

        - Students (K-12)
        - Educational Articles
        - Education Videos
        - Nanooze
    - Nano and Society
        - SEI at NNCI Sites
        - Winter School
        - Science Outside the Lab
- Dashboard

Footer Buttons

- Ask a Question
- New User Gateway

Footer

- About NNCI
- Privacy Policy
- Contact Us
- Sitemap

8. NNCI Annual Conference (January 2017)

In the proposal for the Coordinating Office, it was suggested that “A flagship event for the NNCI network will be the annual ***NNCI Conference***, which will be held at different network sites and will not only highlight the research supported by the NNCI facilities, but also provide a venue to share best practices as a result of the work of various working groups and committees.” It was further detailed: “The Coordinating Office will work with the site directors to organize the annual ***NNCI Conference***, which will be held each year at a different NNCI site. The conference attendees will include the site directors and other site management personnel, the External Advisory Board, as well as NNCI site staff who are members of the working groups. As mentioned above, individual working groups might organize parallel sessions where findings in the specific topical area can be shared with other interested NNCI staff. While the first NNCI Conference will be NNCI internal only, we plan on opening up the conference to a broader audience, including the National Labs, non-NNCI nanotechnology facilities, vendors, users and prospective users of the sites, etc., in subsequent years. We envision a 1.5-2 day meeting, that includes half-a-day of network overview and site presentations, half-a-day of user presentations, possibly in parallel sessions, and at least a half-a-day of time for dedicated panels on E&O, SEI, computation and select working groups (safety, vendor relations, etc.). The goal is to have a working meeting that strengthens the network and its sites, helps with future planning and is not just a review. As an example, each year’s conference could have a dedicated panel on “Emerging Research Areas”, using invited talks to stimulate discussion among the NNCI sites on promising future research directions and the tools required to support these. We also envision that satellite events, such as an SEI Conference, could be organized in conjunction with the annual NNCI Conference. Poster and presentation awards as well as certificates for certain panel participation may be a way for student and staff development, respectively, as part of the annual event.”

The first NNCI Conference was held on January 18-19, 2017 in the conference facility of the Marcus Nanotechnology Building at the Georgia Institute of Technology in Atlanta, GA. The 1.5-day event had an attendance of 78, including all 16 site directors, 8 of 10 advisory board members, Dr. Larry Goldberg and Dr. Fred Kronz, NSF program directors, as well as three invited speakers, Dr. Magnus Egerstedt from Georgia Tech, Dr. Jeffrey Morse from the University of Massachusetts, Amherst, and Dr. Ravi Bellamkonda from Duke University (see photo below). Following the initial idea, the three invited lectures introduced “emerging research areas” for the NNCI network, in this case robotics, roll-to-roll manufacturing, and cancer nanotechnology. Besides the 45-minute invited lectures, the 1.5-day program featured:

1. Presentations by the Director and the three Associate Directors of the Coordinating Office with an NNCI Overview and Reports on Education & Outreach, Societal & Ethical Implications and Modeling/Simulation, respectively.
2. Short 10-minute site reports from each of the 16 NNCI sites.

Both the Coordinating Office presentations and the site reports are provided, along with the full meeting agenda, on the NNCI website at http://nnci.net/nnci-annual-conference-2017.

3. Nine breakout groups grouped in 2 sessions with subsequent reporting back to all attendees. Topics included: Future Research Directions, Working with Users / User Support, Education & Outreach, Non-Traditional Users, NNCI Website, Facility Operations, Marketing & User Recruitment, Computational Resources, Societal & Ethical Implications. After the

conference, the breakout session reports were provided to each of the site directors for distribution as appropriate.

4. Separate meetings by the External Advisory Board and the Site Directors/Coordinating Office. The Advisory Board discussions resulted in a written report to the Coordinating Office which is attached here as Appendix 11.1.

9. NNCI Network Usage

Individual NNCI site performance, and that of the network as a whole, can generally be assessed based on four major criteria: (1) ability to serve the greatest number and broadest set of researchers from academia, industry, and government, while keeping in mind site's capabilities and focus, (2) impact on the research enterprise and its economic importance in the commercial realm, (3) societal impact based on improved public awareness, diversity, and workforce development for nanoscale activity, and (4) contributions of sites to the NNCI network. Given these broad criteria, each site determines the set of metrics for their annual site report to NSF that best fit their own technical specialization (if any), regional user base and commercial interests, and any partnership arrangements. A non-exhaustive list of examples of potential metrics, many based on experience from NNIN, is provided in Table 5 in the report of the *Metrics and Assessment Subcommittee*.

NNCI sites collect statistical data about its users in an effort to assess the strength and success of the internal and external users program. Research disciplines can be used to help track usage in non-traditional areas. Productivity is implied from annual assessment of user research publications, patents, and presentations that rely on use of the shared facilities and the research budgets enabled. It is more difficult to quantify the productivity of industrial usage, where publications are not the norm, but data on numbers of start-up companies, their financial well-being, patent applications and personnel hiring can be used as indirect measures. In addition, sites may decide to conduct regular user and/or PI satisfaction surveys as a means of assessing site quality and making adjustments to procedures as needed. Education and outreach evaluation plans will provide assessments to guide program improvement as well as impact and effectiveness of programs. Finally, each site's contributions to creating a unified network that surpasses the sum of its parts can be assessed by participation of site personnel in network activities.

That being said, it is important that a common set of data for the NNCI network sites, as well as aggregated data for the network as a whole, be regularly collected. The NNCI Coordinating Office has established a *Metrics and Assessment Subcommittee* that has begun to develop a common and agreed upon set of site and network metrics. In order that there is no data vacuum within the early years of NNCI, the Coordinating Office requested that individual sites continue to collect user data consistent with the NNIN format until the new NNCI metrics are established. In order to assist sites, particularly those new to this data set, the Coordinating Office held a webinar on data collection and compilation on October 27, 2016 which was attended by the majority of NNCI sites. The following are the definitions provided to all sites for creating a uniform set of metrics.

1. An on-site user is someone who physically comes to a site facility (or partner facility) to access the tool set. A remote user is someone who contracts to have processing and/or characterization done by site staff for them. In general, there should only be one remote user for any given piece of work. Faculty (both internal and external) and industry PIs, unless they actually do hands-on work themselves, should not be counted as users – only the students/researchers who do the work are users. Site staff should not be counted as users, unless they have a dual role and act as a student/researcher as well. All included facilities are OPEN, SHARED, USER facilities, where the tools are available to all researchers (internal and external) for hands-on use. Purely service facilities or individual PI labs should not be

included. It is also important to not count users more than once for using multiple facilities of a single NNCI site. In short, every user in the cumulative user count corresponds to a single, unique individual. Even though summer interns/REU students are typically paid with internal funding and working on internal projects, these users are counted as EXTERNAL users as their home institution is another university/college, which is the primary factor that governs affiliation.

2. Stats are broken down by Affiliation, meaning the type of institution, and Discipline, meaning the area of research. Local Site Academic refers to users who are either students or employees of a site (or partners). All other Affiliations are for external users. A Small Company is defined as one with <500 employees. Disciplines are often self-selected by the user, or perhaps by site staff. In the Discipline category "Educational Lab Use" is NOT intended to count students in a regular university class which uses the NNCI site facilities. Rather, this category is applied to users who attend workshops or short courses, created as part of a sites NNCI education and outreach, where hands-on work (attendees actually go into the lab) is part of the program.
3. Lab Time refers to actual time in the cleanroom OR tool time for all users during a given month. These should not be double counted. In other words, if a student is using multiple tools in the cleanroom, only the time in the cleanroom should be used. If a student is outside the cleanroom, but a process is still running, the tool time can still be counted. Most characterization tools, outside the cleanroom, are counted as straight tool usage time. For cases when users are logged into a cleanroom tool, but he/she is not inside the cleanroom (for example, during extended furnace runs), tool time is recorded.
4. Monthly Users are the total number of unique individuals who access a site in a given month. In this case, the Total amount may be different than the sum of On-Site + Remote if a user accesses the site via both methods in a given month.
5. Cumulative Users is the running total of all users since the beginning of the NNCI year on October 1. Each year on October 1, the cumulative count starts over with all users counted again.
6. Fees data are the revenue from all user fees for use of a site's facilities. This data does not include indirect charges (if they are assessed). If a site uses a cap on charges after a certain hour limit, only the actual fees charged are reported, but the actual hours used over the cap limit are reported in Lab Time.
7. New Users Trained refers to those users who are first time users (and go through a site's orientation program) in that month. In this section all users should only be included ONE TIME during the entire life of the NNCI program.

9.1. NNCI Aggregate User Data (Oct. 1, 2015 - Sept. 30, 2016)

Since each site provides its own usage data as part of their annual report, we have not included individual site data here, but rather the aggregate for the NNCI network. In Table 8 below, we provide the NNCI totals, along with the average for the 16 sites, as well as the minimum and maximum values for the sites as an indication of the wide variation among the sites.

Table 8: Summary of NNCI Aggregate Usage Data

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users*	10,909	682 (125 – 1,446)
Unique External Users*	2,567 23.8%	160 (19 – 461) 23.8% (6.0% – 42.1%)
Industry Users*	1,413	88 (9 – 202)
External Academic Users*	1,154	72 (7 – 352)
Average Monthly Users	4,427	277 (40 – 679)
New Users Trained	4,116	257 (36 – 699)
Facility Hours**	909, 151	~57, 000 (~3,600 – ~175,000)
Facility Hours – External Users**	173,510 20.2%	~10,800 (322 – 50,500) 20.2% (1.4% – 43.4%)
Hours/User*	83	83 (27 – 170)
User Fees Internal Users External Users	 $20.6M $13.5M	 $1.29M $0.84M

*This table only contains partial data from one site which was unable to provide cumulative user numbers for the requested time period. Thus, numbers of users should be considered a lower bound.

**Hours were collected as lab usage hours (time in the cleanroom), tool usage hours (when operated while not in the cleanroom), and tool usage hours for non-cleanroom tools. While we have conveyed this definition to the sites (see above), we have not made an attempt to standardize the data collected.

The >2500 external users come from 988 distinct external institutions (Full list shown in Appendix 11.2): 213 academic institutions, 486 small companies, 210 large companies, 23 US local/federal government organizations, 35 international institutions, and 21 other institutions (museums and non-profits, for example). This number excludes cases where an external institution (not necessarily the same PI or user) is working at multiple NNCI sites. For academic institutions a network map showing the NNCI nodes and associated colleges and universities is shown in Figure 3 below. Universities with projects at three or more NNCI sites (22 institutions) are labeled.

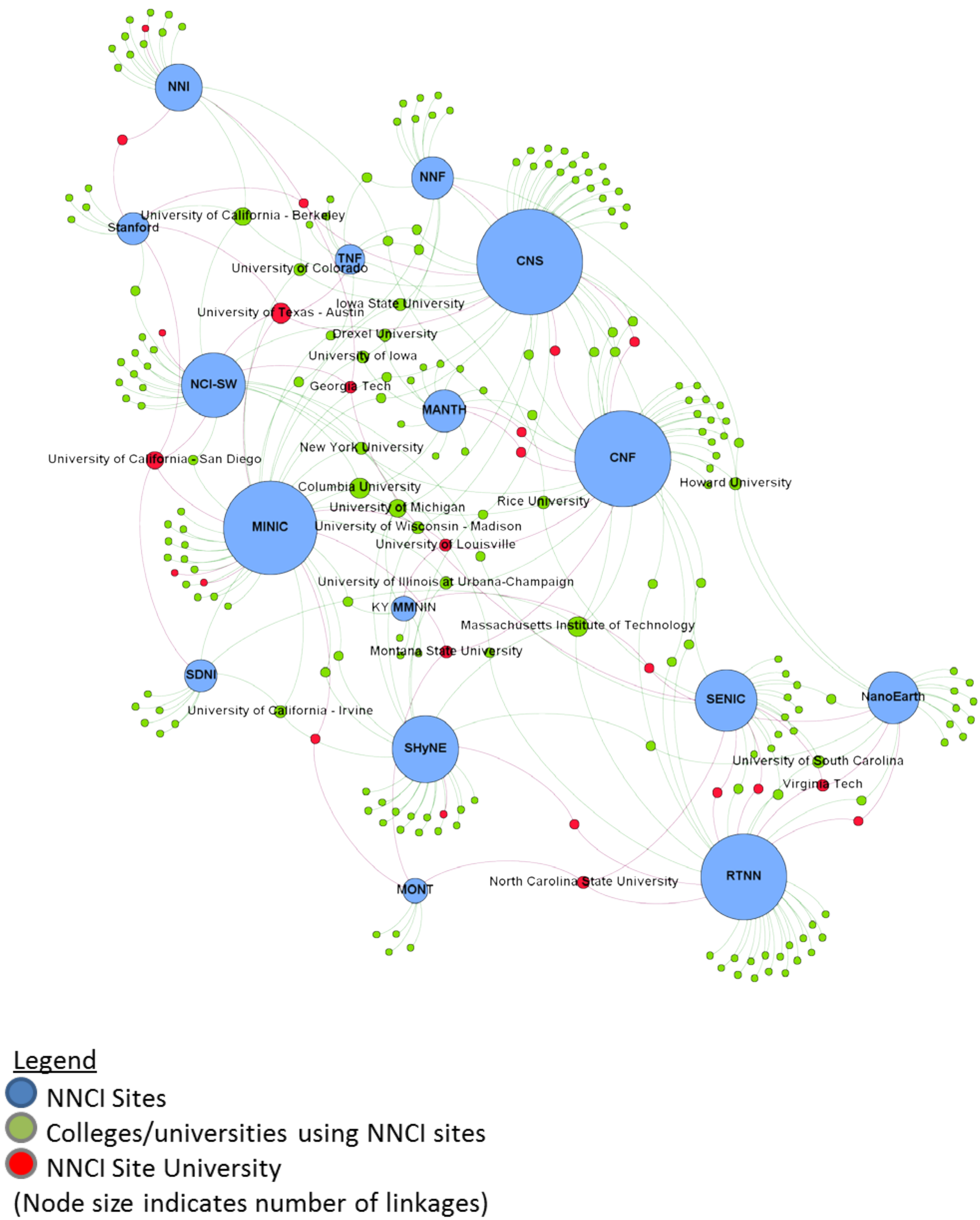


Figure 3: NNCI Academic User Network Map

9.2. Non-Traditional Users

One important, though troublesome, metric is how well NNCI reaches and assists non-traditional users. In order to determine the best way to assess this aspect of NNCI activity, a breakout session on this topic was held at the January, 2017 NNCI Conference. The following is a summary of a portion of that group's findings.

A great deal of time was spent on the topic of how to define "non-traditional." Previously, non-traditional has referred to specific disciplines (for example, life sciences). However, there was opinion that the lines are starting to blur between disciplines, and now the disciplines that were once considered non-traditional are becoming traditional or typical users of NNCI user facilities. In this way, some members of the group thought that the large number of non-traditional users reported may be inflated.

The group solicited input from NSF (Dr. Larry Goldberg) who suggested the definition that "a non-traditional user is someone who does not normally use the facility but whose research could benefit from using the facility." It was indicated that non-traditional users are still very important to the NSF, and especially from those "non-traditional" directorates that help support NNCI. However, it was felt that such a definition would be difficult to measure, as it is not discipline-specific. In addition, it is broad enough to include users from community colleges or non-research 1 institutions as well as underrepresented groups. More discussion is needed on determining a standardized definition of non-traditional users across the network.

Another issue of concern is that many of the non-traditional users are "light" (low usage hours) users of the facilities. There is a concern that if too much emphasis is placed on non-traditional users it will be at the expense of traditional users who help to ensure that the facilities are more financially sustainable. It is critical that a balance be struck between these.

The charts below illustrate the usage of the NNCI network by users in specific disciplines (internal and external). It is worth remembering that in many cases these disciplines are self-selected, and may reflect with the user's home department or their specific area of research. Figure 4 illustrates the breakdown by number of users in specific disciplines, while Figure 5 illustrates the usage hours by discipline.

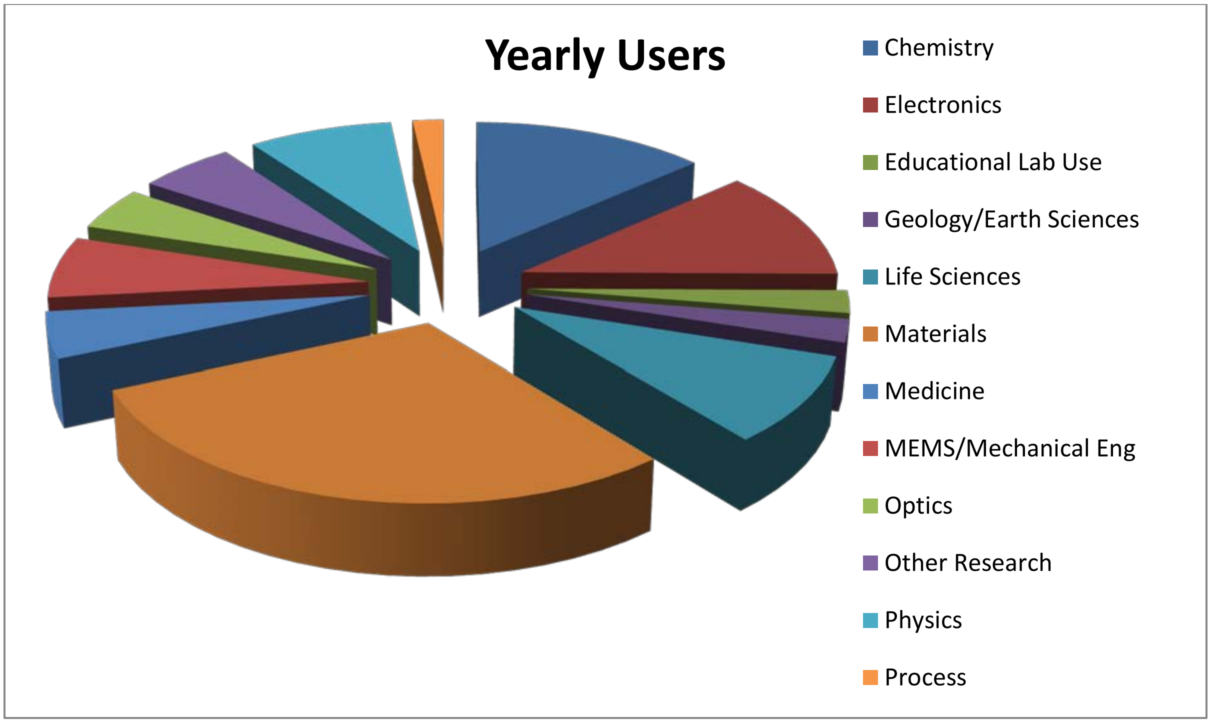


Figure 4: NNCI Year 1 Users by Discipline

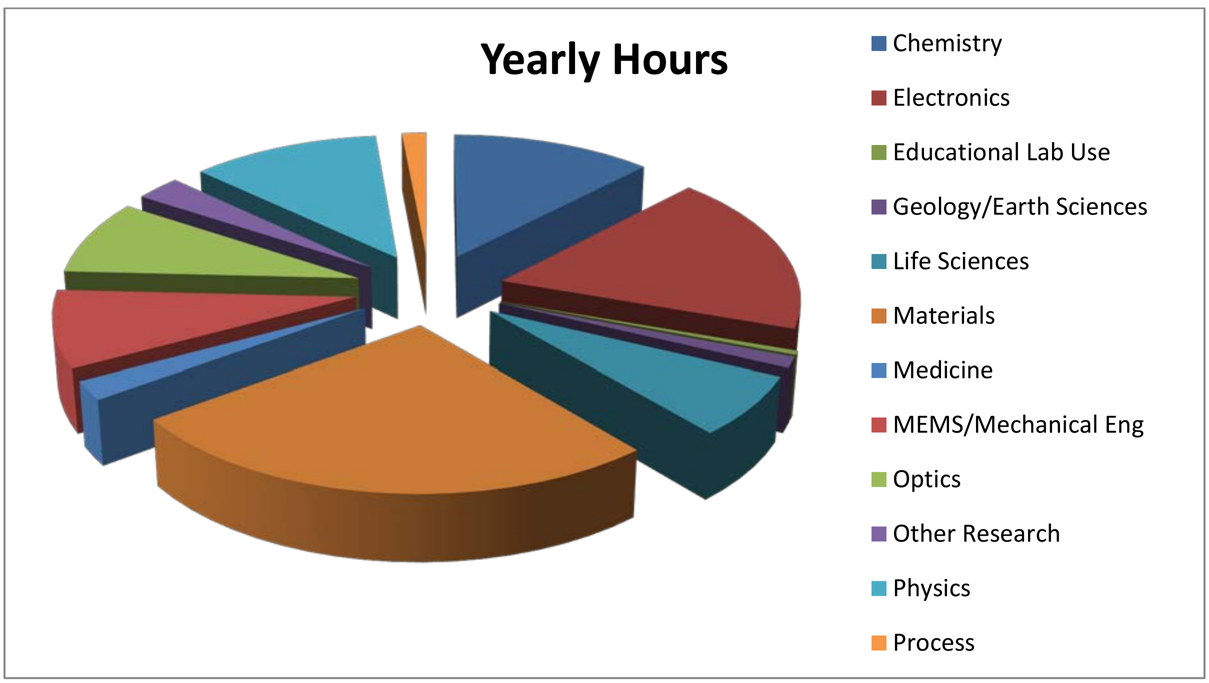


Figure 5: NNCI Year 1 Usage Hours by Discipline

If it is assumed that the "traditional" disciplines include the engineering-related electronics, materials, MEMS, and process development disciplines, whereas "non-traditional" is everything else, than it can be seen that the relative usage breakdown by number of users and hours is given in Table 9 below. While number of users is nearly an even split between traditional and non-traditional, there is a slightly larger number of hours (55%) for the traditional users, as one might expect for typical fabrication-heavy research, compared to the non-traditional users.

Table 9: Usage by Traditional and Non-Traditional Disciplines

	# of Users	Hours of Usage
Traditional	5386 (51%)	495,215 (55%)
Electronics		
Materials		
MEMS/ME		
Process		
Non-Traditional	5262 (49%)	409,935 (45%)
Chemistry		
Physics		
Optics		
Medicine		
Life Sciences		
Geo/Earth Sciences		
Other		

9.3. Publications Information

The publications data shown below (Table 10) was collected by sites for the calendar year 2015. Since only one-half of sites were part of NNIN, and thus had an established history of working with external users and collecting such information, this should be considered a lower limit of the actual publications data. In addition, no attempt was made to remove duplicates, where authors might have been from multiple NNCI sites.

