# Annual Report of the National Nanotechnology Infrastructure Network

**10 month period**
**March 1, 2010 through Dec 31, 2010**
**"Year 7"**

Cooperative Agreement: ECS-0335765

March. 2011

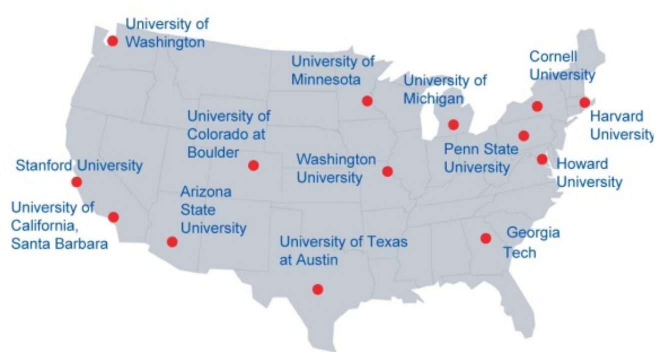
***Participating Institutions**:* Arizona State University, Cornell University, Georgia Institute of Technology, Harvard University, Howard University, Pennsylvania State University, Stanford University, University of California at Santa Barbara, University of Colorado, University of Michigan, University of Minnesota, University of Texas at Austin, University of Washington, and Washington University in St. Louis

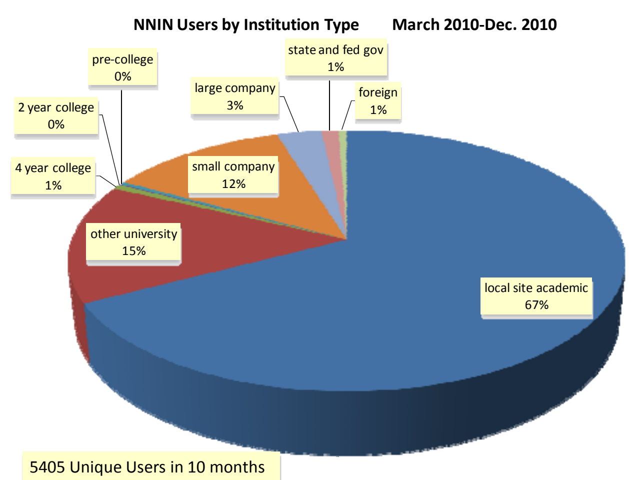
# National Nanotechnology Infrastructure Network 2010-11 Annual Report

## *Executive Summary*

**Introduction:** The National Nanotechnology Infrastructure Network (NNIN) is a collective of fourteen university-based nanotechnology facilities with the mission to enable rapid advancements in nanoscale science, technology and engineering through open and efficient access to advanced processes, equipment, and expertise. Completing its 7th year of operation, NNIN provides a distributed facilities-based infrastructure resource that is openly accessible to the nation's students, scientists and engineers from academe, small and large companies, and national laboratories. It enables the reduction of nanotechnology based ideas to practice by providing the capacity to explore materials, structures, devices and systems through access to tools, training and specialized staff support– all at affordable cost, with minimum administrative barriers and with only a few weeks of preparation following initial contact. NNIN also provides computational resources with an emphasis on advanced scientific computing and modeling at the nanoscale, particularly in support of experimental efforts, and in building repositories of trusted critical scientific information, e.g., interatomic and pseudopotentials. NNIN also leverages its infrastructure resources and its geographic and institutional diversity to conduct broader impact activities: in education, in enhancing diversity in technical disciplines, in societal and ethical implications of nanotechnology and in health and environment studies

Figure 1: Institutions of NNIN and the experimental research & development usage of NNIN during 2010-11.



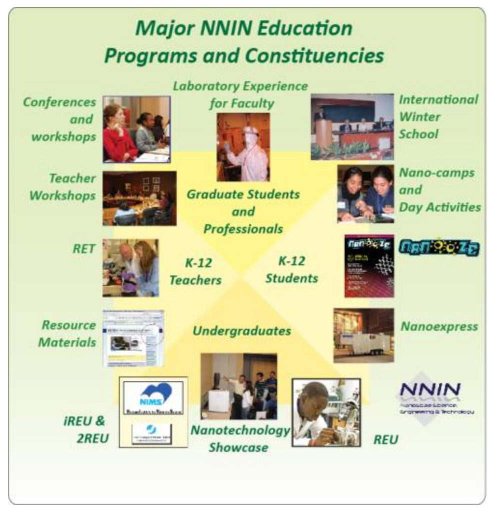

Three new universities were added to NNIN in 2008, expanding NNIN's expertise in inorganic-organic interfaces through Arizona State University, energy and precision sciences through University of Colorado and public health and environment through Washington University in St. Louis. The universities are now thoroughly integrated and operating as a networked resource.