Table 10: NNCI 2015 Publications Data

Publication Type (CY 2015)	
Internal User (Site) Papers	1980
External User Papers	311
Internal User Conference Presentations	889
External User Conference Presentations	85
Books/Book Chapters	32
Patents/Applications/Invention Disclosures	336
Total	**3633***

*Does not include 469 publications from one site which was not able to categorize them. **Total publications including this site are 4102.**

10. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 1 report. Specific information requested included:

1. A brief narrative not to exceed 3 pages, corresponding to the NNCI year Oct. 1, 2015 - Sept. 30, 2016.
    a. Facilities, tools, staff updates during the year
    b. User base – marketing and outreach activities and brief narrative of site usage statistics.
    c. Research highlights (2-3 short vignettes of research, with figure). In particular, indicate any specific research strengths or focus at your site, and consider including projects performed by external users. Anecdotal evidence of users taking advantage of the network nature of NNCI (i.e. using more than one site), is also desired.
    d. Education and outreach activities summary
    e. Societal and ethical implications activities (if applicable)
    f. Computation activities (if applicable)
2. A listing of all external user institutions for NNCI Year 1, separated as follows: Academic, Small company (<500 employees), Large company, Government, International, Other. See Appendix 11.2 for the complete listing.
3. The number of publications in each category for calendar year 2015. The publications list would have been part of each site's Year 1 report to NSF, but the data requested here is only numbers of publications. See Table 10 above.

<u>The reports below are presented as provided by the sites, with only minor editing for format.</u>

10.1. Center for Nanoscale Systems (CNS)

Facility, Tools, and Staff Updates

This year we have added a number of new staff; some allowing us to expand our research capabilities and some re-staffing to back-fill for newly retired or departed staff.

Dr. Antonio Ambrosio; Optics and Scanning Probe Microscopy/Spectroscopy:
Dr. Austin Akey; Atom Probe Tomography, Focused Ion Beam Fabrication
Mr. Tim Cavanaugh; Scanning Electron Microscopy
Ms. Linda Wang; Associate; Director of Finance and Administration

We have also expanded the capabilities available to the userbase both in the nanofab and other parts of the lab. The new tools and instrumentation include:

Imaging and Analysis additions

- ***JOEL 200F ARM STEM****: 67pm resolution*
- ***Molecular Vista Photo Induced Force Microscope (PiFM)***
- **IsoPlane 160 spectrometer and Pixis Camera**
- **Coherent Micra femtosecond laser**
- **PTI Quantamaster 40 steady state spectrofluorometer** (Wyss Donation)
- **Thermo Electron K-alpha XPS**

Fig. 1 Heidelburg Maskless Aligner

Nanofabrication additions:

- **Nanoscribe 3D lithography system**
- ***Heidelberg MLA-150***
- **Asylum Cypher Atomic Force Microscope**
- **100MHz high speed blanker for Ellionix –E125 E-beam Lithography tool**
- **Cambridge Nanotech - ALD;** Atomic layer deposition system
- **Phi-ALD** Atomic layer deposition system)

These new tools expand our processing capabilities an offer an opportunity for *"in-house"* process development. The ALDs for example have been instrumental in our rapidly expanding efforts in nanoscale photonics; while the PiFM instrument has offered a unique instrument development opportunity enabling nanoscale spectroscopy.

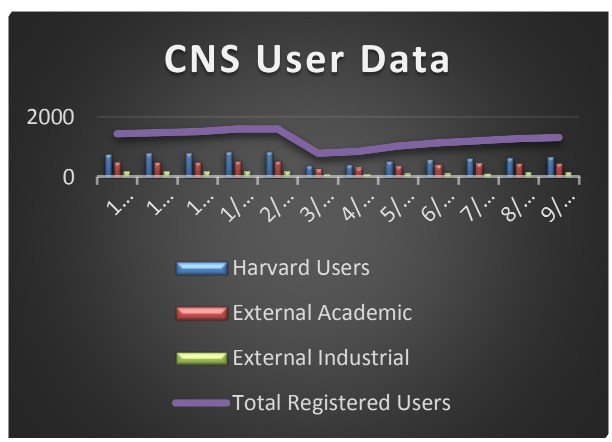


Fig. 2 Cumulative user data for year 1.

User Base

The CNS user data for program year #1 is summarized in figure 2. Note the chart is for cumulative registered users and our re-enrollment period starts on March 1. (Most users initiate re-registration before the March 1 trigger which is why we don't completely reset to zero.) Detailed data is reported elsewhere in this report. Note our fraction of external usage ranges from 46 to 51% during the year.

<u>Research Highlights</u>

Nanophotonics: *High Precision flat, Visible Metasurfaces for High performance Optics*; Robert Devlin, Federico Capasso, et al, Harvard University: Metasurfaces are optical elements that can mimic and go beyond the functionality of refractive optics in a compact and planar configuration. Of late, transmissive metasurfaces have been limited to infrared wavelengths because currently used materials have significant optical absorption and loss at visible wavelengths. The Capasso Group have recently demonstrated high performance dielectric metasurfaces using nanostructured titanium dioxide (TiO_2). These TiO_2 metasurfaces exhibit low surface roughness, highly anisotropic features and negligible optical loss at visible wavelengths. This device process strategy was developed at CNS with the help of the CNS ALD staff. The team demonstrated high numerical aperture meta-lenses showing diffraction limited focal spots and sub-wavelength resolution imaging at visible wavelengths. This work was featured and highlighted on the cover of Science in June and was chosen as one of the breakthroughs of the year by the Science editorial staff.

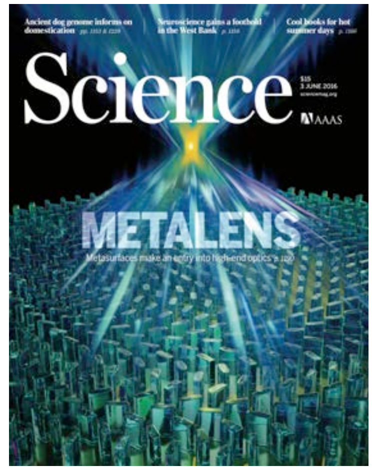


Fig 3: June 2016 Science cover of a flat metasurface metallic lens created by an array of optical NanoFin antennas on a transparent substrate by Capasso's group.

Fundamental Physics: *Observation of the Wigner-Huntington Transition to Metallic Hydrogen;* Ranga P. Dias and Issac F. Silvera; Department of Physics Harvard University: Producing metallic hydrogen has been one of the "holy grails" of condensed matter physics. It has been predicted that metallic hydrogen will be a room temperature superconductor and metastable when the pressure is released which could make it and important need material system. The have studied solid molecular hydrogen under extremely high pressure at low temperatures. They show at a pressure of 495 GPa hydrogen becomes metallic with reflectivity as high as 0.91. They fit the reflectance using a Drude free electron model to determine the plasma frequency of 32.5 ± 2.1 eV at T = 5.5 K, with a corresponding electron carrier density 7.7 ± 1.1×10^{23} particles/cm^3, consistent with theoretical estimates of the atomic density. The properties measured are those of an atomic metal. Importantly they carried out a rigorous strategy to achieve the higher pressures needed to transform to Solid Metallic Hydrogen (SMH) in a diamond anvil cell. Diamond failure had been the principal limitation for achieving the required pressures to observe SMH associated with surface

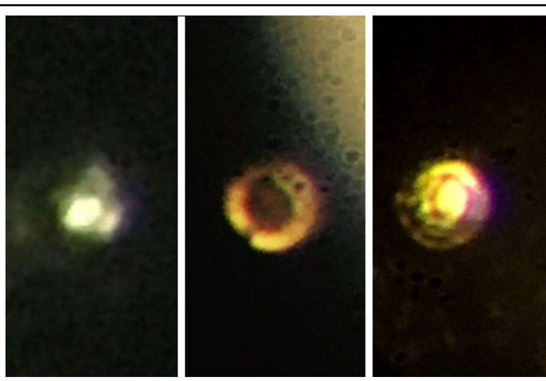


Fig 4: Microscopic images of the creation of metallic hydrogen with increased pressure: Transparent molecular hydrogen (left) at 200 GPa, converted into black molecular hydrogen, and finally reflective metallic hydrogen at 495 GPa.

defects. They utilized diamond processing at CNS to etch off 5 microns from the diamond culets to remove surface defects. This enabled them to reach the required pressures. This work was published in Science on 1/2017

Education and Outreach Activities

In FY16 we began development of the cornerstone educational initiatives which will be the hallmarks at CNS. First a traditional REU program. This year there were 6 students chosen using a joint Harvard website hosting potential research project campus wide. The students selected, their institution, and their summer project and Mentor/Mentors are listed in table 1. This was the first year the Harvard site recruited and selected students from the composite University site and we believe the process went well. PI Westervelt and co-PI Wilson used the STC college network and several other vehicles to ensure a diverse candidate pool. We also selected the first 5 REV interns. These students were selected from a pool at Bunker Hill Community College. BHCC has a very vibrant STEM focused directed at VETs and served as an ideal option for a fast start. A list of the Vet interns and their current summer projects are listed in table 2. Next year we will expand our Vet recruiting to Northeastern university and will advertise to the Vet community.

Table 1: Student interns and projects for FY16

Student	Project	Institution
Luke Soule (REU)	*Fabrication of Nano-Porous Templates and Masks for Synthesis of Nano-Structures and Devices Using Directed Molecular Self-Assembly of Diblock Copolymers*	New Mexico Institute of Mining & Technology
Jonathan Schwartz (REU)	*Innovative sensor development and fabrication using 3D lithography*	Arizona State University
Cole Reynolds (REU)	*Innovative sensor development and fabrication using 3D lithography*	Texas A&M University
Zachary Pitcher (REV)	*Raman and other Characterization of ALD nucleation on Graphene and other 2-D Materials*	University of Colorado – Colorado Springs
Daniel Ortiz (REV)	*Photolithography Process Database Development*	Bunker Hill Comm College
Antonett Nunez-DelPrado (REU)	*Characterization of Oxide Film Nucleation and Quality, using High Pressure ALD Deposition*	University of Central Florida
Rachel Marshall (REU)	*Plasma Etching of Polycrystalline Diamond Film*	Bunker Hill Comm College
Ariel Jimenez-Fong (REV)	*Further Development of a Novel Liquid Phase/Vapor Phase Silica Deposition Process*	Bunker Hill Comm College
Ethan Davis (REV)	*Deep Reactive Ion Etch of Silicon*	Bunker Hill Comm College
Sam Aguiar (REU)	*"Photon-less" optical nano-imaging*	Arizona State University

We have begun two initiatives focused on more mature scientific researchers. One CNS Scholars program offers direct fabrication and instrumentation support for researchers from under-represented groups, small or minority serving institutions. We are funding use with some materials and supply support. The initial enrollees, institutions and projects are listed in table 2. All submitted brief proposals, which were evaluated by CNS senior staff. We have also initiated a partnership with Harvard Catalyst. Catalyst provides seed support for projects in the translational biosciences. Currently we are not using NNCI funding to support any of these initial researchers, but we anticipate possibly inclusion of some of these bioscience teams in CNS Scholars.

Table 2: CNS Scholars Participants

Scholar	Project	Institution
Prof. Thomas Searles	*Atomic Layered 2D Materials based Meta surfaces*	Howard University
Prof. Renita Horton	*Vasculopathy on a Chip*	Mississippi State Univ
Prof. Katherine Aidala	*Fabrication of Ferromagnetic Nanostructures*	Mt. Holyoke College
Dr. Tina Brower-Thomas	*"Twistronics" in decorated 2D Materials*	Howard University

10.2. Cornell Nanoscale Science and Technology Facility (CNF)

Facility, Tools, and Staff Updates

CNF serves as an open resource to scientists and engineers with emphasis on providing complex integration capabilities made possible by an expertly-staffed user program that provides rapid, affordable, hands-on 24/7 open access to advanced nanofabrication tools. The following new tools, processes, and facilities have been acquired over the past year.

- Bruker Quantax 200 Energy Dispersive Spectroscopy
- New Process for ALD Coated Nanoparticles
- Logitech Chemical Mechanical Polishing Tool
- Disco Automated Dicing Saw
- Etching Process for Magnetic Random Access Memory
- Pre-Cast Photosensitive Epoxy Sheets
- Metricon Prism Coupler

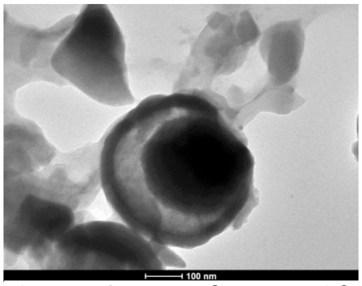
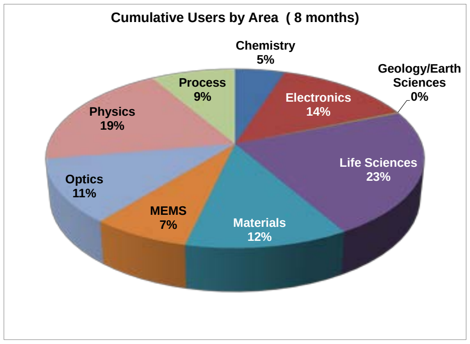


Figure 1: ALD coated nanonparticle

Staffing: XinWei Wu, a Ph.D. Materials Scientist, joined the CNF staff as a half time Research Associate to develop and characterize new material processes. Prof. Dan Ralph served as Director of CNF since 2010. His term as Director and PI for the NNCI award has ended and Prof. Chris Ober, Materials Science and Engineering, is the new Director of CNF.

User Base

CNF established a set of specific milestones to measure our success in serving users, particularly external users, and marking our other proposed goals. We were successful in meeting all of these benchmarks. CNF hosted 198 external users in the cleanroom who alone clocked over 33,000 hours of cleanroom plus equipment hours. External user fees were $1.57M out of a total of about $2.5M and our median Likert scale score for user satisfaction was 4.58/5. Overall cleanroom hours were over 43,000 (12 months) and our monthly average number of users was 176 and our twelve month cumulative users totaled 561. Using the NNCI categories 53% of CNF usage is from non-traditional fields. A recent snapshot of the breakdown by discipline is shown in the pie chart. Remote usage serves as a way to engage future users, achieve higher tool utilization, and enhance the NNCI network value to users. This year 31 remote jobs were completed. We also make use of inter-site capabilities, for example, shipping a user's wafers to U. Penn, Stanford, Georgia Tech, or Harvard when a CNF system is down for repairs or a user need is better met. We have gotten excellent cooperation from the other NNCI sites when users require this backup support.



Research Highlights

Research reports are published annually as the **CNF Research Accomplishments** and online at http://www.cnf.cornell.edu/cnf5_research.html. CNF users compiled over 500 publications, conference presentations, and patents (details in NNCI spreadsheet). Here we highlight some of the most significant examples of research enabled by CNF in the past year.

- In **Nature Communications**, the Badalato group from the U of Rochester, in collaboration with NIST , used CNF to incorporate an individual self-assembled epitaxially grown InAs/GaAs quantum dot at a precisely-located position within an optical resonator device.
- In **Nano Letters**, the Riehn group from NCSU used CNF to make a nanofluidic device that allows targeted studies of physical interactions between different segments of DNA strands that can play a role in gene regulations.
- In the **New Journal of Physics**, the LaHaye group from Syracuse University used CNF to develop a protocol for testing time reversal symmetry in superconducting devices that act as macroscopic artificial atoms.
- In **Applied Physics Letters**, the Takeuchi group from the University of Maryland used CNF to develop a technique that improves the sensitivity of microfabricated cantilevers for magnetic field sensing by a factor of six.
- In **Nano Letters**, a collaboration among UCLA (Suneel Kodambaka), IBM (Frances M. Ross), and the U Penn (Haim H. Bau) used CNF to fabricate fluidic cells compatible with transmission electron microscopy. They used these fluidic cells to study the growth of individual gold nanoparticles formed by electron irradiation of gold chloride solution.
- In **Nature**, the McEuen group at Cornell used CNF to implement *kirigami*, the Japanese art of paper cutting, with graphene sheets just one atom thick. They applied *kirigami* to build mechanical metamaterials such as stretchable electrodes, springs, and hinges.
- In **Science**, the Wiesner group at Cornell used CNF to invent a simple and rapid method to control three-dimensionally continuous hierarchically porous polymer network structures.
- In **Nature**, the Park group at Cornell used CNF to successfully demonstrate batch fabrication of high performance field-effect transistors from monolayer molybdenum disulphide (MoS_2) at the full 4-inch wafer scale.. This work is a step towards the realization of atomically-thin integrated circuitry.
- In **Proceedings of the National Academy of Sciences**, the Mingming Wu group at Cornell used CNF to make microfluidic devices for studying mammalian reproduction. These results provide previously unidentified directions for the development of in vitro fertilization devices and contraceptives.
- In **Nature Communications**, the Lipson and Gaeta groups at Columbia used CNF to demonstrate a high-performance frequency comb operating over a broad wavelength range in the mid-infrared, based on a silicon microresonator. This device may be used in real-time monitoring of atmospheric gas conditions.
- In **PLOS One**, the Erickson group at Cornell used CNF to make an implantable biosensor system that can be used for continuous monitoring of uric acid levels of birds during flight. Application of the sensor in migratory birds offers a better understanding of the ecology and biology of avian movements.

<u>Education and Outreach Activities</u>

CNF supports a broad range of educational and outreach activities. In 2015-16 CNF hosted 124 individual events with over 3700 direct participants.

Research Experience for Undergraduates (REU) : In 2016, CNF hosted five students including 4 women, 1 underrepresented minority student and 4 from non-R1 institutions. Research reports are available at http://www.cnf.cornell.edu/cnf_2016reu.html

International Research Experience for Undergraduates: Begun under NNIN in 2007, CNF coordinated an international research program for undergraduates selected from the prior year REU program and given an opportunity for a 2nd summer advanced research experience. Dr. Lynn Rathbun wrote a successful proposal to the NSF international division (IRES) to continue this relationship with the National Institute of Materials Science in Tsukuba, Japan. Six students from across the 2015 REU program were selected for this program in 2016. We look forward to expanding this program under NNCI.

International Research Experience for Graduate Students: As a reciprocal program to the IRES funded REU program, Cornell commits to placing selected Japanese graduate students at NNCI sites for the summer. Twenty potential projects were volunteered by five NNCI sites. After a matching process conducted at CNF, three Japanese graduate students came to NNCI sites for summer projects in 2016, two to the University of Louisville and one to the University of Texas. We are pleased with the support that we received from other NNCI sites in support of this program.

Nanooze: CNF produces and distributes *Nanooze*, a children's science magazine relating to nanotechnology. *Nanooze* (**http://www.nanooze.org/**) is a both web-based and printed magazine, with kid-friendly text, topics, and navigation. *Nanooze* is edited by Professor Carl Batt and CNF distributes them to thousands of classrooms throughout the US. We print 100,000 copies per issue as requests from classroom teachers continue to grow. CNF staff work every week to keep up with the requests for classroom packs.

NSF Disney Science Portal: Working with Prof. Carl Batt, CNF submitted a proposal for supplemental funding under the NNCI Cooperative Agreement to retool and update the existing "Take a Nanooze Break" exhibit at Disney EPCOT into a more universal and updateable "NSF Disney Science Portal" to highlight a range of current NSF nanotechnology research. The interactive exhibit will receive hundreds of thousands of visitors each year.

TCN – Technology and Characterization at the Nanoscale: CNF offered an introductory short course on nanotechnology (TCN – Technology and Characterization at the Nanoscale) semi-annually during the summer and winter recess, so that interested students from universities and industry can easily participate. 44 students and scientists participated in the two courses offered this year. The course includes lectures and laboratory demonstrations as well as hands-on equipment sessions. 100% of participants would recommend the course to others.

4-H: CNF is teaming with 4-H to host STEM activities and to use 4-H as a distribution network for demonstration materials and Nanooze science magazines. We hosted a large campus visit of 4-H members and set up stations for hands-on exhibits in Nanotechnology.

Other major educational activities

- USA Science and Engineering Festival
- Blended courses with Syracuse University
- Annual users meeting featuring keynote speaker Mark Eriksson, 16 User Talks, 50 Student Posters, and 27 Company Sponsors
- Junior FIRST Lego

10.3. Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY MMNIN)

Facility, Tools, and Staff Updates

As a new site to the NSF NNCI, the KY MMNIN had an extremely active and productive first year of operation. Our first priority was recruiting and hiring key KY MMNIN staff personnel. This included our overall site coordinator (Ana Sanchez), an integration engineer at the UL node (Doug Jackson), an integration engineer at the UK node (Brian Wajdyk), and recruiting a UK staff member (Tanya Floyd) to coordinate facilities operation software statewide. Our second order of business was the creation of our site website lead by our site coordinator (Figure 1). The website serves as the central portal that tie our 8 user facilities together and houses many interesting features, including a KY MMNIN searchable equipment database, event calendar, site news items, interesting videos about multiscale, outreach activities, social media, and a network forum for our users. The next priority was renegotiating our facility online management license with FOM to a statewide license so that we could include all 8 of our user facilities under a single umbrella. Once that was accomplished, the staff manually inputted all our site tools into FOM, which is used for reservations, training requests, maintenance reporting, billing, collection and yearend reporting. Our site's Advisory Board was formed about midway through the 1st year, met a few months later, and provided many helpful suggestions for increasing our site usage. In terms of equipment purchases using NNCI funds, the UofL node purchased a much-needed SPTS Primaxx HF Vapor Etch System and a couple of benchtop 3D printers for developing novel multiscale integration processes. The UK node negotiated with NanoScribe and is about purchase a state-of-the-art two-photon additive nano-manufacturing system. Other equipment additions for our site included a Hellos Dual Beam system for ebeam imaging and Ga-beam patterning funded through EPSCoR and a Trovata 8-source thermal evaporator for OLED research funded through DOE. Two NSF MRI proposals are pending for a Transmission Electron Microscope for Cross-Disciplinary Research in Materials and Life Sciences (UK) and an In-situ Liquid Cell Electrochemistry System and Cathodoluminescence Imaging System for Electron Microscopy Studies of Novel Energy Materials (UofL). Other accomplishments in year 1 included hiring 3 endowed chair professors in the complementary areas of advanced manufacturing and nano-integration (Profs. Dan Popa, Sundar Atre, and Kevin Chou) and several marketing activities (booths at conferences, newsletters, flyers, etc).

Figure 1. KY MMNIN website.

User Base

Year 1 operation of the KY MMNIN started Oct 1 2015 and concluded Sept 30, 2016. User statistics are summarized in Table 1. The KY MMNIN core facilities were used by 278 users (163 internal and 115 external) from a variety of different disciplines during our first year in the NNCI network. External users constituted 41% of our site usage. Figures 2-4 show a breakdown of our users by discipline, fees, and hours. There are some very interesting take-ways when analyzing these data sets. For example, 10% of our users classified themselves as "MEMS/Mechanical Eng", but that group made up an impressive 23% of our revenue (i.e. fees) and consumed 29% of our lab hours. Physics, on the other hand, constituted 14% of our users, but brought in only 2% of our revenue and consumed 5% of our hours. That analysis, from a purely business perspective, would suggest that we target MEMS users going forward. However, that strategy is not consistent with the over-arching goal of the NNCI, which is to greatly expand the diversity of disciplines that utilize the network. Interestingly, the largest group of our KY MMNIN users fall in the "Other Research" category. This is typically users performing interdisciplinary research which falls into multiple categories, or external users who do not wish to identify the type of research they are performing due to confidential reasons. The KY MMNIN staff trained 111 new users during Year 1, and the total number of facility hours came to 14,629.

	KY MMNIN (10/2015-09/2016) 12 months
# Total User	278
# Av. Monthly Users	103
# Total External Users	115
# External Academic	8
# External Industry	64
# New Users Trained	111
# Facility Hours	14,629

TABLE 1. SUMMARY OF USER STATISTICS

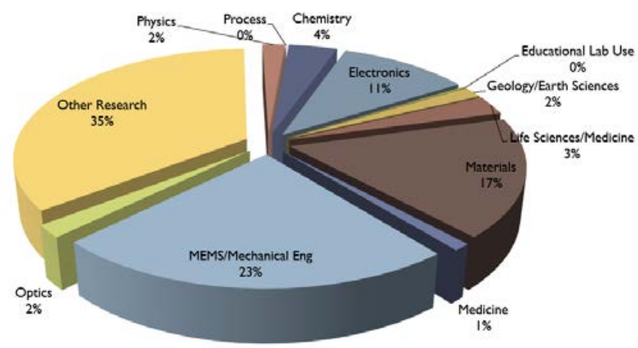


Figure 2. Users by discipline.

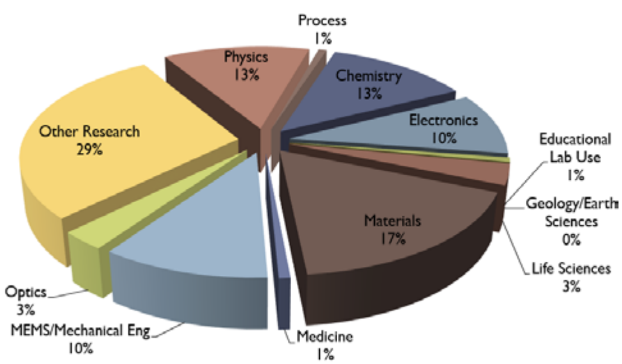


Figure 3. Fees by discipline.

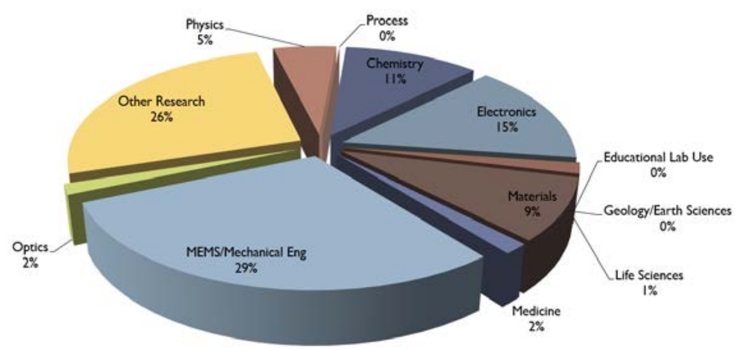


Figure 4. Hours by discipline.

Research Highlights

MEMStim LLC - MEMStim is a medical device startup in Louisville, KY that uses the micro/nano-fabrication and characterization facilities of the KY MMNIN. MEMStim produces implantable electronics for neurological diseases and disorders, such as parkinson's tremors, blindness, hearing loss and heart disease. Their flagship product is a cochlear electrode array for use in implantable hearing aids. With fully automated manufacturing processes that use microfabrication of thin films, MEMStim not only specializes in the manufacturing of low-cost high-yield arrays, but also harness patents and trade secrets to design arrays that incorporate performance enhancing features for minimally invasive surgeries, patient specific stimulation treatments, and the targeted stimulation of specific nerves to minimize unwanted side-effects. To date, MEMStim has acquired several national and international patent approvals, raised nearly $2M in non-dilutive funding, and demonstrated the feasibility of producing clinically viable multi-scale microfabricated cochlear electrode arrays.

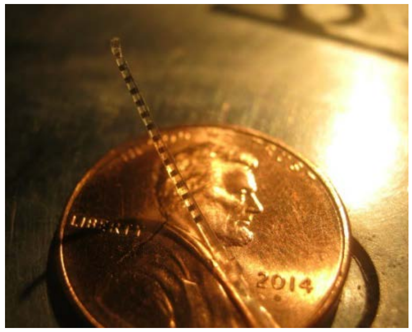


Figure 5. MEMStim chochlear micro-electrode array.

Advanced Semiconductor Processing Technology (ASPT USA) – ASPT USA is a startup company based in Lexington, KY that, along with its Chinese sister company (ASPT Chengdu), produces ultra-low drift moisture sensors for industrial applications. Their current product, shown in Figure 6, provides <1 ppmv trace moisture detection with the world's fastest response speed (data provided by ASPT). The nanotechnology-enabled sensor is based on research from the University of Kentucky and the University of Electronic Science & Technology of China, and is protected by two U.S. patents and one Chinese patent. ASPT's micro- and nano- fabrication and characterization efforts in the US are carried out within the KY MMNIN network using facilities at both UofL and UK. Their engineers can easily reserve instrumentation at both facilities through the MMNIN portal and quickly send personnel and samples between the two sites. Their work is also an excellent example of multi-scale integration as it begins with alumina nanopores, proceeds with microfabrication processes on an unconventional substrate, and concludes with a fully packaged sensor system.

Figure 6. Advanced Semiconductor Processing Technology's industrial moisture sensor.

Education and Outreach Activities

During year 1, much effort was devoted to developing education and outreach activities for our NSF site. A new NSF REU program was started at UofL in the MMNIN theme area of "advanced multi-scale manufacturing" and a student from that program (Robert Accolla of Va. Tech) was 1 of 6 students selected among 30 applicants to represent the NNCI this upcoming summer in the Japanese Nanotechnology Exchange program. A second REU program at UK continued successfully in the complementary area of "nano/bio-active interfaces and devices".

KY MMNIN was selected among all the NNCI sites to host 2 Japanese graduate students as part of the NNCI-JNIMS summer exchange program. A collaboration was established with the KY Science Center (KSC) to promote STEM in the areas of nanotechnology and engineering. As part of that collaboration, UofL and UK played leading roles in NanoDays at the KSC, which attracted over 2,000 students. KY MMNIN participated in the weekend Engineering Expos at both universities. Successful week-long summer camps for high school students interested in nanotechnology were offered at both universities. The KY MMNIN was selected for an NSF and NBC Learn online video as part of their collaborative "Science of Innovation" series. The 6-minute video highlighted the interesting research of a healthcare startup company called MEMStim, which uses the KY MMNIN core facilities to fabricate their patented next-generation cochlear implant micro-electrode arrays. Other educational/outreach activites included: sponsored capstone projects, high school science fair mentoring, visiting research scholars, nano-fabrication demonstrations for the public, participation in NSF "Ask a Nano Expert" video, and serving as a judge for NSF's "Generation Nano" competition.

10.4. Mid-Atlantic Nanotechnology Hub (MANTH)

The Mid-Atlantic Nanotechnology Hub (MANTH), a node of the NSF National Nanotechnology Coordinated Infrastructure (NNCI) program, is housed at the Singh Center for Nanotechnology at the University of Pennsylvania (Penn). MANTH provides open access to leading-edge R&D facilities and expertise for academic, government, and industry researchers conducting activities within all disciplines of nanoscale science, engineering, and technology. Users from the mid-Atlantic and beyond have full access to state-of-the-art instrumentation for the fabrication and characterization of nanoscale structures, devices, and materials in a newly-constructed central facility situated on Penn's main campus. Further, MANTH provides a portal for users to access the intellectual expertise of the Penn faculty and staff in the nano arena as well as other relevant facilities at Penn.

Facility, Tools, and Staff Updates

New equipment for 2016 in our facility includes:

- Tousimis 931 Autosamdri critical point dryer for release of micromechanical structures.
- MRL 1014 150 mm furnaces for silicon oxidation, silicon nitride, silicon oxynitride and annealing;
- Ultratech Fiji 200 Gen 2 plasma ALD, used for deposition of metal thin films, metal-insulator-metal structures and thin film Li-ion battery research;
- Oxford PECVD, IPE CVD-1000 for large substrate deposition and SiC thin films;
- Suss MicroTec conformal imprint lithography system;
- Nanoscribe Photonic Professional GT 3D lithography system that employs two-photon absorption for generating structures down to 600 nm over a volume that spans the millimeter scale;
- Upgrade of Asylum TIRF-AFM optics including new camera hardware and microscope capture/acquisition software for analysis of dynamic processes in cells and tissues;
- Development of electrochemical AFM (Asylum) technique for characterization of materials in solution, part of a research project sponsored by Colgate-Palmolive;
- New ambient STM application module for the Bruker Icon AFM, which facilitates scanning tunneling spectroscopy for characterizing electronic states in metals and semi-metals;

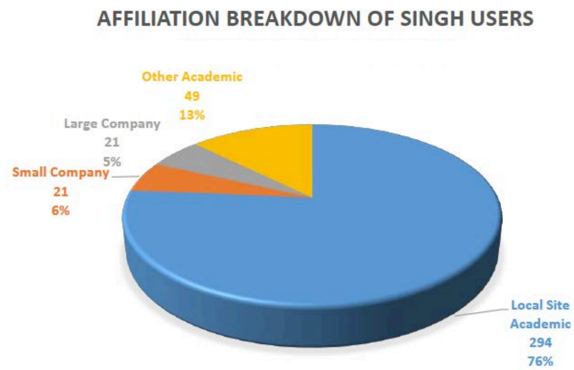
New staff appointments in 2016 include:

- Gyu Seok Kim, User Fabrication Specialist. Dr. Kim joined the NNCI MANTH node in April, 2016. He is responsible for assisting non-expert users with particular fabrication projects as well as supervising remote work activities. Dr. Kim received his Ph.D. from Institut Polytechnique de Grenoble. He has worked as a researcher at Samsung and in 2013 he worked at Penn as a postdoctoral associate before joining MANTH.
- Mr. David J. Jones, User Assistance Specialist. Mr. Jones joined the NNCI MANTH node in January 2016. He is responsible for assisting with the increased burdens of training, equipment, and maintenance dictated by increased external facility use. Mr. Jones received his B.S. in Chemical Engineering (Honors) from Clarkson University in 2011. While at Clarkson, he was also a user at the Cornell Nanoscale Facility. He has also worked at GLOBAL FOUNDRIES, developing 20nm and 14 nm node integrated circuit technologies.

- George Patrick Watson, Director of User Programs. Dr. Watson joined the NNCI MANTH node in August 2016. He is responsible for overall management of the external user program and he is assisting in nanotech-related educational programs. He has a PhD from Cornell in Materials Science with approximately 25 years experience in industry and in shared-use nano-facilities at Bell Laboratories and Princeton University.

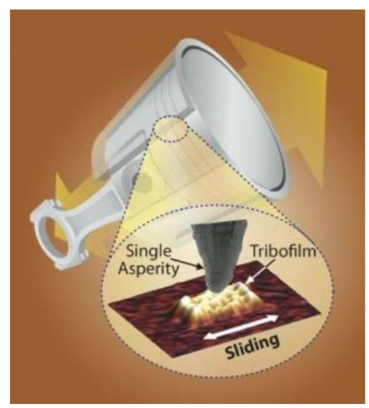
User Base

Over 490 users made use of our facility from October 2015 to September 2016. External academic or commercial users conducted approximately 25% of the research at MANTH. About 25% of the work was in the field of life sciences, an important part of the Philadelphia area's research environment.

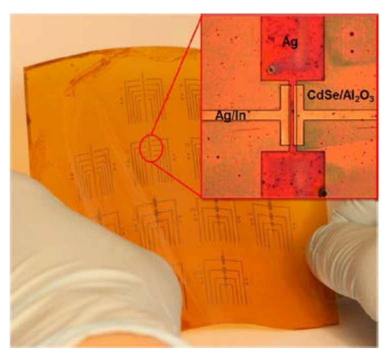


Research Highlights

- Penn and ExxonMobil researchers addressed some longstanding mysteries behind an anti-wear motor oil additive. Zinc dialkyldithiophosphates (ZDDPs) form antiwear tribofilms at sliding interfaces and are widely used as additives in automotive lubricants. Using atomic force microscopy in ZDDP-containing lubricant base stock at elevated temperatures, we monitored the growth and properties of the tribofilms in situ in well-defined single-asperity sliding nanocontacts. Although some models rely on the presence of iron to catalyze tribofilm growth, the films grew regardless of the presence of iron on either the tip or substrate, highlighting the critical role of stress and thermal activation.



- Work by Penn Faculty Dr. Cherie Kagan and Dr. Christopher Murray opens the door for electrical components to be built into flexible or wearable applications, as the lower-temperature process is compatible with a wide array of materials and can be applied to larger areas. Nanocrystal-based field effect transistors were patterned onto flexible plastic backings. The researchers used nanocrystals with the appropriate electrical qualities necessary and dispersed them in a liquid, making nanocrystal inks.



- The Spanier group at Drexel University has been using the Singh Center to carry out photo- and electron beam lithography, RF sputtering and electron beam evaporation of metal, transparent conducting, and dielectric films to produce electrodes onto insulating oxide film and bulk materials. The devices and test structures fabricated are enabling the Spanier group to investigate fundamental nature of light/matter interactions in polar insulators, and the properties of tunable dielectrics, with applications in photovoltaic solar energy conversion and frequency-agile filters and antennas.

Education and Outreach Activities

Our *first annual research day* was held in October 2015 and was attended by approximately 120 participants, including current users as well as others in the community. This event allowed the current users of our facilities to showcase their work and to network with others, including the student and external business communities.

The *2016 Innovation Seed Grant Competition* was designed to encourage individuals and companies from all around the Mid-Atlantic Region to design or prototype a wide range of technologies from many different disciplines, but all utilizing nanotechnology related tools and equipment. The winners included five teams of students and research faculty that were new to the Singh user base.

The Singh Center hosted six REU students for a 10-week summer research program. The students worked on projects that used the Singh Center's Facilities. They participated in weekly brown bags and lecture series and completed assignments which led to final oral presentations and written papers based on their summer research.

The Singh Center plays a central role in the annual *NanoDay@Penn* exhibition. This event is part of a nano-focused week of activities each Fall. In 2016, 150 students from 8 area high schools came to Penn to participate in tours and demos. High school student winners of the Delaware Valley Science Fair were invited to Penn to present their award-winning projects.

MANTH staff members from the Singh Center continue to host monthly Microfluidic Workshops as a form of outreach to local university medical schools (Penn, Drexel, Temple, Jefferson and Cooper) targeting MD/PhD programs where students and researchers are likely to deploy lab-on-chip devices. Approximately 8 researchers enroll in a six-hour hands-on session.

Other outreach activities include MANTH participation in the Philadelphia Science Festival in April 2016 and Philly Materials Day in February 2016. In addition, the Singh Center hosted 7 field trips for the *League of United Latin American Citizen's National Educational Service Centers Upward Bound* program.

10.5. Midwest Nanotechnology Infrastructure Corridor (MINIC)

Facility, Tools, and Staff Updates

The Keller Hall cleanroom continues to be the workhorse facility for MINIC researchers fabricating micron-scale structures. The tool set was expanded to include a deposition system for graphene film growth for 2-D material research. The new cleanroom in the Physics-Nanotechnology (PAN) building is fully operational with a complete suite of tools necessary to support the nano-scale lithography from the Vistec e-beam lithography tool. The addition of two new tools in the PAN clean room greatly expanded our thin film deposition capabilities. The new Fiji plasma-enhanced atomic layer deposition (ALD) system from Ultratech was installed in spring 2016. This tool expands our ALD capabilities to nitride and metal films as well as lower temperature deposition of more traditional oxide films. The second tool is a chemical vapor deposition system with a high density plasma source. This load-locked tool expands our capabilities for depositing high quality thin films to temperatures under 100 ^{o}C, which is important for the growing soft materials/biomedical research community working with polymer-based materials and devices. The tool also can deposit doped and undoped diamond-like carbon (DLC), a new capability, as well as doped films of silicon dioxide. Staffing headcount for the cleanroom technical staff was reduced by one as Bryan Cord took an industry position. His role supporting the e-beam lithography tool was assumed by Kevin Roberts.

Focus Area Work: Focus area one, dealing with 2D materials has made progress on three components user infrastructure. A standard operating procedure (SOP) has been established for a CVD graphene system, and the first users have been trained on the system. A glove box for atmospheric-controlled exfoliation and assembly of 2D material heterostructures has been delivered, with acquisition of internal components (microscopes, stages, etc.) in progress. Finally, the design of a dual-chamber TMD growth system for epitaxial 2D heterostructures from PlanarTech has been completed and the system ordered. Focus area 2, Advanced Packaging has expanded collaborations with internal academic departments and local companies as a first step to grow the client user base. Services have been provided to users from six research groups and three companies. Effort is now being directed towards recruiting more external users to the Advanced Packaging lab in year 2 and beyond. Focus area 3, the Bio-Nano facility expanded capabilities and added tools. A custom electrophoresis system for DNA separation was installed in summer 2016. Tools and supplies for cell culture and preservation were added to the lab, and the lab's CO2 incubators were used to culture cells for the first time. Standard operating procedures were established for cell growth, decontamination, and processing bio-waste, and lab staff demonstrated the safety handling of biosafety level 2 organisms.

User Base

From October 1 2015 to September 30 2016, MINIC hosted a total of 383 users, of which 271 were internal (UMN or NDSU) users, and 112 (29.2%) were external users. Figure 1 shows our overall goal of adding about 100 external users over the next five years. As shown in the chart, we exceeded our goal for FY 2016 and are now running ahead of projections for expanding external usage.

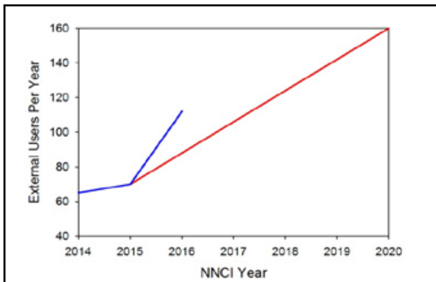


Fig. 1. MINIC external users. Red line show yearly targets; blue line is FY 2016 actual.

As shown in Fig. 2, slightly over half of our external users were from academic institutions, representing 24 large research universities (among them Johns Hopkins, Rutgers, and the Universities of California, Wisconsin, and Chicago) and five smaller institutions (including St. Catharine University and St. Olaf College in Minnesota and the Rose-Hulman Institute of Technology in Indiana). Users from industry comprised 47% of our external user base, with the majority of these users coming from small companies and start-ups. Fifteen users were from large companies (e.g., Boston Scientific, United Technologies, Honeywell, and St. Jude Medical), and a small number were from national laboratories. In year one, MINIC hosted projects from nine international universities and research centers.

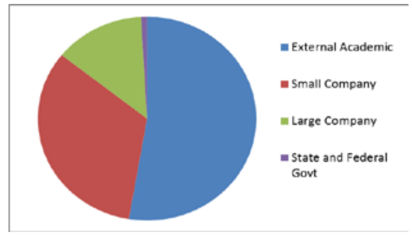


Fig. 2. MINIC external users by category, FY 2016.

Research Highlights

Dr. Val Marinov, CTO and Founder of Uniqarta Inc. Professor, Department of Industrial and Manufacturing Engineering, NDSU

Uniqarta develops manufacturing process technology to transform conventional semiconductor die or wafers into ultra-thin integrated circuits assembled on rigid or flexible substrates. We use the capabilities of the MINIC site at NDSU to support our development efforts and to accomplish the research objectives in several funded research projects currently underway. As a result, we have been able to demonstrate unique, industry-first capabilities for assembly of ultra-thin, flexible ICs on flexible and rigid substrates (Fig. 1) and to initiate collaborative development activities with major providers of microelectronic modules and components for customer electronics. We expect the technology to be implemented in the manufacture of such products as smartphones and wearable electronics.

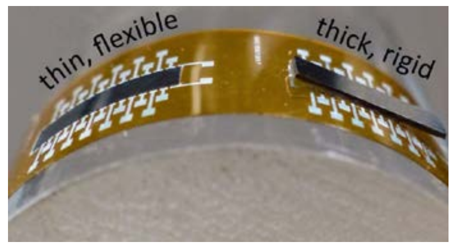


Fig 3 - Advantages of Ultra-Thin devices for flexible substrate applications

Professors Juliet Gopinath and Wounjhang Park, ECE, University of Colorado Boulder

Our group works on integrated, nonlinear optical devices. We have used the e-beam capability of the MINIC site at the University of Minnesota to write waveguides and micro-ring resonators (Fig. 2) for a chalcogenide materials system under study. We will be characterizing the structures shortly and are hoping to achieve frequency comb generation shortly. These elements will be important for providing a tunable mid-infrared source that can be used for sensing. The mid-infrared is called the 'chemical fingerprint' region as it contains many vibrational resonances of interest for chemical sensing.

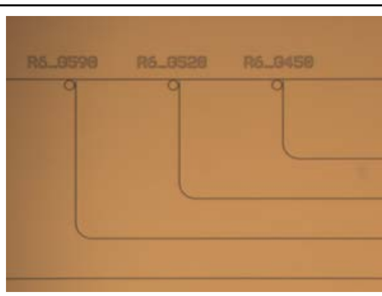


Fig. 4 - Microscope image of ring resonators patterned at MINIC.

Maryam Jalali and Jian Sheng, Department of Engineering Texas A&M University CC

We create the microcosm environment to address critical questions pertaining to marine ecology and microbial environments. Here, we use microfluidics and surface functionalization to recreate the real physical and chemical environment that microbes are subjected to. We termed our approach: ***Ecology-on-a-chip***. We have used MNC to develop Ecology-on-a-chip technology and to apply it to understand oil spills. We use microcosm experiments to discover degradation mechanisms and the role of dispersants on these processes. We have developed a micro-transfer-printing technique to print arrays of isolated stable pico-liter oil drops with well-controlled geometry and volume (Fig. 5a). We then quantify degradation by dissolution and evaporation compared to microbe processes in real time (Fig 5b). Our measurements challenge conventional wisdom on the subject. The MINIC cleanroom and Nao-Bio lab have been essential for performing all of the fabrication work and the biological experiments.

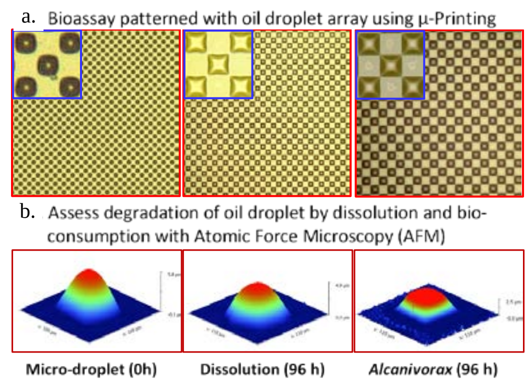


Fig. 5 Ecology-on-a-chip

Education and Outreach Activities

MINIC's educational efforts reached students from middle school to graduate levels. Our main mission is the training and support of graduate students from among about 20 academic departments served by the UMN's Nano Center and NDSU's Center for Nanoscale Science and Engineering. In the first year of NNCI, over 270 grad students were served. MINIC also provides the capstone semester for a two-year nanotechnology program based at a nearby technical college, reaching about ten undergrads last year. In October of 2105 MINIC also initiated an internship program with another local two year college, giving five undergrads hands-on experience with making and characterizing nanoparticles.