**Approach and Usage:** NNIN supports research by providing extensive equipment and process resources together with strong technical staff support. NNIN's staff, made possible by the leverage of NSF funding, provides the training, process, and project support that are necessary for effective user access to the large instrument set of NNIN sites. Technology resources are optimized by connecting specific technical leadership offerings at a site to the intellectual strengths of the individual institutions, thus offering the most advanced knowledge and instrumentation to the user cost-effectively. When coupled with geographic diversity, this distributed approach enables balanced and broad support to the nanotechnology community with maximum efficiency and for maximum impact.

Through its user program, NNIN directly impacts a significant portion of the nanotechnology research in the US. During the 10 months of operation ending December 2010, 5405 unique users performed a significant part of their experimental work at NNIN facilities. Of these, 4490 were academic users, mostly graduate students, 822 industrial users, 63 users from State and Federal laboratories, and 30 users from foreign institutions. More than 330 small companies used NNIN facilities during this period. Over 2500 publications, several of them the significant scientific and engineering highlights of the year, resulted from the work of the user community. A major task of staff of NNIN is in training of this user community, particularly graduate students from across United States, where there is a continuous and significant turnover. During the 10 month period, 1897 new users were trained across the vast instrument set, large and small, of the facilities.

**Education and Outreach:** NNIN has a broad portfolio of education and outreach activities, drawing on its nanotechnology strengths, its geographic and technical diversity, and its ability through this breadth and diversity to make an impact on a national scale. A broad range of National programs (Figure 2) forms the base of the NNIN education program, with those efforts supplemented by local activities reflecting the interests and individuality of the NNIN sites. NNIN, as a network and as individual sites, cooperates significantly with other national and center based nanotechnology education programs.

Figure 2: NNIN's major educational activities.




NNIN national education programs include: **(a) Research Experience for Undergraduates** (REU) for a thorough exposure to graduate-level research to undergraduate students across the breadth of nanosciences and engineering, **(b) International Research Experience for Undergraduates (iREU)** for an international laboratory exposure mentored by a senior research scientist to a select exceptional group of prior year REU students, **(c) Laboratory Experience for Faculty (LEF)** that brings research experience opportunity to faculty from under-represented communities or institutions devoted to under-represented communities, **(c) Showcase for Students,** which is a day-long showcase of nanotechnology at major conferences devoted to underrepresented science and engineering students featuring hands-on table-top laboratory demonstrations with short lectures presented at major conferences, **(d) international Winter School for Graduate Students (iWSG)**, which teaches an advanced emerging nanotechnology subject area to a select group of US graduate students at a 3$^{rd}$ world institution combined with a rural field experience to appreciate the context in which technology impacts a large portion of the world's population, **(e) Symposia** - four times a year on major technical themes that bring together leaders for talks and discussions with users/participants to define challenges of critical/emerging/changing areas and possible NNIN contributions to them, **(f) Nanooze,** a web and print science magazine for middle school children, featuring interesting content delivered in an engaging manner, in support of curriculum and enrichment activity, **(f) Open Textbook,** a web-based senior/graduate level text that grows and changes with learning of the field, and **( g) Technical Workshops,** which are topical and hands-on workshops connected to research. Nearly 34,000 people have participated in these events during the year, including nearly a thousand in the technically rigorous workshops and symposia.

During 2010, NNIN's symposia included two: **Synergies in Nanoscale Manufacturing and Research** and **Interdisciplinary Challenges Beyond Moore's Law** that had a significant impact vector on federally supported research. Each brought together an invited group of leading academic and industrial researchers to examine the future of nanotechnology in these critical areas. Proceedings from both symposia are available on the NNIN web site.

Local activities from NNIN include day and longer camps for middle and high school students, local outreach through workshops for teachers, school and community-connected activities, and from Howard University, a laboratory on wheels that brings nanotechnology activities to high schools in eastern part of the country.


Figure 3: Selections from two issues of Nanooze. Up to 100 thousand copies of each issue of the print edition are distributed to classrooms around the country, free of charge.

**Computation and Modeling:** As a complement to its laboratory support resources, NNIN provides extensive computational and modeling resources in support of interdisciplinary problems that bring together theory and experiment. NNIN computational scientists (Ph.D. level, "Domain Experts") are available to support both experienced computational scientist as well as to experimentalists new to the computational area. In such cases, a domain expert staff member can help with selecting appropriate codes and modifying open source codes to extract new or novel information. Domain experts are in residence at Harvard and Cornell for science and engineering of problems evolving from condensed matter, at Stanford for problems evolving from interfaces, molecular dynamics and materials science, and at Michigan for problems evolving from fluidics and mechanics. In addition, NNIN has been expanding its initiative of providing a repository and archive of trusted the pseudo-potentials, interatomic potentials, input structure files, etc. This archive preserves and distributes vetted resources to computational scientists, providing a significant boost to both experienced and novice users.