In year one, MINIC offered classes, camps, tours, and events to over 750 external students and teachers and to over 250 members of the public. These activities included

- Nanotechnology classes and cleanroom tours for middle and high school students
- Outreach to Minnesota secondary science teachers about our program offerings
- Classes and lab tours for science and engineering undergraduates from local colleges
- Summer STEM classes and a "STEM Bootcamp" experience for students grades 8 and up
- Nanoscience programs offered through the Science Museum of Minnesota
- Tours for high school students in the six-week North Dakota Governor's School
- A workshop on electronics packaging for North Dakota tribal college students

MINIC staff also presented to over 450 industry professionals about the research resources available at UMN and NDSU. This was done via technical talks at local companies, hosting onsite tours, and staffing booths at biomedical and electronics conferences.


Fig. 6. First MINIC Summer School on 2D Materials.

On June 6-7, MINIC hosted the "First Annual 2D Materials Summer School". The purpose was to teach graduate students new to 2D materials about this topic, both with lectures from top experts in the field as well as with hands-on experimental and theoretical demos. The lecture day featured prominent speakers from prestigious institutions such as Standard, Harvard and Illinois, while the experimental demos showed students how to transfer CVD graphene, exfoliate and align black phosphorus and measure and an actual 2D MOSFET. A group photo is shown below in Fig. 6.

10.6. Montana Nanotechnology Facility (MONT)

MONT Facilities include: Montana Microfabrication Facility (MMF), Imaging and Chemical Anaylsis Lab (ICAL), Center for Biofilm Engineering (CBE) and Mass Spectrometry, Metabolomics, Proteomics, Facility (MSMP); Partner site with the Science Education Resource Center at Carleton College

Facility, Tools and Staff Updates

During Year 1 we purchased and installed the following tools:

- PHI 710 nanoAuger. The PHI 710 is delivered and installed in ICAL, and staff training is complete. This is the first Auger nanoprobe available to users in the NNCI collective, as far as we know.
- EVG 610 Contact Mask Aligner (purchased from the Cornell facility). This tool has been delivered and hooked up. We are still working with EVG technicians to troubleshoot and bring online. We hope to add tooling for nanoimprint lithography and bond alignment.
- Filmetrics thin film measurement tool. This instrument is installed and in use. It provides spectral measurement of transparent thin films, replacing our Nanometrics instrument.

During Year 1 we hired the following staff members:

- Dr. Chung-Hsuan (Benjamin) Huang was hired as a lithography specialist to augment our technical staff in the MMF. Dr. Huang joins MMF after working as a research associate at the Vollmer Laboratory of Nanophotonics and Biosensing at Harvard Medical School.
- Dr. Manjula Nandasiri was hired as a staff scientist in ICAL. Dr. Nandasiri has experience in a user facility at Pacific Northwest National Lab. This is a 0.5 FTE position.
- Heather Rauser was hired to be our Program Manager and admin for the MONT Facility.

User Base

We worked with the CBE to reach out to the CBE Industrial Associates to promote nanotechnology as a tool in biofilm engineering. These companies pay membership fees annually to support CBE and gain access to biofilm-related expertise and technology (list at www.biofilm.montana.edu/industry/associates). All of these companies have interests in interactions of bacteria with surfaces and represent potential new MONT users. The entire membership was emailed with an overview of MONT resources and expertise in nanofabrication and nanotechnology. MONT then partnered with CBE to host a full-day workshop in July. This hands-on workshop was geared toward CBE members and prospective members; it combined a morning session covering biofilm reactor basics with an afternoon session highlighting MONT capabilities. Workshop attendees toured MONT's facilities in small groups, in addition to receiving classroom instruction. At the Montana Biofilm Meeting that followed the workshop, MONT director Dr. David Dickensheets made a plenary presentation to a larger group (approximately 80) of mostly industrial attendees about the MONT capabilities.

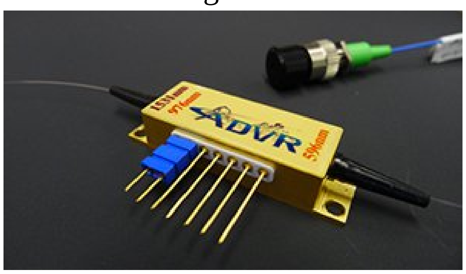
Other marketing and promotion activities included: an open campus seminar on MONT (Physics Colloquium, 4/1/2016); Freshman Research Seminar (10/1/2015) promoting opportunities for undergraduate research in nanotechnology; one webinar on MONT capabilities related to e-beam imaging/analysis; and a complete redesign of the MONT web portal, with links to our various facilities and information about user access, housing assistance, etc.

At the end of Year 1, **we count 125 unique users of MONT**, with an average addition of 3 new users trained each month and an average of 2.4 additional **external users** each month. A key metric for our site is the total number of external and non-traditional users in the facility. MONT **served 29 external users, who made up 23% of our total user base** and 41% of our user fee income. We treat the following categories as Nontraditional: Educational Lab Use, Geology/Earth Sciences, Life Sciences, Medicine, Optics, and Other Research. With that division **we count 62 of 125 users as "Nontraditional", making up 50% of our user base.**

Research Highlights

1. External industrial user AdvR., Inc. of Bozeman uses MONT to build laser wavelength converters

AdvR, Inc., of Bozeman, MT is a recognized leader in the engineering of nonlinear optical structures for a host of photonic devices and applications. AdvR uses the MONT facilities to fabricate waveguides in nonlinear optical materials such as KTP, LN, and Mg:LN. These

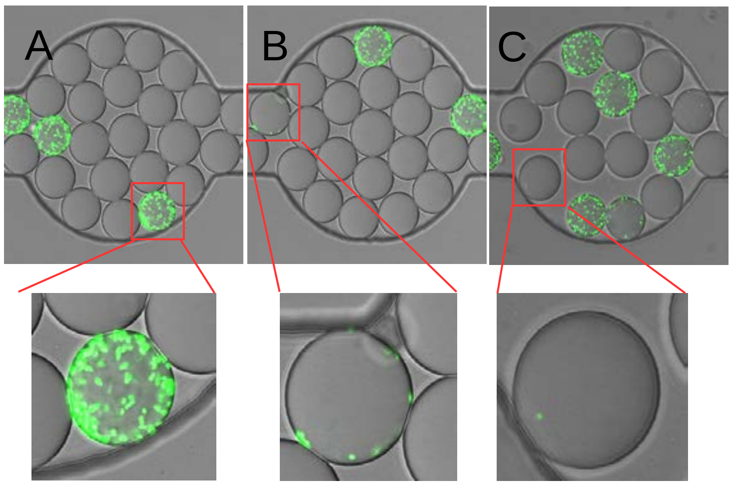


waveguides can be periodically poled in various configurations and used to generate second harmonic generation, sum frequency generation, downconversion, difference frequency generation, Bragg stabilization, and phase modulation. These waveguides have been used in various frequency conversion applications, spectrometers, lidar systems, and for research in quantum information science. The fabrication of these waveguides requires precise lithography, and very pure and durable masking layers. MMF has the PVD tools needed to create the high purity dielectric coatings that serve as a mask for high temperature diffusion, along side a lithography suite that allows for patterning at the 2um level. ICAL has the equipment available to analyze film composition and physical structure. Together these facilities allow for the continuing improvement and analysis of the processes involved in creating these waveguides.

AdvR has commercialized fully packaged devices including a fiber pigtailed frequency conversion module. These devices have been used to create planar lightwave circuits for seed laser control in high spectral resolution lidar systems, and other frequency conversion applications. AdvR also has various ongoing R&D efforts, including a joint DOE Phase II STTR with MIT to develop a multifunctional KTP waveguide that includes integrated wavelength division multiplexing and quasi phase matching sections for type II wavelength conversion. This device has the potential to be used for fiber-link timing synchronization measured in attoseconds, which is needed to meet next generation particle accelerator performance requirements. Most of the fabrication for these devices is accomplished at MONT. **Additionally, AdvR has been a long-time user of other NNIN and now NNCI facilities including Cornell, Santa Barbara, University of Washington and University of Utah. Access locally to MONT is critical to take full advantage of advanced capabilities at these other sites, and the personal relationships between MONT staff and staff at the other sites is a big part of making the "whole greater than the sum of the parts" for users like AdvR.**

2. MONT Users Perform "Droplet Engineering" to Study Single Bacteria Cells

MONT users garnered a competitively funded Montana State University Graduate Student Research grant based on research conducted at the MONT facility: *Resuscitation of dormant Pseudomonas aeruginosa requires hibernation promoting factor (PA4463) for ribosome preservation***,** by Tatsuya Akiyama, Kerry S. Williamson, Robert Schaefer, Connie B. Chang, and Michael J. Franklin. In this work, drop-based microfluidics were used to study the growth of bacterial cells at the single-cell level. The researchers are interested in understanding the role of dormant subpopulations of *P. aeruginosa* biofilms in chronic infections. They encapsulate single cells of *P. aeruginosa* into drops that are missing the HPF gene (hibernation promoting factor) and compare the growth of these cells compared to wild-type *P. aeruginosa*, in order to study the effect of HPF in ribosome preservation and cell integrity during starvation. The images below are drops containing bacteria that have been incubated in the drops for 24 hours after starvation in media containing no nutrient. The drops are 15 µm in diameter and have been injected into a modified "Dropspots" immobilization device[1], which allows viewing of a monolayer of drops immobilized in an array of round chambers. The drops are imaged using an inverted confocal microscope in the MONT facility. Drops with 1 cell can be distinguished from drops containing multiple cells. This method can be applied towards studying the growth of microbes that are unculturable using standard culture methods in the laboratory, or for the study of persister cells in biofilms that are not susceptible to antibiotics.



Examples of cell resuscitation of individual *P. aeruignosa* bacteria within 15 mm diameter oil microdroplets. Following growth to stationary phase in TSB medium, cells were starved for 0 to 5 days in PBS, then encapsulated in microdroplets containing TSB medium. Cells were encapsulated into droplets at ratio of 1:5 to 1:10. Cells were then incubated inside droplet for 24 hr at 37C. Bacteria expressed the green fluorescent protein from plasmid pMF230 for visualization by confocal scanning laser microscopy (CSLM). Shown are maximum projection images of CSLM fields, using a 40x objective lens. (A) *P. aeruginosa* PAO1 at day 0 of starvation, showing regrowth of cells and filling of the droplets. (B) *P. aeruginosa* PAO1 *Dhpf* at day 0 of starvation, showing a droplet with a slowly growing cell. (C) *P. aeruginosa* PAO1 *Dhpf* after 2 days

[1]Schmitz, C. H., Rowat, A. C., Köster, S., & Weitz, D. A. (2009). Dropspots: a picoliter array in a microfluidic device. Lab on a Chip, 9(1), 44-49.

Education and Outreach Activities

We have established our web portal, with links to our partner institution Carleton College who are now hosting tutorial materials. We offered our first topical webinar with 72 participants. Our summer course for Masters of Science in Science Education enrolled STEM teachers from Maryland, Pennsylvania, New Hampshire, Idaho, Nevada, Wisconsin, Colorado, Montana, and Bolivia. Other MSU courses served a total of 70 students who were trained to operate and use Facility instruments. K-12 outreach programs saw hundreds of students on campus to participate in NanoDays, Shadow an Engineer and other programs. **Other Outreach**: presented research opportunities in MONT to MSU's Honors College undergraduate scholars program; co-PI Phil Stewart gave a Provost's lecture about biofilm research that was promoted to the general public.

SEI Activities

New web-based instructional modules have been to be added to the current Teaching Geoethics Across the Geoscience Curriculum website (http://serc.carleton.edu/geoethics/index.html). Specific case studies related to the impacts of nanoparticles on society and the environment are in development and will be added to our collection of case studies. Our training short courses in the MONT facility explicitly address ethical issues related to the responsible conduct of research (e.g., integrity of data acquisition, reduction and representation; dealing with uncertainty in experimental and analytical results; lab safety; appropriate use and disposal of hazardous materials, etc.).

10.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

<u>Facility, Tools, and Staff Updates</u>

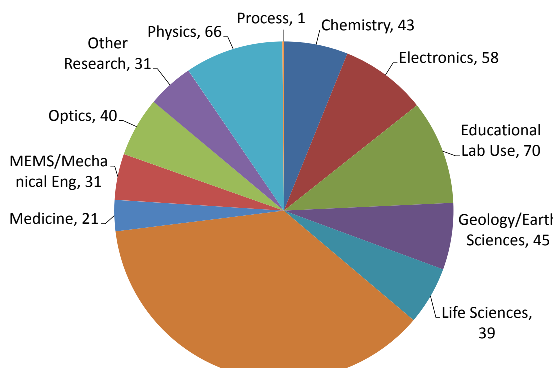
To capture the site activities under one umbrella we have built a new web site under the NCI-SW banner, www.ncisouthwest.org. The web site provides access to all of the NCI-SW activities including links to the six research centers, and descriptions of the educational and outreach programs, including REU and RET opportunities.

A desktop scanning electron microscope has been acquired and widely used for the education and outreach programs described below.

Two new staff members have been hired to support external users working with the Solar Power Lab (SPL) and the Peptide Array Core Facility (PACF). Both centers are offering their capabilities to external users for the first time as part of the NCI-SW. Three Ph.D. student NCI-SW 'super-users' have been recruited to assist external users.

<u>User Base</u>

Marketing of the NCI-SW is directed by Antony Evans of the Seidman Institute in the ASU WP Carey School of Business and by Mike Lesiecki of the Maricopa County Community College District (MCCCD). Activities include: an actively managed social media presence coordinated through an NCI-SW Facebook page and Twitter account; quarterly newsletters emailed to a distribution list of >5,000 contacts through a database maintained by our partners at MCCCD; regular webinar series that promote activities within the NCI-SW. An industry open house is scheduled for March 23rd, 2017 to recruit new users from the greater Phoenix area. During the first 12 months of operation the NCI-SW supported the work of 536 internal users and 169 users from outside ASU. The users spent >43,000 hours in the various NCI-SW laboratories and contributed $3.15M towards their operating costs.

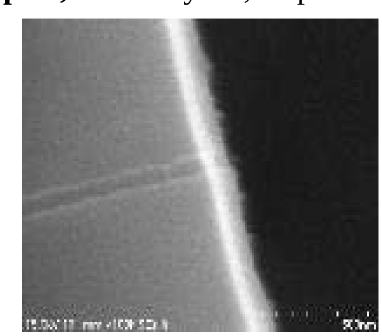


During year 1 the NCI-SW supported 705 cumulative users.

<u>Research Highlights</u>

"Development of a Nanofluidic Chip Representative of a Shale Sample", S. A. Aryana, Dept. of Petroleum Engineering, University of Wyoming

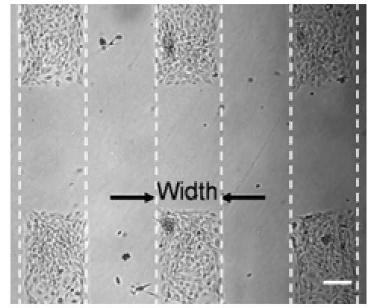
The goal of this study is to create a shale-mimicking fluidic model to understand fluid flow in rocks with a nanoscale pore structure. To that end, a shale sample is characterized and the data is converted into a two-dimensional representation, to be etched into a substrate while preserving its nanoscale features. The findings are used to create a quasi 2D representation of the sample with interconnected pore space. Electron beam lithography is used to pattern channels as small as 20nm in width, and 20-30 nm in depth. The channels are etched into a silicon wafer and bonded onto a blank wafer by anodic bonding. The resulting nanofluidic device is used to study gas slippage in nanoscale channels.



SEM image of etched 20 nm channel in silicon.

"Probing Endothelial Cell Migration by Plasma Lithography Geometric Confinement", Pak Kin Wong, Aerospace and Mechanical Engineering, University of Arizona

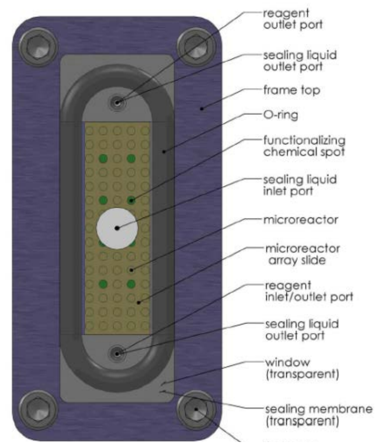
When blood vessels are injured, leader cells emerge in the endothelium to heal the wound and restore the vasculature integrity. The characteristics of leader cells during endothelial collective migration under diverse physiological conditions, however, are poorly understood. Here we investigate the regulation and function of endothelial leader cells by plasma lithography geometric confinement. By challenging the cells with converging, diverging and competing patterns, we show that the density of leader cells correlates with the size and coherence of the migrating clusters.



Cell migration in confined microenvironments.

"Microreactor Array Device", Peter Wiktor, Engineering Arts, Tempe, AZ

We have developed a device to fill an array of small chemical microreactors with reagent and then seal them using pressurized viscous liquid acting through a flexible membrane. The device enables multiple, independent chemical reactions involving free floating intermediate molecules without interference from neighboring reactions or external environments. The device is validated by protein expressed in-situ directly from DNA in a microarray of ~ 10,000 spots with no diffusion during three hours incubation. Using the device to probe for an autoantibody cancer biomarker in blood serum sample gave five times higher signal to background ratio compared to standard protein microarray expressed on a flat microscope slide.



Schematic of microreactor array fill & seal device.

Education and Outreach Activities

Twenty-four lab tours have been conducted since the NCI-SW project started in September 2015. The tours visited facilities within the LeRoy Eyring Center for Solid State Science (LE-CSSS), as well as the ASU NanoFab. Of the 24 tours, 15 were conducted for K-12 students, 2 were for community college students, and the remaining 7 were for students and faculty of 4-year schools and research universities. In total, about 740 students went on these tours.

A desktop scanning electron microscope has been set up to be remotely accessed and controlled over a web-based connection. This remote access (RA) feature was used in 6 events coordinated through MCCCD and Science Foundation Arizona. Users at the remote locations had hands-on experiences imaging various samples at the nano-scale. Three of the RA sessions were done with K-12 schools and introduced this capability to about 150 students. Another 2 sessions were public outreach events as described below, with an estimated exposure to about 700 event participants. One RA session was conducted with the faculty of a rural 2-year school (Arizona Western College), as a demonstration of an educational resource available for distance learning.

The NCI-SW took part in two major public outreach events, one on the ASU campus as part of "Night of the Open Door" and another for the City of Tempe's "Geeks' Night Out". The events were a collaboration between ASU and Rio Salado Community College and volunteers from both schools helped members of the public to control a remotely accessible scanning electron microscope to view a variety of micro- and nano-sized objects. Our assessment team counted more than 500 participants at the NCI-SW tables during the Night of the Open Door event.

As a platform for developing online teaching materials a virtual panoramic tour of the NanoFab has been produced. The tour will serve as a template to host classroom materials as well as training documentation and outreach programs. Two versions of the tour are available: one for virtual reality headsets such as Google Cardboard (http://vft.asu.edu/vftvr/nanofab/), and another for work stations/laptops/tablets (http://vft.asu.edu/VFTNanofab/panos/nanofab/cleanroom.html).

Attendees at the 2016 MRS Spring Meeting take a virtual reality tour of the ASU NanoFab.

SEI Activities

The NCI-SW SEI User Facility has been engaged in three major projects. First, we hosted 57 external users looking to gain a better understanding of a number of social science tools. The vast majority of the users in the first year participated in a series of four workshops that trained outside users on how to develop future scenarios. In October 2015 we hosted a program on the future of Health Monitoring and Pre-Symptomatic Medicine. In November 2015 we hosted a program on Future Scenarios of Wastewater Sensing Technology. In April 2016 we hosted one on the Air Capture Technology. And in August 2016 we hosted a workshop on Sensors and Humans in Networking Environments (SHINE).

Second, we launched the first "Science Outside the Lab" workshop in Washington, DC. We took 14 graduate student scientists and engineers from ASU and Georgia Tech on a whirlwind introduction to the variety of ways that nanoscience is used by the federal government, and the ways in which the federal government in turn influences nanoscience. Over the course of the week we met with 25 speakers from the EPA, NSF, NCO, AFL/CIO, MRS, State Department, and the US Court of Appeals for the Federal Circuit among others. We are currently evaluating the program, but the verbal feedback from the students, as well as the local policymakers involved, was very enthusiastic. We are working to get as broad a participation from the 16 NNCI sites as possible for the 2017 edition of the program.

Third, we have been working with the Coordinating Office to organize SEI efforts across the NNCI. Many of these efforts have been focused on running the Winter School on Responsible Innovation and Social Studies of Emerging Technologies, which will be held in January 2017.

Computation Activities

The NCI-SW computational nanoelectronics activity is coordinated by Dr. Dragica Vasileska, Professor of Electrical Engineering at ASU. Dr. Vasileska has been a long time contributor and user of NCN's nanoHUB. She is the nanoHUB's third largest contributor (see statistics on https://nanohub.org/members/9736/usage.). At ASU Dr. Vasileska regularly teaches the EEE533 Semiconductor Device & Process Simulation course, and is now converting it into a nanoHUB course. The goal is to prepare and voice 20-30 thirty minute lectures that will train students on the principles of semiconductor device modeling and process simulation. As examples she will use device modeling scripts that run Padre (the nanoHUB drift-diffusion simulator) and the commercial device modeling tools from Silvaco.

10.8. Nebraska Nanoscale Facility (NNF)

The *aim* of the Nebraska Nanoscale Facility (NNF) is to be an internationally recognized center of excellence for nanoscience, and a NNCI research hub for integrated fabrication, characterization and education in nanotechnology for the western region of the United States Midwest. NNF builds upon the established Central Facilities of the Nebraska Center for Materials and Nanoscience (NCMN) to promote nanoscience and nanotechnology research and educational outreach activities in Nebraska and throughout the region. NNF provides open and affordable access to state-of-the-art facilities, expertise, training and services in nanoscience, nanotechnology, materials science and engineering to users from academia, industries and government labs. The Central and Shared Laboratory Facilities associated with NNF include: Nanofabrication Cleanroom, Nanomaterials and Thin-Film Preparation, Nanoengineered Materials and Structures, Electron Microscopy, X-ray Structural Characterization, Scanning Probe and Materials Characterization, Low-Dimensional Nanostructure Synthesis, and Laser Nanofabrication and Characterization.

General *goals* of NNF are to: (a) assist NNCI in strengthening the quality and quantity of research and applications of nanoscience, nanotechnology and materials in the United States, (b) engage new university and industry users in our region in fabrication and characterization of nanoscale materials and structures, (c) provide critical assistance to companies and start-ups in order to benefit commercialization of nanotechnology, and (d) stimulate more students, including under-represented groups, to enter engineering and science careers.

Facility, Tools, and Staff Updates

The enhancement of our NNF facilities has proceeded in the last year through funds received from the University of Nebraska, U.S. Army Research Office and NSF-NNCI. Following is a list of major acquisitions.

- In the Nanomaterials and Thin-Films Facility a Hex Deposition System from Mantis Deposition, LTD, and an ASAP2460 Surface Area and Porosity Measurement System from Micromeritics Instrument Corp. were installed. A Quantum Design Squid magnetometer MPMS-XL was donated to the Facility by the University of Nebraska at Omaha and an Evercool I closed-cycle refrigerator was purchased for the system.
- In the X-Ray Structural Characterization Facility, the detector on the Bruker Smart Apex Single Crystal Diffractometer was upgraded to the latest model, the Photon 100, which is based on CMOS technology.
- The Nanofabrication Cleanroom Facility purchased a Kulicke & Soffa iBond 5000-Dual wire bonding system, an Intlvac Nanoquest I-UHV Ion Beam Etching System, and a Class One Equipment silicon wafer-cleaning system.
- The Electron Nanoscopy Instrumentation Facility purchased a 3032 Diamond Wire Saw from Well Diamond Wire Saws, Inc. and upgraded the JEOL JEM 2010 TEM with a high-definition streaming video suit software from Gatan, Inc. A Bruker Quantax Micro-XRF high-performance micro-spot x-ray source for our FEI SEM has been purchased.
- The Nanoengineering Facility purchased a FEI Helios NanoLab 660 system, a Keyence Laser Scanning VK-X200K Microscope, an Anasys nanoIR2-sTM system, an ATC

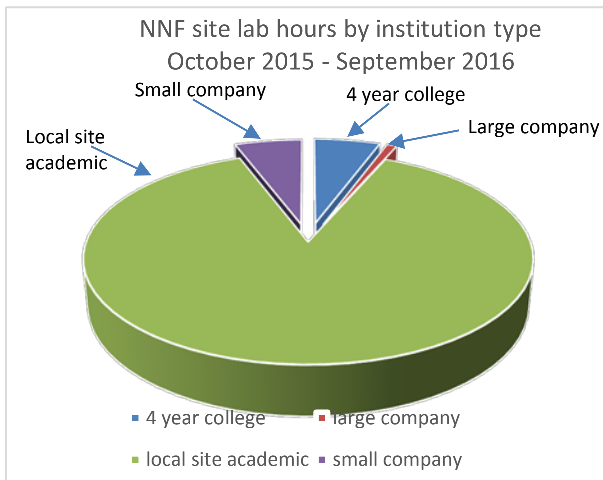
Series AJA Sputtering system, and an Optomec Laser Engineered Net Shaping (LENS) 3D Metal printer. A cell culture laboratory was added to the Facility.

- The Surface and Materials Characterization Facility purchased a High Magnetic Field (4.5T) annealing system.

Total User Hours:	23,446
Cumulative Users:	314
External Users:	17
Industry Users:	8
External Academic Users:	9
Average Monthly Users:	529
External Facility Hours:	322

Ongoing staff members supported by the University of Nebraska include: Administrative Coordinator (Shelli Krupicka), Administrative Technician (Jaimie Iuranich), Business Manager (Patricia Fleek), Accounting Technician (Karen Gildea), Nanofabrication Cleanroom Specialist (Jiong Hua), Nanomaterials and Thin-Films Specialist (Stephen Michalski), Nanoengineering Specialist (Wen Qian), X-Ray Structures Specialist (Shah Valloppilly), Surface and Materials Characterization Specialist (Lanping Yue), Electron Nanoscopy Specialist (Jim Li).

Staff members supported wholly or in part by NNF include: Education-Outreach Coordinator (Terese Janovec), Coordinator-User Contact (Jacob John), Research Technologists (Andrei Sokolov, Anand Sarella), Engineering Associate (Zach Sun).



User Base

External Users Base Expansion: The expansion to outside users from academia and industry will rely in large part on newly hired, NNF-supported technical staff. Our present Education-Outreach Coordinator, new NNF staff, and six Central Facility Specialists have been promoting our user-base expansion in ways described below.

Annual Academic and Industry User Workshop: Our first Workshop, held on March 22, 2016, was a successful event with 65 attendees, mostly from regional industry.

Nanotech Minicourses: The first set of these Minicourses was held during June 21-23, 2016. The attendance was 38, a number that was limited to enable each researcher to have both lecture and hands-on experience by our Facility Specialists. We also have created Facility Training Videos for several of our instruments. These will be useful for both internal and external first-time users.

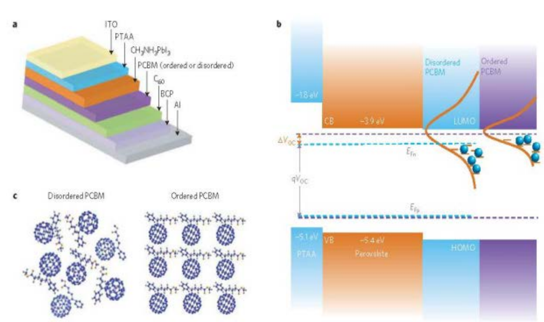


Fig. 1. Device structure and mechanism to enhance voltage by reducing energy disorder.

Outreach to New Regional Users: This activity is being ramped up and is led by our new Coordinator and User Contact. We plan for the Coordinator to visit 2-4 companies and universities per month, along with a faculty member and/or Research Technologist. Discussions with potential users about capabilities and procedures will help to generate new users.

<u>Research Highlights</u>

- ***Nature Energy:*** Studies were performed in NNF of the correlation of energy disorder and open-circuit voltage in hybrid perovskite solar cells. The Huang group showed that a decrease in disorder in the fullerene electron transport layer provides an increase in voltage and understanding that may lead to a further increase in efficiency (Fig. 1).
- ***Nano Letters:*** Synthesis and size-induced ferromagnetism was discovered by the Sellmyer group in Mn_5Si_3 nanoparticles. Low-temperature antiferromagnetism in the bulk was converted into high-temperature ferromagnetism (T_c = 590 K) by low-dimensional and quantum-confinement effects, evident from first-principle density-functional theory calculations. Several facilities in NNF were used to fabricate and characterize the nanomagnets (Fig. 2).

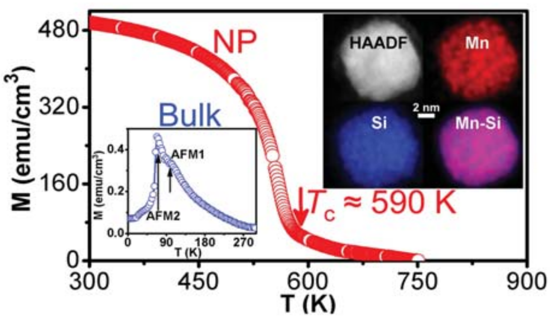


Fig. 2. M(T) in bulk and nanoparticle (NP) Mn_5Si_3, and TEM (inset).

- ***Nature Communications:*** The group of Liou, in collaboration with researchers from Fudan and Hefei, China, used NNF to demonstrate in perovskite manganites that edge states exists in strongly correlated oxides. Besides providing a new understanding of the broken symmetry effect, the discoveries indicate that novel edge-state physics exists beyond the current two-dimensional electronic systems (Fig. 3).

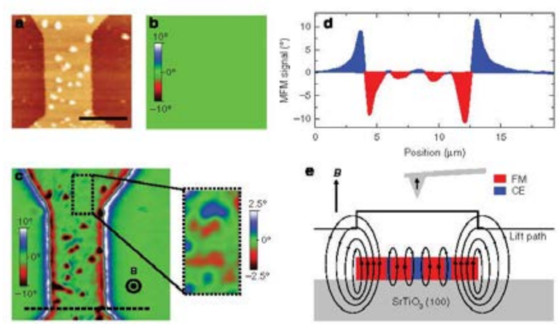


Fig. 3. The geometry and magnetic structures of manganite strip on $SrTiO_3$ (100).

External User Research Highlight

- ***Acta Biomateriala:*** The Gendelman group at UNMC, Omaha used NNF to demonstrate the use of europium (Eu^{3+}) doped cobalt ferrite (Si-CFEu) nanoparticles as a bioimaging probe. The group showed that the decoration of the Si-CFEu particles with folic acid increased its sensitivity and specificity for magnetic resonance imaging over a more conventional ultrasmall superparamagnetic iron oxide particles (Fig. 4.) The future use of these particles in theranostic tests will serve as a platform for designing improved drug delivery strategies to combat inflammatory and infectious diseases.

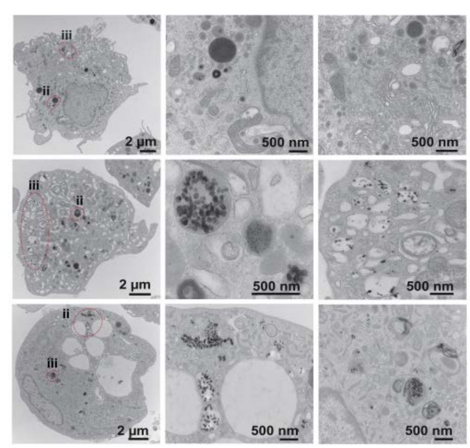


Fig. 4. TEM images showing the nanoparticles entrapped in endosome vesicles of macrophages.

<u>Education and Outreach Activities</u>

Conference for Undergraduate Women in Physical Sciences, WoPhy: NNF partnered with NCMN and the Department of Physics and Astronomy, along with other sponsors, to bring together 124 outstanding student researchers from across the US in Physics for the annual WoPHY Conference in October.

Traveling Nanoscience Exhibit - 25,000 Attended: NNF sponsored a "Nano" exhibition in four museums across Nebraska. This exhibition targeted children and families of underserved populations including both rural populations and the growing number of ethnic minorities in those communities.

Upward Bound Program: Diverse high school students - 4 day summer camp.
NNF partnered with the Upward Bound program to bring a summer NanoPhysics camp to 10th & 11th grade students from Lincoln high schools. The camp included tours of nano related research in NCMN facilities and hands on activities about the ever growing area of Nanoelectronics.

After School Program: NNF Faculty members, students and staff provided regular programming during the school year for a Nanoscience After School Program to middle school students who had limited knowledge of nanoscience. Information included videos, hands-on activities, and discussions of nano applications which provided a broad overview of nanotechnology as a field with many career opportunities.

University of Nebraska's College Prep Academy Program Nano Experience: First generation high school students – 2 day summer camps - 45 students attended. 10th-grade students from Grand Island and Omaha high schools participated in a Nanoscience Camp. Part of the camp included tours of nano-related research and facility tours of NNF.

NanoDays - April 2, 2016: Annual nationwide celebration of nanoscale science at local shopping mall - 400 attended. NNF, NCMN, and the University of Nebraska–Lincoln's Materials Research Science and Engineering Center (MRSEC) held Lincoln's annual NanoDays event at Gateway Shopping Center. NanoDays is a nationwide festival of educational programs about nanoscale science and engineering and its potential impact on the future.

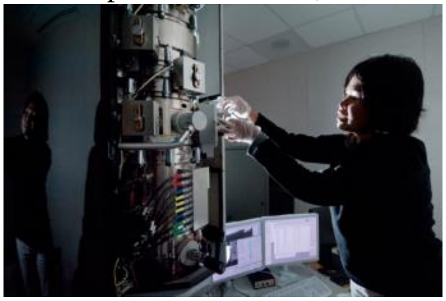
Industry/Academic Workshop - 65 business reps and university faculty attended: This workshop included tours and activities taught by NNF faculty, postdocs, and specialists to increase the understanding, knowledge and actual experience with resources available at NNF for future users from industry, universities, and government entities.

REU Program – (June 6 – August 10) 2 undergraduate students: NNF, NCMN, and UNL's Graduate Studies Office hosted this summer a Research Experience for Undergraduates (REU) focused on Nanoscience areas. Selected students spent 8-10 weeks in research labs under faculty supervision and participated in a variety of other activities.

10.9. NNCI Site @ Stanford (nano@stanford)

Facility, Tools, and Staff Updates

Stanford's facilities offer a comprehensive array of advanced nanofabrication and nanocharacterization tools, including resources that are not routinely available at shared nanofacilities, such as an MOCVD laboratory that can deposit films of GaAs or GaN; a JEOL e-beam lithography tool that can inscribe sub-10-nm features over 8-inch wafers; a Cameca NanoSIMS that combines the high mass resolution, isotopic identification, and sub-ppm sensitivity of conventional SIMS with 50-nm spatial resolution; and a unique scanning SQUID microscope with world-leading spin sensitivity. The facilities occupy ~30,000 sqft of space including 16,000 sqft of cleanrooms, 6,000 sqft of which meet stringent specifications on the control of vibration, acoustics, light, cleanliness, and electromagnetic interference.



The following briefly describes some of the new capabilities added to the NNCI Site @ Stanford during this reporting period.

The newly launched ***Experimental Fab*** (ExFab) provides the tool set and the know-how for integrating a wide range of materials, from organic molecules and nanostructures, to polymer and metal thin-films, to semiconductors, including the integration of electronic and optoelectronic chips with other materials. The ***ZEISS Xradia 520 Versa x-ray microscope*** allows researchers to get a nondestructive view of the inside of a sample. An x-ray microscope uses x-ray radiation to produce magnified images of the objects under investigation. A second ***X-ray Photoelectron Spectroscopy*** (XPS) system was installed recently. XPS provides elemental and chemical information about the surface region (first 1- 30 monolayers) of nearly any solid material. XPS is useful for determining the elemental composition on the surface of all non-volatile materials semi quantitatively. The PHI VersaProbe 3 XPS offers improved sensitivity over the VersaProbe 1 through greater signal collection for elemental surface composition measurements and high-resolution binding energy chemical shift measurements of solid samples under high vacuum.

Two new staff members joined the NNCI Site @ Stanford. ***Dr. Shiva Bhaskaran*** moved from the University of Chicago to support a growing external user base. ***Dr. Angel Hwang*** moved from Iridiscent, an educational start-up, to lead the education and outreach programs.

User Base

Between October 2015 and September 2016, SNSF and SNF served a total of 1142 users: 952 internal users, 154 industrial users, and 36 external academic users. Figure 1 shows the cumulative number of unique users who have

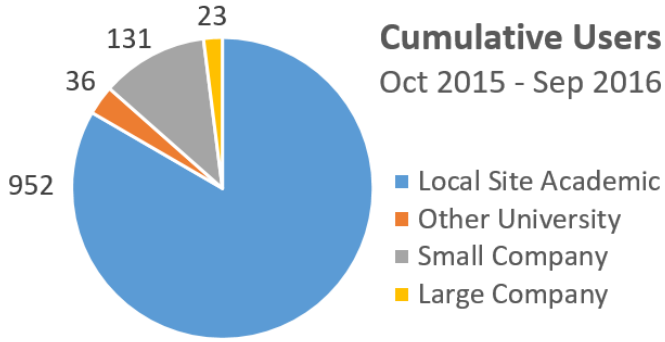


Figure 1 Cumulative number of unique users at the NNCI Site @ Stanford from October 2015 through September 2016 grouped by affiliation.

been billed for usage at the NNCI Site @ Stanford. Billed user fees during this time accumulated to about $4.5M of which about $1.9M was collected from external users.

Research Highlights

Graphene: a key material high-density, energy-efficient memory: Phase-change memory (PCM) is an important class of data storage, yet lowering the programming current of individual devices is known to be a significant challenge. A team of researchers from the groups of ***Professors K. Goodson, E. Pop and H.S.P. Wong*** showed an improvement of the energy-efficiency of PCM by placing a graphene layer at the interface between the phase-change material, $Ge_2Sb_2Te_5$ (GST), and the bottom electrode (W) heater.

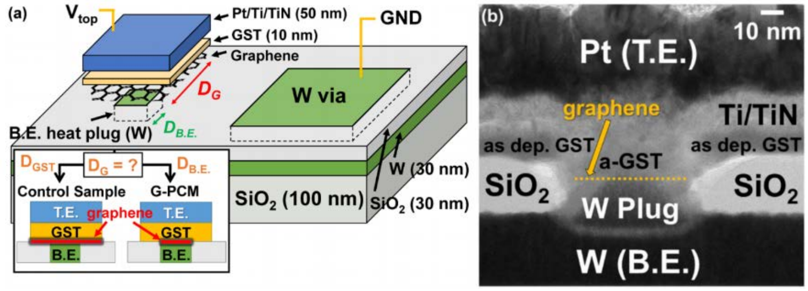


Figure 2 Schematic representation of the G-PCM device fabricated in this work. The top electrode voltage (Vtop) is applied to the Pt/Ti top electrode, and the larger area W via, which connects the smaller e-beam patterned heat plug through the bottom electrode underneath, is electrically grounded. (b) Cross-sectional HR-TEM image of the G-PCM device in the high-resistance state (HRS) with typical resistances of a few MΩ's and the effective contact size.

DOI: 10.1021/acs.nanolett.5b02661

Integrated photonic devices: Integrated photonic devices are poised to play a key role in a wide variety of applications, ranging from optical interconnects and sensors to quantum computing. However, only a small library of semi-analytically designed devices is currently known. A team of researchers from ***Professor Jelena Vuckovic***'s group demonstrated the use of an inverse design method that explores the full design space of fabricable devices and allowed them to design devices with previously unattainable functionality, higher performance and robustness, and smaller footprints than conventional devices. They designed a silicon wavelength demultiplexer that splits 1,300 nm and 1,550 nm light from an input waveguide into two output waveguides

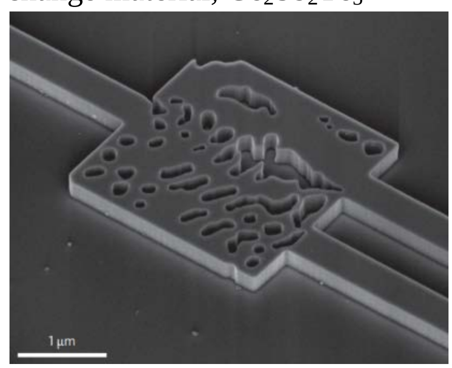


Figure 3 SEM image of the fabricated wavelength demultiplexer. The device was fabricated by fully etching the 220-nm-thick device layer of an SOI substrate, leaving the structure with an air cladding. The angled view clearly shows the vertical sidewalls.

DOI:
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Rigetti Computing - On a mission to build the world's most powerful computer: ***Rigetti Computing*** is developing a scalable quantum computing platform based on superconducting microwave circuits. One of the critical components of these circuits is

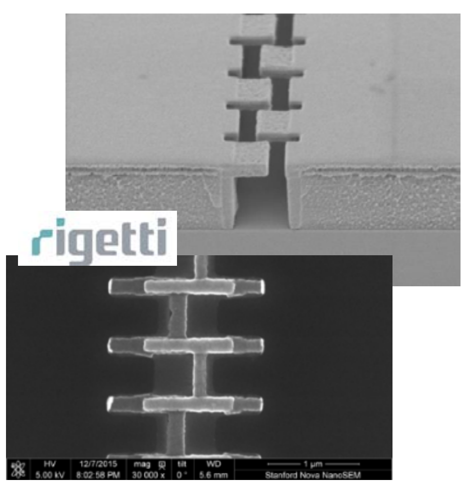


Figure 4 Two-layer electron-beam resist, with controlled undercut fabricated by a 100 kV electron beam. Bottom: Resulting aluminum structures after double-angle evaporation and liftoff. The bright horizontal bars, where the two layers overlap (with an oxide layer in between), form Josephson junctions. The vertical bars alternate between the two metal layers, so that supercurrents flowing through the array pass through the junctions in series. Images courtesy of Dr. A Bestwick, Rigetti Computing

precisely tuned nanoscale Josephson junctions, comprised of aluminum electrodes separated by a thin insulating barrier. At Stanford, Rigetti has been researching Josephson junction design and fabrication techniques. Using the JEOL 6300-FS electron-beam lithography system, two-layer resists are selectively exposed to engineer undercuts, allowing for double-angle evaporation of aluminum separated by an oxidation step. This produces arrays of Josephson junctions that form the basis for highly coherent quantum information systems.

<u>Education and Outreach Activities</u>

The shared facilities participating in the NNCI Site @ Stanford support Stanford's educational mission by exposing students to industrial perspectives, facilitating joint research with external users, and helping students build networks. We seek to achieve five overarching goals for education: 1) Lower the barriers to nanofacilities for new and non-traditional users by creating new curricula. 2) Create a just-in-time library of educational materials that will help users acquire foundational information independently and expeditiously before they seek personalized help from experts. 3) Conduct educational outreach to pre-college students. 4) Broaden participation at all levels of the NNCI site. 5) Support and encourage entrepreneurship and commercialization.

The NNCI Site @ Stanford has undertaken to provide extensive nanofabrication and nanocharacterization information to its users and the larger nano-community. This information will be distributed through the web featuring a variety of content. We have already begun to develop and test individual modules containing a series of components.

The NNCI Site @ Stanford started the proposed collaboration with selected partner institutions in order to provide them with materials and access to our facilities. A group of students from our partner institution at ***Cal State, East Bay (CSEB)*** visited the NNCI Site @ Stanford. CSEB does not have fabrication and characterization capabilities available at their location and the visit enabled the group to experience these capabilities in person. We hosted a variety of groups for ***walk-through tours*** as well as provided ***hands-on experience*** with the instruments available at the NNCI Site. Depending on the visitor group, we vary the content, duration and hands-on experience to give each group an insight into our tools and capabilities as well as pique their interest in the nanoscale science and engineering. Several ***workshops*** were hosted at Stanford to expose internal and external researchers to new capabilities available at Stanford. Many of these workshops were hosted in collaboration with industry partners ***(Gatan, Park Systems, Molecular Vista, KJ Lesker, KLA Tencor, Silicon Materials, SIMTech, Applied Materials and Sensofar).***

Figure 5 ***Left***: *Dr. Tobi Beetz gives a presentation with hands-on activities a girls High School.* ***Middle***: *Visitors to the Bay Area Science Festival at AT&T park engage with NNCI students in nanotechnology hands-on activities.* ***Right***: *Staff member Dr. Juliet Jamtgaard demonstrates to a group of middle school students how the FEI Helios FIB/SEM is being used to fabricate an characterize materials at the nanoscale.*

Computation Activities

Stanford researchers have created software to model and simulate piezoresistive and piezoelectric sensors, heterogeneous catalytic reactions, photonic structures, metallic single-wall carbon nanotubes, carbon nanotube transistors, graphene transistors, 2D field-effect transistors, and resistive random access memories.

10.10. Northwest Nanotechnology Infrastructure (NNI)

Facility, Tools, and Staff Updates

Nanotechnology infrastructure at the University of Washington is growing with two major ongoing projects. The new $65 million Nano Engineering & Sciences (NanoES) building is set to open in September 2017. It will provide approximately 43,000 assignable square feet (sf) of flexible research space and 8,300 assignable sf of learning space. The ground floor will accommodate vibration-sensitive instrumentation and connect with the NNCI Molecular Analysis Facility in the adjacent Molecular Engineering & Sciences (MolES) building.

In Fluke Hall, a $37.5 million phased renovation and expansion of the Washington Nanofabrication Facility (WNF) has started in spring of 2016. This expansion will produce 15,000 sf of ISO Class 5, 6, and 7 spaces for fabrication. Phasing the project allows the site to remain operational throughout the construction with minimal interruptions to users. As of February 2017, renovation is in Phase 2, and the project will be completed in summer 2017.

New lab capabilities include the development of chemical vapor deposition (CVD) of tantalum nitride (TaN) and copper as well as electrochemical deposition (plating) for high aspect ratio through silicon vias (TSVs). In addition, new precision (< 1 μm) wafer thinning and chemical mechanical polishing (CMP) processes have been established.

The Molecular Analysis Facility (MAF) complements the WNF cleanroom with resources for microscopy, spectroscopy and surface science. The build-out of two more MAF lab spaces in the MolES building is now complete. One area houses the profilometer and AFM systems including a Cypher AFM system. The other lab area houses the X-ray Absorption Near Edge Spectroscopy (XANES) system that is now operational and available for use through the MAF, as well as the new J105 imaging ToF-SIMS system that is currently being commissioned. An agreement has been reached for a liquid TEM holder to be loaned to the MAF from Hummingbird Scientific, (who does their device fabrication at WNF) and it is now available to MAF users. MAF staff have written two successful NNCI-specific, UW-internal proposals leveraging student technology fees (STF): (1) $19,556 for data analysis stations (4 new computers) for the MAF; and (2) a shared proposal with the Materials Science Department for an upgrade of XRD software (JADE analysis software and ICDD database) for $37,884.

User Base

The Northwest sites continued to see steady growth, with the University of Washington logging 21,151 user hours during the 2015-2016 academic year (10,720 UW; 9,863 industrial; 568 outside academic), with 438 unique users (314 UW, 97 industrial, 27 outside academic) generating user revenue of $2.37 million ($600k UW; $1.7M industrial, $73k other academic). Monthly user counts and account types are shown in Figure 1 with the diversity breakdown by subject area shown in Figure 2. During this period 85 new users were trained at UW.

Research Highlights

Our site is emphasizing three focus areas, which are aligned with major research efforts at UW and OSU: Integrated Photonics, Advanced Energy Materials and Devices, and Bio-nano Interfaces and Systems. Due to limited space, here we highlight only one project in Integrated Photonics:

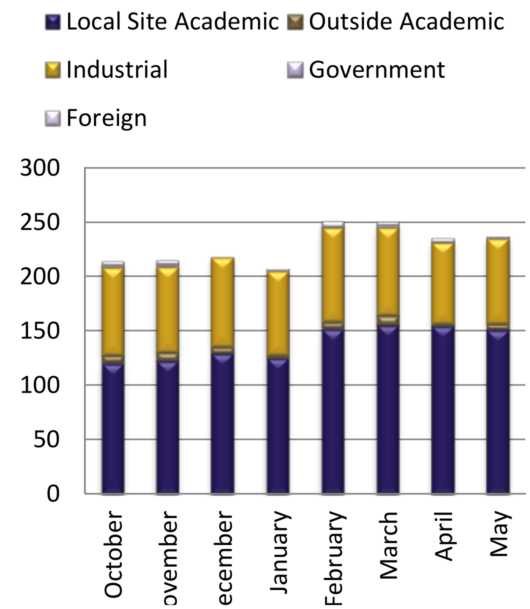


Figure 1: WNF user breakdown by month 2015-2016

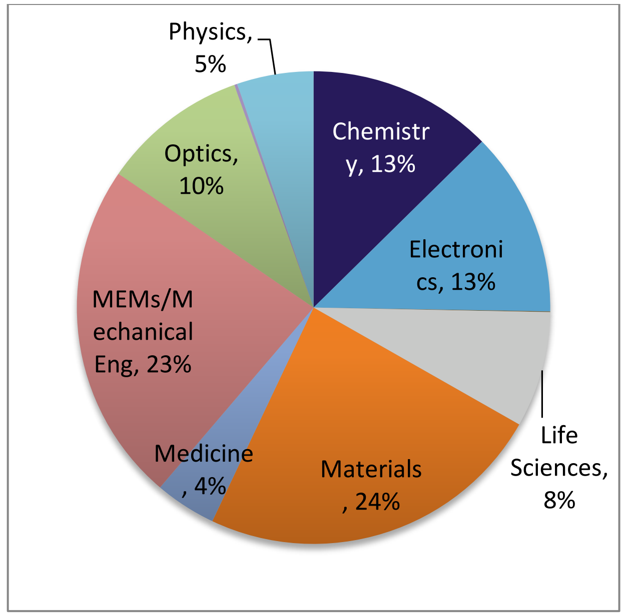


Figure 2: WNF user demographics by discipline

Prof. Kai-Mei Fu (Physics/Electrical Engineering, UW) is the area lead for Integrated Photonics. Her graduate student Michael Gould has developed a gallium-phosphide (GaP)-on-diamond integrated photonics platform for quantum information processing with single atomic defects in diamond. Large numbers (hundreds) of devices were fabricated on a single chip, and Prof. Fu's automated testing capabilities allowed for statistical analysis of device performance. Several key components of an eventual complete integrated system have been demonstrated, including disk resonators, directional couplers, and off-chip couplers (see Figure 3). Michael Gould and his co-workers have also demonstrated optical coupling of disk resonators to single atomic defects in 10 individual devices. For all of these devices, the photon collection efficiency (at the wavelength used for quantum information) was higher than what is theoretically possible using only free-space optics. Notably, the demonstrated efficiencies represent a shift to a regime wherein many-defect quantum networks are possible. Free-space optics systems are limited to 2-defect networks.

Publications and conference presentations:

- M. Gould, E. Schmidgall, S. Dadgostar, F. Hatami and K.-M. C. Fu, "Efficient extraction of zero- phonon-line photons from single nitrogen-vacancy centers in an integrated GaP-on-diamond platform," arXiv:1606.01826 (2016).
- "Efficient coupling of single nitrogen-vacancy center photons to a GaP-on-diamond integrated optics platform," CLEO:2016.
- "Enhanced emission of zero-phonon line photons from a single nitrogen-vacancy center in diamond," 18th Annual SQuInT Workshop (2016).
- M. Gould, S. Chakravarthi, I. R. Christen, N. Thomas, S. Dadgostar, Y. Song, M. L. Lee, F. Hatami and K.-M. C. Fu, "Large-scale GaP-on-diamond integrated photonics platform for NV center-based quantum information," J. Opt. Soc. Am. B 33(3), B35-B42 (2016).

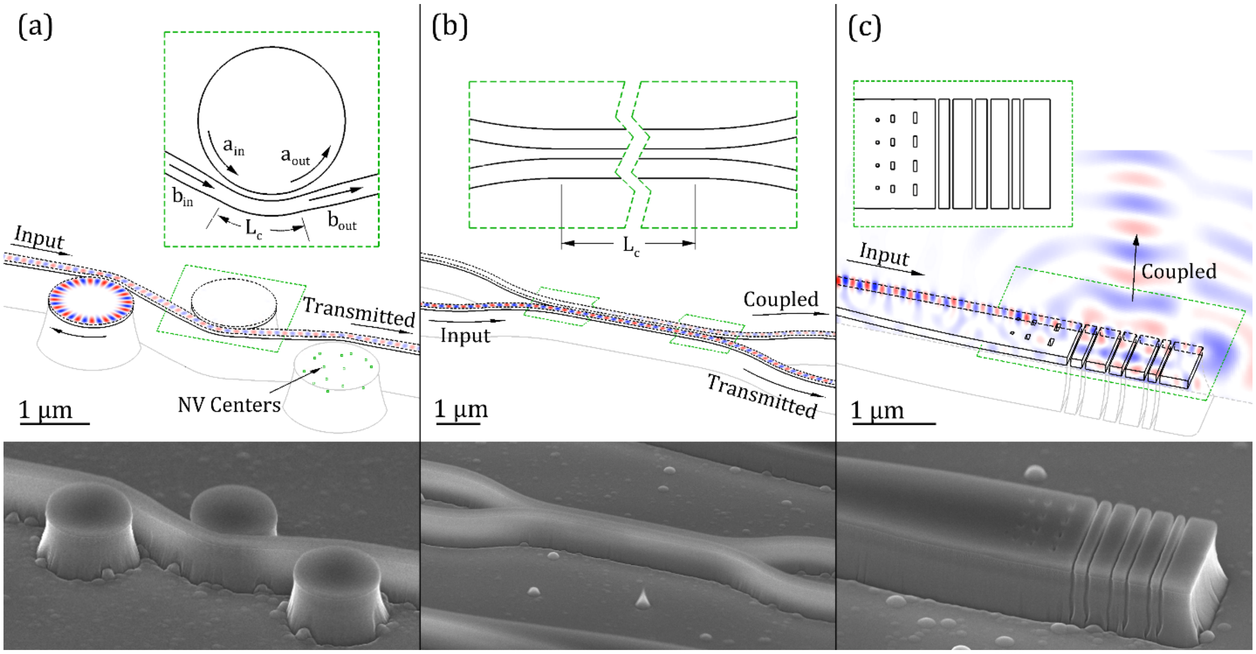


Figure 3: Schematic diagrams with simulated fields, and scanning electron micrographs of (a) disk resonators; (b) a directional coupler; (c) an off-chip coupler.

Education and Outreach Activities

The NSF NNCI Northwest Nanotechnology Infrastructure Site has developed a comprehensive portfolio of educational and outreach activities with the goal of impacting K through gray audiences throughout the Pacific Northwest Region, with a particular emphasis on K-12 outreach, nanotechnology educational material development through educators-in-residence, workforce development, and partnership with Regional and National First Nation Tribes to recruit students to our respective programs at UW and OSU.

(1) Workforce Development — In the first year of the NNCI program, 27 paid internships for undergraduates were created within NNCI-supported facilities. Community college students and 4-year undergraduates engaged in real-world exposure to cutting-edge nanotechnology solutions through participation in NNCI-NNI cleanroom labs that provided hands-on nanofabrication and characterization experiences, including professional skills development in project management, fabrication techniques, instrument operation and maintenance, and interdisciplinary working teams with members from government, industry, academy, and international partners.

Our 27-student internship program drew from a diverse group, including 10 women, 4 URM/EOP, and students from 6 majors (Biology, Geology, Mechanical Engineering, Materials Science, Chemical Engineering, Aeronautical Engineering, and pre-majors). We were particularly excited by our growing engagement with students from UW's Office of Minority Affairs and Diversity's Educational Opportunity Program (EOP), which supports under-represented ethnic minority, economically disadvantaged, and first-generation college students within the university.

(2) Pre-college Outreach — Our NNCI site has been active in both local and regional STEM K-12 and community STEM outreach events. In addition to a variety of local K-12 school

outreach events, typically attended by 25-50 students and parents, NNCI Northwest staff and faculty presented at a regional STEM career fair hosted by Sammamish High School, where over 400 high school students and their parents were in attendance. Larger regional events included UW's Engineering Discovery Days (April 21-22, 2016), attended by over 8,000 students and 2,300 chaperones, and the regional Pacific Northwest Science Center Paws on Science Days with 5,283 student attendees. At these events, NNCI site staff and faculty presented both hands-on nanofabrication demos and engaging research highlights, in addition to participating in moderated panel sessions encouraging students to pursue their studies within STEM disciplines.

(3) First Nations Engagement — NNCI support has enabled us to hire Ms. Laurel James (member of the Yakama Nation) to serve part-time as a program manager and liaison with the American Indian Science and Engineering Society (AISES). We presented a booth at their national conference, interacting with over 100 participants as we work towards building relationships to recruit students to future REU programs, recruit possible graduate school applicants to NNCI Northwest faculty laboratories, as well as identify candidates for our existing cleanroom internship program.

(4) Educators-in-Residence — NNCI Northwest is establishing an exciting new program to bring regional K-12 educators into UW laboratories and the cleanroom to develop curricular and co-curricular materials on nanotechnology education to bring back to their classrooms and to disseminate to their peers. To establish this program, we are building partnerships with local school districts, including the Seattle Public School District, the Bellevue Public School District, the Shoreline Public School District, and other Puget Sound school districts. Priority is being given initially to teachers at schools that serve a high percentage of students that qualify for free and reduced lunch. Prof. Ratner is working with teaching faculty within these districts to establish a working group to define program goals, milestones, measurable outcomes, a plan for sustainability, and pilot the first cohort of EIRs on the UW campus in the coming academic year.

Computation Activities

Expertise at the UW in Data Science supports the development and use of new algorithms for machine learning and data mining that might help discover new materials for clean energy and other nanotechnology applications.

Co-PI Jim Pfaendtner, lead for computational activities at the NNCI UW site, studies applications of Data Science in Chemical Engineering. He and his coworkers published a review article, "Data Science: Accelerating Innovation and Discovery in Chemical Engineering" (DOI: 10.1002/aic.15192). Featured on the May 2016 journal cover of the American Institute for Chemical Engineers, this article discusses the many ways that the emerging field of Data Science is making an impact on science and engineering research related to molecules and materials modeling and design.

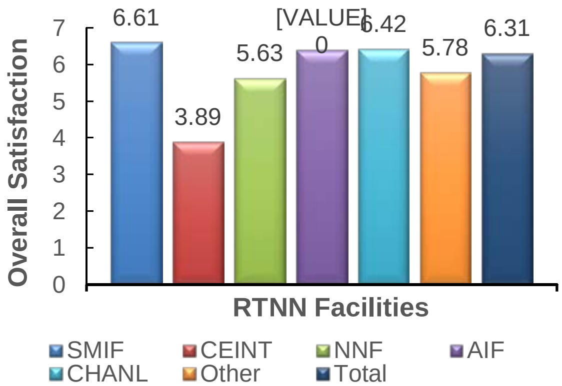
10.11. Research Triangle Nanotechnology Network (RTNN)

<u>Facility, Tools, and Staff Updates</u>

Staff hires: In year 1, RTNN hired diverse staff members across all institutions: Maude Cuchiara (RTNN manager), Phillip Strader (RTNN process scientist), Be'Ledda Dixon (Program Coordinator for Duke's Shared Material Instrumentation Facility, SMIF), Holly Leddy (R&D and Outreach Engineer for SMIF), and Jun Yan (Fabrication Scientist at UNC's Chapel Hill Analytical and Nanofabrication Laboratory, CHANL). In SEI, two graduate students were hired to collect and analyze assessment data, and an undergraduate student was brought on to launch our social media campaign. Several new techniques were developed: voltage contrast imaging of mixed insulating and conducting samples, automation of atomic layer deposition on textile samples, nanoindentation of fibers, and measurement of elastic moduli of materials using atomic force microscopy in fluids. A cryo-scanning electron microscope was installed, and new systems for atomic layer deposition and e-beam/focused ion beam lithography were incorporated.

<u>User Base</u>

In year 1, over 1,100 people used RTNN facilities for a collective 53,000 hours. Over 15% of the total users were external to the three partner institutions including 61 small companies. More than half of these users came from non-traditional disciplines such as the life sciences, textiles, and agriculture. Furthermore, the RTNN trained over 400 new users. Assessment tools developed by the SEI team enabled the evaluation of user demographic and satisfaction data. Overall, users were highly satisfied with their experiences in RTNN facilities (see below, 7=very satisfied). We used three items to measure the satisfaction level of each facility: the general experience, the physical facilities, and the support staff and technicians.



Facility	Satisfaction	N	SD
SMIF (Duke)	6.61	50	0.53
CEINT (Duke)	3.89	3	2.59
NNF (NC State)	5.63	22	1.30
AIF (NC State)	6.40	65	1.08
CHANL (UNC)	6.42	18	0.47
Other	5.78	3	1.58
Total	**6.31**	**161**	**1.06**

Note: $F(5, 155) = 7.16$, $p = 0.000$

There was a significant difference between facilities at the $p < 0.001$ level. The mean score of SMIF was significantly higher than CEINT and NNF. Additionally, the mean score of AIF was significantly higher than that of NNF. All other comparisons were not significant. (AIF: Analytical Instrumentation Facility, NNF: NC State Nanofabrication Facility, CEINT: Center for the Environmental Implications of Nanotechnology)

In addition to the education and outreach activities described later, RTNN uses other methods to increase and diversify the user base. The free use of facilities program provides free access to facilities for new, non-traditional users. In year one, 22 proposals were selected: 7 industry (6 start-up companies); 10 4-year college/university (80% non-R1 institutions); 1 community college; and 4 high school. RTNN also held 35 workshops and short courses with over 200 total participants. We use the RTNN website (rtnn.org) to market events and publicize research accomplishments. We maintain two listservs and widely distribute an attractive printed brochure to help disseminate information.

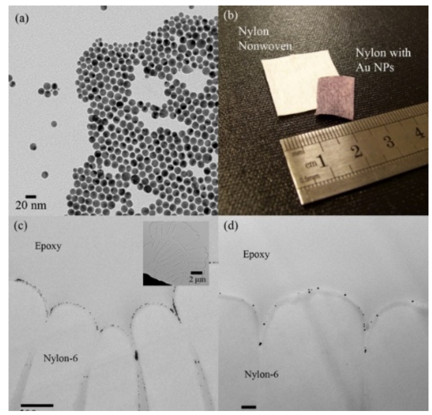
Research Highlights

Core technical capabilities and specialized expertise and facilities in the RTNN span the following areas: interfaces, metamaterials, fluidics and heterogenous integration; nanomaterials for biology and environmental assessment; organic and inorganic 1-D and 2-D nanomaterials; and textile nanoscience and flexible integrated systems. In addition, several of our users, including members of co-PI Jim Cahoon's group, have used facilities at the Joint School of Nanosciences and Nanoengineering (JSNN), part of the SENIC NNCI site. Users housed at JSNN have also used RTNN characterization tools such as ToF-SIMS, SEM/EDS, XRD, and Raman Spectroscopy.

Thermal Stability of Gold Nanoparticles Embedded within Metal Oxide Frameworks Fabricated by Hybrid Modifications onto Sacrificial Textile Templates *PI: Jesse S. Jur, Department of Textile Engineering, Chemistry and Science; North Carolina State University*

This work demonstrates the entrapment of gold nanoparticles (NPs) embedded in a porous inorganic matrix. A unique feature of this work is the use of a TEM equipped with an *in situ* annealing sample holder. TEM analysis indicates thermal stability up to 670 °C and agglomeration characteristics thereafter. The vapor phase processes developed in this work will facilitate new complex NP/oxide materials useful for catalytic platforms.

Richard P. Padbury, Jonathan C. Halbur, Peter J. Krommenhoek, Joseph B. Tracy, and Jesse S. Jur. Langmuir, ***2015*** *31(3): 1135–1141*

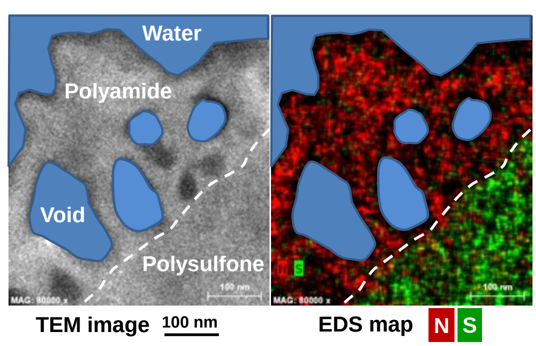


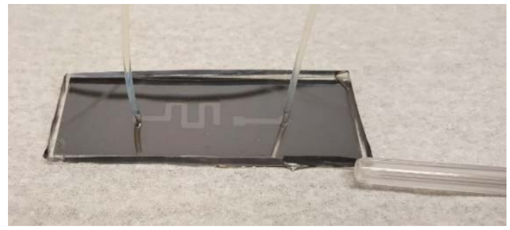
a. TEM image of Au NPs; b. photograph of nylon with and without Au NP loading; c, d. cross-sectional TEM images of the Au NPs dispersed on the surface of the nylon nonwoven after loading. The inset in panel c shows the full cross-section of the nylon fiber used for nanoparticle surface loading.

Investigating the void structure of the polyamide active layers of thin-film composite membranes *PI: Orlando Coronell, Department of Environmental Science & Engineering, University of North Carolina-Chapel Hill*

It was demonstrated that the polyamide desalting barrier of reverse osmosis and nanofiltration membranes is not a dense polymer film but rather contains void globular regions that fill with water. The experimental work used a variety of thin-film characterization techniques to assess the polyamide desalting barrier: TEM, SEM, ellipsometry, STEM-EDS, and STEM-EELS. The quantitative characterization of the void structure of the polyamide desalting barrier signifies a more complete understanding of membrane structure at the nanoscale and enables a more accurate description of water and contaminant transport through membranes.

Lin Lin, Rene Lopez, Guy Z. Ramon, and Orlando Coronell. Journal of Membrane Science ***2016****, 497: 365–376.*





High Throughput Microfluidic Device for Single Cell Storage and Monitoring *Student: Korine A. Ohiri, PI: Gabriel P Lopez*
Department of Biomedical Engineering, Duke University
This work seeks to add functionality to the microfluidic cell de-bulking and analysis process by *on chip* integration of both passive hydrodynamic and active external forces. Here, traditional hydrodynamic cell trapping mechanisms for use as "coarse alignment" are combined with active forces for use as "fine alignment" in order to reduce the overall complexity of microfluidic bio-analytical devices while increasing the associated efficiency, speed, and throughput.
Shields IV, C. W., Cruz, D. F., Ohiri, K. A., Yellen, B. B., Lopez, G. P. Fabrication and Operation of Acoustofluidic Devices Supporting Bulk Acoustic Standing Waves for Sheathless Focusing of Particles. J. Vis. Exp. ***2016*** *109: e53861.*

Education and Outreach Activities

The RTNN's educational and outreach activities are a focal point of RTNN's goal to build its user base. Throughout the year, the RTNN hosts facility tours, conducts nanotechnology-based demonstrations, and provides opportunities for hands-on activities. Overall, ~52% of the over 1,800 participants in year 1 of these programs were from underrepresented groups. **"Monster Under the Bed" program**: Here, students collect their own samples with scotch tape and then mail or bring them to RTNN facilities for imaging. RTNN staff and students are available to answer questions throughout the process. Participants can also access the facilities remotely via Google Hangouts. **Nanotechnology workshop for community college educators**: This workshop, held in May 2016, aimed to help participants learn basic nanoscience principles and current nanotechnology applications and provided strategies for them to incorporate these ideas into their own classrooms. **MOOC, "Nanotechnology, A Maker's Course":** This course was developed to introduce students to nano -fabrication and -characterization techniques and tools. We wrote scripts and storyboards and then filmed equipment demonstrations within facilities. It will be launched on Coursera in Spring 2017. **Lesson Plans:** Working with educators, we developed nano-themed lesson plans that meet specific educational standards and include the on-site or remote use of RTNN facilities.

SEI Activities

The primary duty for the SEI team in the first year was assessment. As such, we undertook the construction of surveys which were housed on Qualtrics. We developed a two-step user survey and a single-step survey for workshops, symposia, and tours. The two-step user survey involved collecting demographic information when the user enters the system and a satisfaction survey when they leave. Ongoing users received both surveys quarterly. We connected the two steps with email addresses. We wrote code that deletes the email address out of the data to protect anonymity during SPSS analysis. Since user data is associated with demographic data, we acquired IRB approval for all our work. As we anticipated the Coursera education initiative, we began a comprehensive review of online resources involving audio-video instruction and presentations. This material is part of our coordinated clearinghouse and was posted online in September 2016. We have produced a "citizen alert" service whereby developments in nanotechnology are contextualized for public consumption. The second generation of the NanoHype blog launched in October 2016 (nanohype.wordpress.com).

10.12. San Diego Nanotechnology Infrastructure (SDNI)

Facility, Tools, and Staff Updates

Facility: SDNI supports a wide range of nanotechnologies for research and development, education, and commercialization. The SDNI facility is especially focused on three nanotechnology subareas: nanobiomedicine, nanophotonics, and nanomagnetics based on UCSD's unique research strengths in these areas and the particularly active local industry and the innovation ecosystem.

Staff hiring: SDNI has successfully hired a PhD level nanofabrication specialist with significant experience in focused ion beam process to prepare biological samples under cryogenic temperature, geographic and soil samples, and sensitive semiconductor samples. SDNI also hired a seasoned equipment engineer, a microfluidic device processing expert, a PhD level photonics testing expert, and a part time software development engineer. The expanding staff will accelerate the development of nanotechnologies, produce better and quicker user services, and more effectively educate and train users.

Tools Acquisition: We are most excited to have acquired a new Zeiss Sigma 500 SEM with ultra-high resolution at very low beam energies, adding great strengths to our imaging capabilities for life science samples, which are often beam-sensitive or prone to charging. Recognizing UCSD's unique user base, Zeiss has entered a strategic relationship with our site. The company's newly developed He-ion and electron microscopy systems can be seamlessly integrated with optical microscopes providing auto-registration capabilities especially important for life science research. Zeiss has generously agreed to send one microscopy scientist to SDNI one day per month at company's expense to educate users the newest tools and capabilities Zeiss develops. Since April 2016, three such meetings have been held, each drawing over 50 academic and industrial attendees.

SDNI has also formed partnership with Asahi Glass, the world leading material suppliers for electronics, display, and surface coating. Under the partnership, Asahi Glass will provide a family of its Cytop materials (some still in the experimental stage) to SDNI to develop new microfluidic devices. Because of the great success of Cytop materials in electronics, display, and more recently, flexible and wearable devices, there have been expectations that such success can be replicated in the rapidly growing nanobiomedical device area. SDNI's strategic partnership with Asahi is a crucial step towards this goal.

User Base

Electronics (41%), Materials (39%), and lifesciences/medicine (15%) are three most popular areas for SDNI users. However, most users' work is multidisciplinary so it is difficult to assign their application to one single category. For example, we have put photonics and optoelectronic work to the area of electronics. If the photonics work is related to novel materials such as metamaterials, we have listed the work under the "materials" category. As another example, we listed biomaterials such as nanostructures for drug delivery, biosensors, and energy production (e.g. water splitting) under "materials" although they could also be listed under life sciences/medicine, chemistry, or environment. For works in the areas of nanomagnetic materials, magnetic sensors, superconductivity, storage devices, etc., some were listed under electronics, and others listed under materials or physics. Overall we observe a general trend of increasing usage in bioelectronics, biomaterials for biological and medical applications.

Over the report period from 10/1/2015 to 9/30/2016, the average usage is around 4000 hours per month. The number of external users has increased appreciably over the past 6 months. An increasing number of external users are far from our location. Contracted service becomes an attractive approach for companies to work with our staff to realize their ideas and produce prototypes without geographic boundaries. We consider this an effective means of proliferating nanotechnologies through NNCI.

From 10/1/2015 to 9/30/2016, we had users from 9 academic institutes that are not affiliated with UCSD, 35 small companies, 18 large companies, 4 government labs, and 3 international labs. We also like to mention that some small companies (especially startups and companies in incubation) are affiliated with UCSD through collaborations with UCSD faculty and/or having their research employees also be visiting researchers with UCSD.

Research Highlights

Pushing the technology envelope: Our technical staff are experts in nanofabrication and have contributed to the development of cutting edge technologies. For example, our e-beam lithography specialist, Dr. Maribel Montero, has created nanostructures for novel memory devices for Samsung Electronics, a task the companies had failed to accomplish internally. We received a letter of special acknowledgment, explaining that devices fabricated by UCSD broke Samsung's device performance records, receiving special attention by upper management of the company. Dr. Montero is also engaged with the manufacturer of UCSD's electron-beam lithography tool, to create nanostructures on non-planar, 3D patterned surfaces. In a similar vein, SDNI process development scientist, Dr. Xuekun Lu, has created unique process based on grey scaled lithography to address the technology challenge for Qualcomm in display for mobile devices. SDNI also enables research breakthroughs, and following are a few such examples:

Demonstration of BIC laser: Using nanophotonics technologies, Professor Boubacar Kante's team demonstrates the world's first Bound State In Continuum (BIC) laser (*Nature* 541, 2017). The device has great potential for a wide range of applications such as optical tweezers, biosensing, imaging, and quantum communications. The fabrication of suspended 2D photonic crystal structure supporting bound states in continuum was realized by SDNI nanofabrication staff scientists.

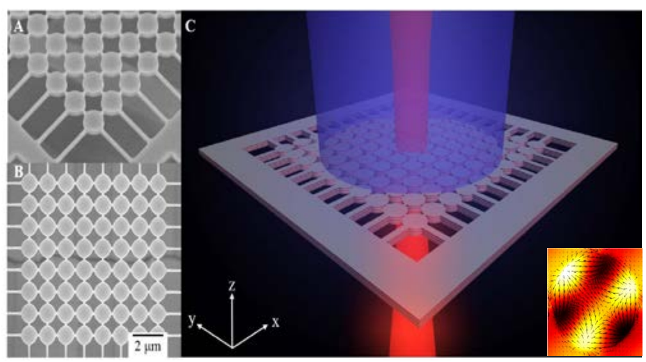


Figure 1. Bound State in Continuum (BIC) laser on a free-standing nanophotonic structure.

Discovery of Cycling Excitation Process. Another ground breaking research supported by SDNI is the discovery and demonstration of cycling excitation process (CEP), an intrinsic physical mechanism in semiconductors that can amplify signals (e.g. photocurrent) with ultrahigh gain, high energy efficiency, and above all, ultralow noise approaching the quantum limit. The work, by Professors Yuhwa Lo and Lu Sham, is the only new physical mechanism for intrinsic signal amplification since the discovery of impact ionization by Zener more than half a century ago.

The discovery has tremendous potential impact on photonics and electronics, including optical and quantum communications, sensing, and imaging. The American Institute of Physics issued a press release on the discovery of the CEP effect and the Nature (September 2015) magazine highlighted the work.

Invention of 3D printed micro-fish. Researchers (Professors Shaochen Chen and Joseph Wang) have used 3D printing technology at SDNI to create "microfish" that can swim around in fluids and then perform tasks such as detecting and neutralizing toxins. The microfish uses nanoparticles for a propulsion system to navigate in fluids as a "tiny robotic swimmer." The microfish could be engineered to have different shapes such as microsharks to swim around in waters to clean up a toxic spill.

<u>Education and Outreach Activities</u>

REU program: We ran an REU program to recruit underrepresented minority and female undergrads from minority serving institutions (MSI) to attend a 10-week summer research program. At the end all 11 REU students gave their oral and poster presentations in a one-day research conference with other summer research undergraduates on UCSD campus.

RET program: SDNI supported 3 high school science teachers from low-income areas (Sweetwater Unified School District: Otay Ranch High School, Garfield High School, and San Diego Unified School District) for a 6-week summer research program. At the end of the RET program, each participating teacher (a) developed a lab project that can be carried out by students in their science class, (b) received education kits to be used in the classroom, and (c) developed curricula in compliance with the California Next Generation Science Standards.

Outreach activities: SDNI developed a joint program with Johns Hopkins University (Center for Talented Youth) to host a one-day open house and science forum to invite up to 50 high-school students of high performance in math and science from low income families.

In collaboration with other offices of UCSD, SDNI has co-hosted and participated in various activities to promote diversity and outreach. The Comienza Con un Sueno event (March 2016) is one such major events. We invited high school students and their family members from low-income families (mostly Hispanic background) to activities including introduction of college life and career opportunities, financial support availability, and laboratory tours and demonstrations. Nearly 1600 high school students and their parents and siblings have attended the event. SDNI also participated in TESC's Annual Enspire outreach event (Feb. 2016) to show middle and high school students how research is done and how the research work can benefit the society and their own life. The event drew around 400 students from undeserved schools in the SD community.

<u>SEI Activities</u>

To promote the awareness of ethics in nanotechnologies, Professor Kalichman gave a one hour lecture to all the REU students and other students and users on the issue of ethics.

<u>Computation Activities</u>

SDNI has developed custom software for multi-physics computational study of nanoscale materials and devices with unique capabilities. Specifically, two software packages available for download are a GPU accelerated version of the Object Oriented Micromagnetic Framework (OOMMF) and FastMag micromagnetic simulator. OOMMF is a finite difference based simulator for modeling the magnetization dynamics at a high speed. FastMag is a finite element based multi-physics simulator for modeling the operation of highly complex magnetic and microwave devices and materials at nanoscale. Both packages are integrated with pre- and post-processors making them reliable tools for a broad community adoption.

10.13. Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

Facility, Tools, and Staff Updates

The Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource is a joint venture between Northwestern University and University of Chicago. SHyNE Resource provides researchers from academia, government, and companies large and small with access to user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology. Northwestern University, under the leadership of site director, Professor Vinayak Dravid, partnered with University of Chicago and co-director Professor Andrew Cleland to represent the Midwest within the NNCI. The SHyNE Resource coordinates the integration of a diverse group of open-access nanoscale fabrication and characterization facilities across Northwestern University (NU*ANCE*, SQI, NUFAB, IMSERC, NUCAPT, JB Cohen XRD) and the University of Chicago (PNF). This network of facilities includes broad capabilities in nanoscale fabrication and characterization in both traditional and emerging areas related to soft and hybrid nanomaterials. Through the funding under NNCI, SHyNE connects state-of-the-art research capabilities to academic, government and commercial programs across the Midwest, which in turn will lead to life-enhancing breakthroughs.

SHyNE facilities are actively engaged in acquiring, updating or replacing key equipment within the facilities through a combination of internal and external funding mechanisms. These activities are divided broadly along the lines of fabrication and characterization equipment. In terms of fabrication equipment, PNF and NUFAB had a significant number of new equipment installations in Year 1, with additional fabrication equipment housed in the NU*ANCE* Center. In particular, construction of the PNF ISO Class 5 cleanroom was completed and the bulk of equipment installation was completed in Year 1. A full suite of tools enabling end-to-end processing was funded by the Pritzker Foundation and the first users were trained in February 2016. Maintaining an active and engaged user base for SHyNE facilities is contingent upon the successful recruitment and retention of high quality staff. A number of new technical and administrative staff members (8) joined the SHyNE team in Year 1, many with full or partial funding by NNCI.

User Base

For Year 1, SHyNE facilities had 1378 unique users who logged over 144,000 hours of instrument time generating $3.4M in revenue. External users represented 15% of total users and 13% of revenue, but only 6% of total lab time. We expect to increase the percentage of external use in future years by continuing to promote underutilized equipment and our unique and integrated capabilities for soft and hybrid nanotechnology. SHyNE actively engages local and regional companies, colleges, universities, non-profit organizations and governmental agencies to recruit new users. This is accomplished by a number of marketing strategies including: exhibitions at conferences and trade shows, production of a marketing video and promotional materials, networking with alumni, coordination with university-wide corporate engagement offices, and an active social media presence. In particular, SHyNE exhibited at the 2016 Institute of Food Technologists annual meeting (the premier food technology conference). This focus on non-traditional users is reflected in our diverse list of external users, which includes users from food, energy, pharmaceutical and biomedical industries.

<u>Research Highlights</u>

1) IMSERC was able to demonstrate MALDI imaging of a peptide using self-assembled monolayer desorption ionization (SAMDI) process flow (Figure 1). The imaging software and matrix sprayer were funded by a VPR small equipment proposal. IMSERC is collaborating with Mrksich groups to demonstrate quantitative results which can be used to measure reaction rates before progressing to biological samples. In addition, **SAMDITech** (new IMSERC user in 2016) is evaluating the Bruker MALDI system in IMSERC for use in its applications and may collaborate with IMSERC in the future to use imaging based data collection to enable use of higher density testing kits.

Peptide Imaging (Ac-GYNRGC)

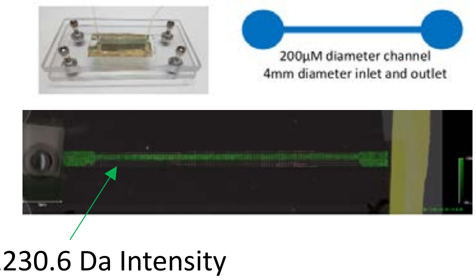


Figure 1: MALDI imaging demonstration using Mrksich group flow reactor and SAMDI process.

2) NU*ANCE* began working with **ACCO Brands** to perform material analysis on several coatings developed for use in their products (Figure 2). FIB/SEM was utilized to help analyze and understand several factors: the various layer thicknesses within the coating, the material composition of the particles within the coating, the size of the particles in the coating, and the overall surface finish of the coatings. Through this, ACCO was able to validate that the coatings were utilizing nanotechnology. This information and the images taken by the NU*ANCE* Center was used to develop sales and marketing collateral.

Figure 2: ACCO Brands marketing material for "Nano Coated" dry erase boards

3) NUCAPT staff collaborated with Oleg Senkov of the **Air Force Research Laboratory** to study Ta-Nb-Mo-Al-Zr-Ti high entropy alloys by atom probe tomography (Figure 3). These alloys are a new class of materials with approximately equimolar concentrations of constituents, whose miscibility gaps are explored to create precipitation-hardened, high-

temperature resistant, high-strength alloys. This work resulted in a publication: O. N. Senkov, D. Isheim, D. N. Seidman, A. L. Pilchak, "Development of a Refractory High Entropy Superalloy," *Entropy* 18, 102, 2016.

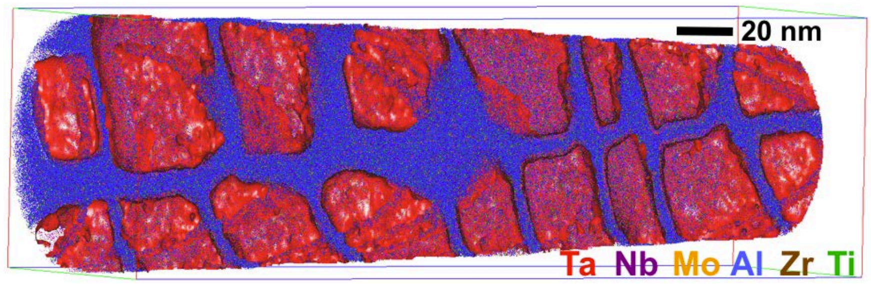


Figure 3: Atom probe tomography data of rafted precipitates in a Ta-Nb-Mo-Al-Zr-Ti high-entropy alloy.

Education and Outreach Activities

Education and outreach activities are a critical part of SHyNE's mission and include academic courses with laboratory components, an REU program, hands-on workshops, seminars, vendor symposia/demos, facility tours/demos (K-12, higher education and public). More than 1350 students participated in courses utilizing SHyNE facilities in Year 1. SHyNE sponsored four REU students in a unique, facilities-focused REU program that exposed undergraduates to advanced instrumentation as a key component of their projects. SHyNE co-hosted several workshops with vendors including a Scanned Probe Microscopy workshop with Bruker, a CryoSEM workshop with Mager Scientific (Leica), a FIB nanofabrication workshop with Raith and an advanced SEM workshop with Hitachi.

SEI Activities

NanoJournalism – SHyNE Resource is collaborating with Northwestern's Medill School of Journalism to establish a novel NanoScience Journalism focus within the existing Health, Environment and Science Journalism program. The program will kick off in Fall 2016 and has multiple components designed to bring journalism students into the facilities to learn about nanoscience research and connect scientists and researchers with the Medill experts in science writing to help them effectively communicate their research to a general audience. Several programs have been developed to provide an immersive and experiential learning experience for both Masters (MSJ) and Bachelors (BSJ) in Journalism students. In Fall 2016, the MSJ students will be provided with a half-day field trip including a presentation by SHyNE Director, Professor Vinayak Dravid and demos and tours in SHyNE facilities. Select MSJ students can participate in a Practicum during Fall quarter, which would involve shadowing facility staff and researchers to provide an opportunity to better understand the process of discovery. Students will have the opportunity to write stories on various aspects of the exciting research being conducted in the facilities. In addition, SHyNE staff will be sending the coordinators of the MSJ program news items in order to be featured in SPOT news articles.

10.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Facility, Tools, and Staff Updates

Further build-out of the Georgia Tech Marcus Nanotechnology Building continued this year with the completion of the nanomaterials research laboratory space which is occupied by three faculty research groups. Tool installation in the Inorganic Cleanroom has been essentially completed, with 95% occupancy of the original equipment space. There is approximately 13,000 sq. ft. of remaining shelled cleanroom space that can be built out adjacent to the inorganic cleanroom and plans are underway to complete this area, partly for the Marcus Center for Therapeutic Cell Characterization and Manufacturing (http://cellmanufacturing.gatech.edu). During the past year, the IEN's materials growth, characterization, and CMP areas have installed and upgraded several tools. The Organic Cleanroom added new UV-Vis, TGA/DSC, and Surface Zeta Potential capabilities. In addition, IEN's integrated hardware team converted a legacy sputtering system with no remaining supply chain to a new user-friendly, fully automated sputter tool with GUI-based software. JSNN carried out a number of operational and process improvements in its core facilities. JSNN hired 2.5 FTE research staff to support its analytical, microscopy and biocleanroom operations, and new processing capabilities were added to several 200 mm compatible tools. JSNN also obtained ISO 17025 certification for its Gateway Materials Test Center which specializes in ASTM AATCC testing for the automotive, aerospace and textile industries. The JSNN Soft Matter and Nanobiology labs also acquired a number of tools and capabilities.

In March 2016, IEN deployed the new Shared User Management System (SUMS) software tool (http://sums.gatech.edu/department/IEN). SUMS controls user access to all tools via touchscreens in each lab, allows users to request training for any tool, schedule check-off sessions with equipment instructors to evaluate user knowledge and give users operator access, and enables researchers to schedule time. It provides each researcher, their department, and/or their financial personnel real-time usage information for billing, including automated payments processing while providing very detailed, specific usage information, with the ability to authorize or remove users in real time. The data analytics assess and quantify instrumentation usage and downtime, which enables efficient operations management, with dramatic efficiency increases, significantly lowered costs, and streamlined business processes.

User Base

Marketing of SENIC began with creation of a new website (http://senic.gatech.edu/), which highlights membership in NNCI and the capabilities of the combined IEN and JSNN facilities, as well as Education/Outreach and SEI activities. Additional promotion and communication efforts have proceeded via social media, with SENIC specific efforts on Facebook, LinkedIn, and Twitter. Collateral marketing materials, such as SENIC-branded bookmarks, brochures, and banners, have also been produced.

User recruitment efforts have involved a number of ongoing activities at both IEN and JSNN. IEN hosts 15 Nano@Tech seminars each academic year with speakers primarily from the local community, which includes Georgia Tech faculty, as well as faculty from neighboring universities and researchers at companies in the region. In the fall of 2015 we also began live-streaming of these lectures via the Nano@Tech YouTube channel. JSNN also holds a weekly seminar series with more than 20 seminars per year, and this is also streamed and archived.

IEN's NanoFANS Forum, a biannual symposium at the intersection of life sciences and nanotechnology was held in October 2015 (Ophthalmology) and May 2016 (Cancer) with more than 100 attendees at each event. IEN also hosted CDC-Emory-Morehouse School of Medicine Day (July 2016) as an outreach event for users from non-traditional disciplines and an Economic Development Day (June 2016) for officials from county economic development groups to learn more about the value of the shared user facilities for local companies. Vendor supported and sponsored workshops were held at both locations. In May 2016, IEN held its annual User Science and Engineering Review (USER) Day at which current facility users presented posters on their current research and heard a keynote address from Dr. Ryan Diestelhorst, CTO of NextInput, which is a Georgia Tech startup and IEN industry user company. In addition, JSNN held its 4th annual Nanomanufacturing Conference in September 2016, with a focus on advanced nanomanufacturing innovation and commercialization. These events were attended by NNCI staff from both IEN and JSNN.

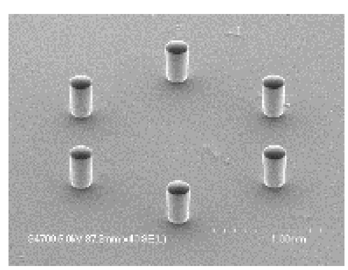
Both IEN and JSNN attended or exhibited at local and regional conferences and events to help recruit new users. JSNN hosted an exhibit booth for 60 participants at the American Chemical Society Piedmont Regional Poster and Vendors Night (April 2016), while IEN exhibited at Pittcon (March 2016), JEC Americas (May 2016), and at the Southeastern Association of Shared Resources Conference (June 2016).

Since 2013, IEN has held a biannual seed grant competition that seeks to provide no-cost facility access to beginning graduate students so that they can start their cleanroom training without regard to financial concerns. After reviews of the 2-page proposals, 3-5 awards are made each submission cycle for a six-month grant period. While this program had been restricted to Georgia Tech projects, with the advent of SENIC the program is now open to any academic researcher in the southeastern US.

During the first year of the NNCI program (Oct. 2015 - Sept. 2016), the SENIC facilities have served nearly 1100 individual users, including more than 160 external users representing 72 companies and 21 colleges and universities. Within this time, we have contracted with more than 50 new external entities at Georgia Tech and within the JSNN consortium. A reciprocal billing agreement has led to the first users accessing capabilities at both SENIC locations. The majority of users access the facilities on-site, although 111 users obtained services remotely, and some users operated in both on-site and remote fashions. Monthly users averaged 447, and 26 new users were trained each month on average (313 total during the reporting period).

Research Highlights

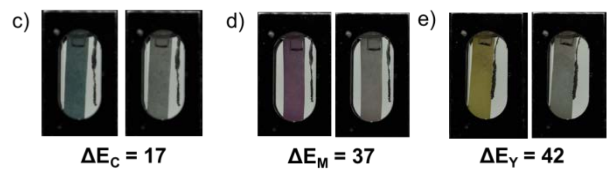
Notable new academia, industry, and international users came to SENIC from University of British Columbia, University of Pretoria, Robert Bosch LLC, Matthews International Corp, Quantum Information Extraction LLC, Auburn University, Emory Univ. School of Medicine, Univ. of California-Davis, University of Missouri, and University of Florida. Research highlights include:



Hollow Microneedles for Drug Delivery, *M. Raeiszadeh, K. Walus, and B. Stoeber (University of British Columbia)*: Microdermics Inc. and UBC collaborate in prototyping and manufacturing of high-aspect ratio hollow microneedles out of polymeric and silicon molds. Multiple etching tools were used to etch 1 and 2 mm thick silicon wafers to produce high-aspect-ratio pillars with more than

500 micrometer height which were used as a mold for fabrication of hollow-core microneedles. The IEN user facility allowed for process development for this new technology as several etching tools with different performances and characteristics were available for testing.

Paper-based Electrochromic Devices Enabled by Inkjet-printed PEDOT:PSS, *A. W. Lang, A. M. Österholm, D. E. Shen, R. J. Moon, and J. R. Reynolds (Georgia Tech)*: This work used inkjet printing to fine tune printed PEDOT:PSS to achieve conductive, color neutral, and redox stable electrodes. By tuning ink formulation using a surfactant and utilizing cellulose nanofiber coated paper substrates, continuous PEDOT:PSS films were generated. An in-plane device based on patterned PEDOT:PSS pixels shows an 81% retention of charge after 10,000 cycles demonstrating practical viability for fabricating paper-based displays.



Education and Outreach Activities

SENIC's vision for education and outreach is focused on the development of a strong workforce capable of meeting the needs of a growing nanotechnology-enabled economy. We have been very successful in our first year in providing education and outreach (E&O) reaching >10,000 individuals. In 2016, SENIC had six undergraduate interns at GT and four at JSNN. We submitted an REU proposal to NSF in the fall of 2016, which is pending. In addition, JSNN had five interns from Forsyth Technical Community College spending ten weeks training in nanomanufacturing. GT submitted to the NSF an Advanced Technical Education proposal in collaboration with three metro Atlanta technical colleges, which was declined. SENIC facilities serve as technical training centers for graduate students and post-docs. In addition, GT and JSNN have provided technical workshops, symposia, and conferences that have been attended by graduate students, post-docs, and government and industry professionals. IEN conducted hands-on short courses on "Microfabrication" (Oct. 2015, March 2016, Aug. 2016) and "Soft Lithography for Microfludics" (Oct. 2015, April 2016, July 2016, and Oct. 2016) attended by 109 participants. Both GT and JSNN have been active in providing outreach to K-12 students and teachers and the general public. JSNN's NanoBus had its ribbon cutting ceremony during year one and visited 18 schools reaching >2,000 students. Both SENIC sites supported their local science festivals – NC Science Festival and Atlanta Science Festival. In addition, GT in collaboration with the NNCI site at Cornell, exhibited at the 4th USA Science and Engineering Festival held in Washington, DC April 15-17, 2016. We provided hands-on activities to some of the >350,000 attendees. In terms of reaching K-12 teachers, GT exhibited at the Georgia STEM Forum and Georgia Science Teachers Association. We also co-exhibited with the NNCO at the annual meeting of the National Science Teachers Association held in Nashville, TN March 31-April 2, 2016.

SEI Activities

The aim of the SEI work at SENIC is to increase attention to application of nanotechnology, while still attending to social and ethical implications. Much of our effort has been on developing a model which incorporates societal impacts in a pragmatic manner that parallels elements of the I-Corps program. The results have appeared in a paper, published in the Journal of Technology Transfer. We have also made presentations at the Public Values Consortium 5th Biennial

Workshop January 8, 2016, Nano@Tech in March of 2016, the 2017 NNCI Winter School in Arizona, and the Technology Transfer Society Annual Conference in November, 2016. We developed an exercise on this topic as well, which we piloted at the 2017 NNCI Winter School. In addition, we have developed lists of researchers from our nanotechnology publications dataset based on Web of Science information through to 2015, from a manufacturing dataset, and from an SBIR award download to contribute to broadening of external participation in SENIC.

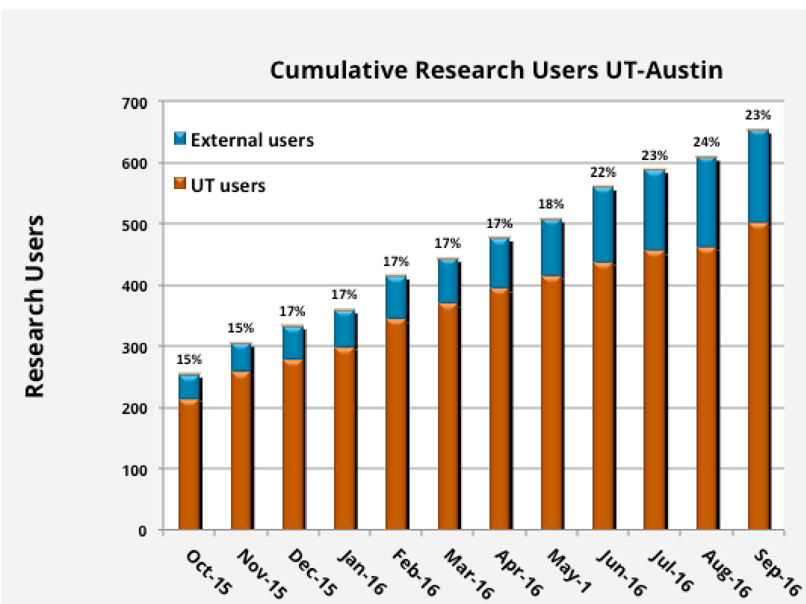
10.15. Texas Nanofabrication Facility (TNF)

Facility, Tools, and Staff Updates

NNCI TNF expanded its capabilities from the NNIN University of Texas Microelectronics Research Center (MRC) facilities by including resources from the Center for Nano and Molecular Science and Technology (CNM), Texas Materials Institute (TMI), and NASCENT Nanosystems ERC. This partnership of University of Texas (UT) centers is more than an aggregate of shared facilities; it is a network of 24 professionals (technicians, engineers, and administrative staff) dedicated to their user base: research associates, professors, start-ups, small and large company users. The NNCI TNF (composed of MRC, TMI[1] and NASCENT facilities) has 22,000 sq. ft. cleanroom space (class 100) and 20,000 sq. ft. of labs. TNF offers over 130 state-of-the-art tools necessary for micro and nanofabrication, as well as an expanded suite of characterization tools, crystal growth and nanomanufacturing systems. TNF acquired new instruments that complement its existing characterization strengths.

- Laser Scanning **Microscope LEXT OLS4100 from Olympus (acquired with MRC user fees)**. Acquisition time is much faster than AFM. For MEMS applications, it is equipped with a 50x large working distance objective (10.6mm) to measure deep etched features.
- TNF received a donation ($80k replacement cost) from one of his faculty. A **Hysitron TriboIndenter TI 950** for nanomechanical and nanotribological characterization is utilized to report on adhesive interactions between diamond indenters and monolayer, bilayer and trilayer graphene on silicon oxide as well as bare silicon oxide and graphite over relatively small spatial domains. This tool will benefit the 2D material and packaging communities.
- **Small Angle X-ray Scattering Instrument with In situ Capabilities (NSF-MRI award).** To be acquired mid-2017 and installed in new Engineering Education Research Center building and managed by TMI

User Base



The NNCI-TNF is a partnership between 3 existing UT facilities, with two already organized as shared facilities. For the past 12 cumulative months of NNCI program, TNF were able to host ~ 650 unique research users, totalizing an average of ~5,600 lab hours/month for a revenue of ~ $87k/month through user fees. TNF was used by 23% of external users (company and outside UT academic)

[1] TMI absorbed CNM technical staff, space and equipment in the fall 2016 under one institution.

Research Highlights

- *Pattern transfer from Canon Nanotechnologies in TNF-LAM 300mm Exelan Flex 45 etcher*. Canon Nanotechnologies Inc., together with Canon, is the market and technology leader for high-resolution, low cost-of-ownership nanoimprint lithography systems and solutions for the semiconductor industry. Jet and Flash Imprint Lithography (J-FIL) creates 20nm line and space pattern (1/2 pitch) Etching process to transfer the patterned features from resist to the underlying substrate while maintaining acceptable critical dimension uniformity is developed at TNF.

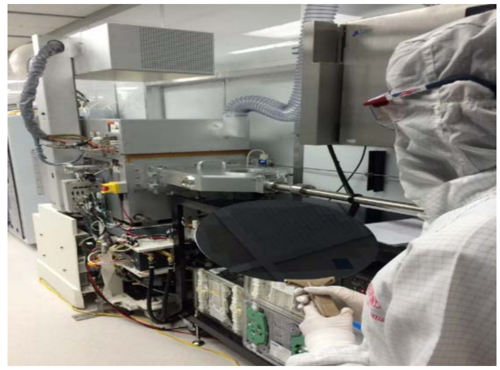


Figure 1: Canon Nanotechnologies Dry Etch Development scaling up for use on 300mm wafers

- *Prof. Ray Chen founder and Chairman of the Board of Omega Optics Inc.* (our main user of the E-ebeam lithography tool at TNF) gave an invited technology transfer tutorial entitled "Silicon Nanomembranes for Sensing Applications" in the 2016 Optical Society (OSA) Conference on Lasers and Electro-Optics Technology (CLEO)
- *The aging JEOL 6000FSE E-beam lithography equipment*, acquired thanks to a NSF MRI award in 2003 was down due to a major software crash. ASU, the Arizona NNCI site shared with TNF their software copy. TNF was able to recover its e-beam workhorse tool.

Education and Outreach Activities

TNF hosted the first **NNCI Research Experience for Undergraduate** (REU) program for 9-week research internship. Without coordinated REU program, TNF had to (1) advertise its local program, to (2) develop a secure portal to receive and to (3) review applications. The REU coordination effort was merged in between the two TNF entities (MRC and NASCENT). The 10 NSF funded interns (5 NNCI , 5 NASCENT ERC) were joined by REU students funded by other institutions (Japanese Nanonet, American University of Beirut, Austin Community College). The undergraduates concluded their internship by an oral presentation and poster session with all the REU candidates at UT. The participating numbers and demographics per REU programs is reported in the Table below.

TNF Institutions	*Female*	*Male*	*Underrepresented Minorities*	*Total Participants*
TNF (NSF)	*2*	*3*	*1*	*5*
NASCENT NERC (NSF)	*2*	*2*	*4*	*5*
Other programs	*2*	*4*	*1*	*5*
TOTAL	*6*	*9*	*6*	*15*

The Secretary of State John F. Kerry visited UT Austin's MRC a week after he signed a global agreement at the United Nations to reduce greenhouse gases and curb global warming. Kerry's 90-minute visit started with a tour of the MRC, led by Prof. Sanjay Banerjee. It was the opportunity for MRC researchers to show Kerry the progress they are making in alternative energy and renewable technologies, from solar cells, to grid infrastructure, to biofuels.

Figure 2: The Secretary of State John F. Kerry visited the MRC solar cells capabilities.

MRC UT-Austin offered cleanroom tours. MRC Director and specialists gave a synopsis of micro and nano fabrication, equipment and applications. Individuals from dissimilar age groups and different professional areas attended the tours: summer camp students, 12 examiners from the US Patent and Trade Office, 15 high school students from NASCENT Nano-camp, Chinese delegation of industry and academic leaders (Oct 2016). Women and URMs were highly represented in the USPTO (9 female scientists) and high school tours (10 females, 5 students from underrepresented minorities).

TNF organized technical workshops in collaboration with manufacturer: AFM- Park System (Oct. 2016) Polymer Pen Lithography (PPL)- TERA-print, (Dec. 2016)

<u>SEI Activities</u>

The SEI team is composed of **LeeAnn Kahlor (SEI Director- NNCI Co-PI) and Jacy Jones (Graduate Research Assistant).** Based on prior research, a pilot SEI training module (V.1) for scientists to begin thinking about SEI and how to apply SEI into their work was produced. The purpose of the module is to integrate SEI considerations into lab trainings. The pilot module V.1 was shared with TNF/MRC researchers. Feedback was gathered and revisions were made (V.2).
The REU 2016 summer intern hosted by the SEI team (K. Keller) helped strategize, develop & facilitate a focus group to collect data on pilot module V.2, and created a database of published nanoscientists for future SEI survey. The focus group composed by the 2016 TNF REU interns reviewed the pilot module V.2. From the transcript of the focus group recorded meeting, a thematic analysis was conducted to identify themes within the data. The pilot module V.3 is in production, with revisions guided by the focus group feedback. J Jones began to work on her MA thesis, which is focused on SEI.

10.16. Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth)

<u>Facility, Tools, and Staff Updates</u>

NanoEarth had a busy first year expanding our capabilities via facility, tools, and staff additions.

Facilities

- Extensive interior remodeling on the second floor of our main facility, which includes private offices, cubicle offices, relaxation space, and a data processing room, all for NanoEarth, was completed. Up to 25 students and professionals can be accommodated at the same time, perfect for nanocamps (high school students), graduate student, post-doc, and faculty workshops, university lab classes, faculty on sabbatical, etc.

Tools

- Instrument and laboratory portions of NanoEarth not already set up as a cost-service center have now been added to an overarching electronic system. New software is now tracking the usage time on all analytical instruments, in both our NCFL and VTSuN facilities. NanoEarth materials synthesis time (typically aqueous- or gaseous-based), ultrafiltration time, and reactivity vessel time are collected manually and entered by hand into our tracking system.
- A search for funding, as well as discussions with the manufacturer (JEOL), is ongoing for the addition of our 4th modern generation TEM. This instrument will be an aberration-corrected atomic resolution microscope which can operate at low voltages. Michael Hochella (PI) and Mitsuhiro Murayama (NanoEarth Deputy Director) visited JEOL's headquarters in Japan twice and the US office in Boston once in this period.
- We obtained funding for the acquisition of a PANalytical Empyrean XRD, a scanning mobility particle sizer spectrometer, a 4 rotor ultracentrifuge, montage capabilities for one of our TEMs, 3D reconstruction software for our FIB, and a polarization upgrade for the Raman.
- Approval to prepare an NSF MRI proposal for the acquisition of a ToF-SIMS was granted by Virginia Tech for one of our NanoEarth co-PIs.

Staff

Our center has acquired six new team members:

- Debora Berti, Research Associate – NCFL lab coordinator for NanoEarth visitors and TEM/mineralogy/general analytics expert (background in mineralogy & geology)
- Weinan Leng, VTSuN Lab Manager & Research Scientist (background in physical chemistry and biomedical engineering)
- Angelica Melvin, Diversity Assistant Coordinator – coordinates the MUNI program to attract and assist MUNI visitors (background in psychology)
- Mitsuhiro Murayama, Deputy Director – technical coordinator and world-class TEM microscopist (background in materials and nuclear science and engineering)
- Tonya Pruitt, Assistant Director – manages day-to-day operations, budgeting, and reporting (background in agricultural and extension education & biochemistry)
- Ya-Peng Yu, Instrument Specialist – materials/TEM/FIB expert (background in chemistry, chemical engineering, & materials science and engineering)

<u>User Base</u>

NanoEarth is designed for users in the Earth and environmental sciences and engineering fields, but many other fields accomplish important research in related fields. In the case of NanoEarth, Earth and environmental science and engineering related users have included those in the fields of chemistry, mechanical engineering, medicine, materials, electronics, and physics.

We have appeared prominently in three magazine articles published to highlight NanoEarth facilities and to help draw in users. We had a major piece in *Physics Today* (November 2015, Vol. 68, no. 24), NSF's *EAR To The Ground* (Winter edition, 2015), and *Elements Magazine* (February 2016). Additionally, we have presented posters, hosted booths, and given talks at numerous conferences. We find that personal connections produce the best results.

We also attract underrepresented and non-traditional users through MUNI (Multicultural and Underrepresented Nanoscience Initiative) which provides financial support for individuals and groups to visit our facilities for both research and educational purposes. In our first year, we supported the visits of 23 individuals from 9 colleges and universities.

In total, in our first year we had 280 users and 7,627 recorded hours. Of these, 81 users (29%) and 2,799.84 hours (37%) were directly recruited through NanoEarth. Of course, a key goal is to attract external users: 16% (48) of our facility users were external and 46% (22) of these were attracted directly through NanoEarth.

<u>Research Highlights</u>

De Yoreo, J.J., Gilbert, P.U.P.A., Sommerdijk, N.A.J.M., Penn, R.L., Whitelam, S., Joester, D., Zhang, H.Z., Rimer, J.D., Navrotsky, A., Banfield, J.F., Wallace, A.F., Michel, F.M., Meldrum, F.C., Cölfen, H., and Dove, P.M. (2015) Toward a comprehensive picture of crystallization by particle attachment. *Science*, 349, 6247.

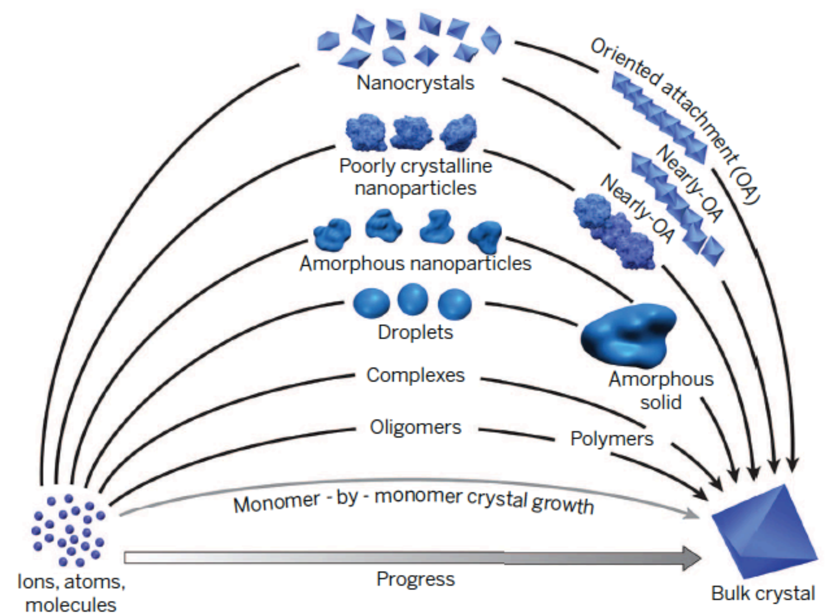
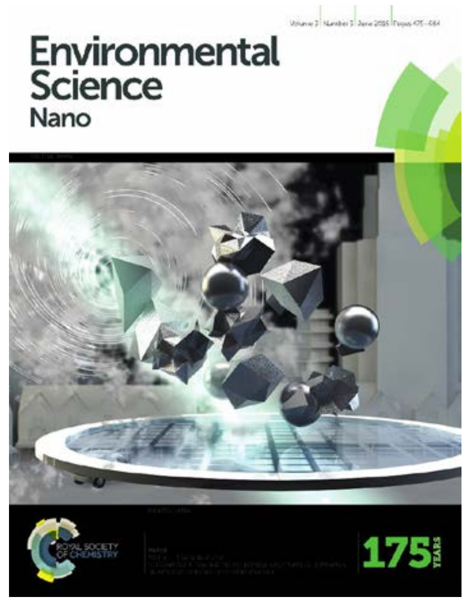


Fig. 1. Pathways to crystallization by particle attachment. In contrast to monomer-by-monomer addition as envisioned in classical models of crystal growth (gray curve), CPA occurs by the addition of higher-order species ranging from multi-ion complexes to fully formed nanocrystals. (The final faceted bulk crystal is a schematic representation of a final single-crystal state. As Figs. 2 and 3 show, the final crystal can have more complex morphologies, including spheroidal.)

Summary – This highly cited paper published in *Science* as a perspective Review is from a large group (15) of leading experts (including NanoEarth co-PI Marc Michel) in the field of "non-classical" examination of crystal growth, this with tremendous geoscience implication and application. "Numerous lines of evidence challenge the traditional interpretations of how crystals nucleate and grow in synthetic and natural systems. In contrast to the monomer-by-monomer addition described in classical models, crystallization by addition of particles, ranging from multi-ion complexes to fully formed nanocrystals, is now recognized as a common phenomenon. This diverse set of pathways results from the complexity of both the free-energy landscapes and the reaction dynamics that govern particle formation and interaction.”

Yang Y., Vance M., Tou F., Tiwari A., Liu M., Hochella, Jr. M. (2016) Nanoparticles in road dust from impervious urban surfaces: Distribution, identification, and environmental implications. *Environmental Science: Nano*, 3, 534-544.



Summary – This paper was an issue cover story and the 4th most downloaded paper in 2016 published in *Environmental Science: Nano*. Nanoparticles (NPs) resulting from urban road dust resuspension are an understudied class of pollutants in urban environments with strong potential for health hazards. The objective of this study was to investigate the heavy metal and nanoparticle content of PM2.5 (the finest dust fraction) generated in the laboratory using novel aerosolization of 66 road dust samples collected throughout the mega-city of Shanghai (China). Results show that metals were generally enriched in aerosolized samples relative to the bulk dust. Elevated concentrations of metals were found mostly in downtown areas with intense traffic. Fe-, Pb-, Zn-, and Ba containing NPs were identified using electron microscopy, spectroscopy, and diffraction, and we tentatively identify most of them as either engineered, incidental, or naturally occurring NPs. Some of these are likely to be highly biotoxic.

Education and Outreach Activities

NanoEarth has a very active and robust Education and Outreach (E&O) program. We have attracted 143 visitors to our site this first year for educational and outreach purposes. We have reached far more than this at conferences and fairs (over 1,000), and exponentially more than even this via *Pulse of the Planet* radio programming (over a million; live national listening audience, and podcast downloads). Syndicated radio producer Jim Metzer (multiple radio media major-award winner, plus multiple NSF, Grammy Foundation, and Fulbright grants) has already produced a total of 10 NanoEarth-sponsored *Pulse of the Planet* radio shows featuring Prof. Kim Jones at Howard (3 programs), Prof. Nadine Kabengi at Georgia State University (3 programs), and Prof. Deborah Berhanu at Kingsborough Community College in New York City (4 programs).

NanoEarth also has a strong focus on industrial engagement and entrepreneurship. In our first year, we have worked to develop the PHENOM: Public Health & Environmental NanOsysteMs Industrial Affiliates Program to better engage industrial affiliates. We also partnered with JEOL and Agilent to host two workshops at our site.