Nearly 300 scientific research users, most of whom are graduate students, employ NNIN computational resources. During this year, publications appeared in prominent journals - Nature, Science, Applied Physics-Physical Review-Nano Letters, with subject areas across the breadth of problems ranging from chaos, ab initio thermal transport, fluid dynamics, multi-phase phenomena, interface and molecular chemical dynamics, and biological phenomena.

**Societal and Ethical Implications of Nanotechnology:** NNIN seeks the integration and development of a social and ethical consciousness within the NNIN user base as well and other network programs. SEI efforts within NNIN therefore embody both the network's research and educational pursuits. NNIN's efforts take advantage of the network's unique strengths as a national resource with geographic diversity, technical breadth and community interests, and, most importantly, the size of its user base.

Within its user community, NNIN provides SEI training and educational opportunities to all its users, through modules and supporting teaching materials as well as ongoing educational programs as well as selective incorporation of these into  network educational programs (REU, RET, workshops, symposia, etc). Collectively, NNIN users represent a significant fraction of nanotechnology researchers in the US, particularly in the academic arena. In addition, NNIN facilitates SEI research on its unique resource – the largest collection of nanotechnology users (students and professionals) representing both broad institutional communities (academe and industry) and broad technologies. NNIN provides researchers from across the country with access to the NNIN user base for social research, and supports these activities through competitive travel grants (outside NNIN) and seed grants (within NNIN).

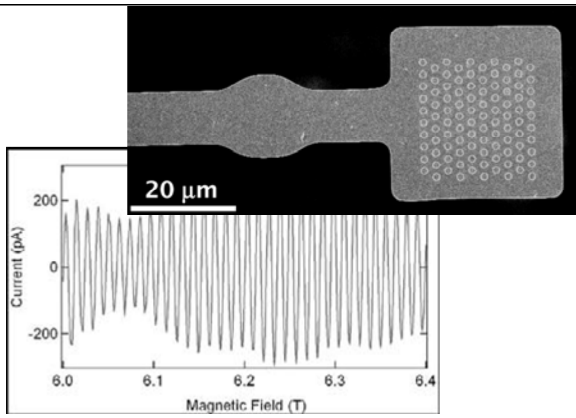
NNIN also supports small internal research efforts related to (a) understanding of interdisciplinary collaborations and their impact on research, (b) the impact on competitiveness and the process of technology transfer and industrial innovation and innovation by industry through NNIN, (c) impact of government-funded faculty research and the faculty's interaction with industry in technology transfer, (d) impact of intellectual exchange, openness and sharing such as in a network in conduct and impact of research, and (e) the ethical issues related to nanotechnology and fostering of ethical conduct. These research projects help sustain the critical mass of SEI activity necessary to support the education, training, and awareness activities of NNIN.

**Figure 4: One of five "Responsible Research in Action" posters available from NNIN.**

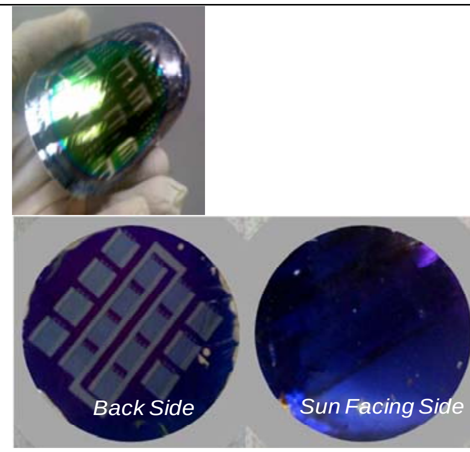
As a recent output of the SEI activity, a set of posters under the banner "Responsible Research in Action" for use in nanotechnology laboratories (Fig. 4) have been widely distributed both within the network and outside. These posters, developed by a Communications major as part of our REU program with input from focus groups of NNIN users at Cornell, promote subtle messages of responsible research conduct in an attractive and effective manner. Images are available for download from the NNIN web site, and high quality prints are available on request for posting in laboratory and student office areas.

**Examples of Scientific Impact from 2010:** The over 2500 publications resulting from work made possible by NNIN encompasses the breadth of nanoscale science and engineering. Over 250 research highlights in detail are available from NNIN's website. NNIN users have made significant contributions across the broad range of nanoscale science, engineering, and technology: electronic and photonic devices, novel electronic materials, sensors, and biomedical devices. These contributions include fundamental physical and biological measurements enabled by clever use of nanoscale structures as well as devices with significant market potential in the communications, health, and energy arenas. Figure 5 shows a few of the significant examples of nanoscale science, engineering and development by NNIN users during the past year.

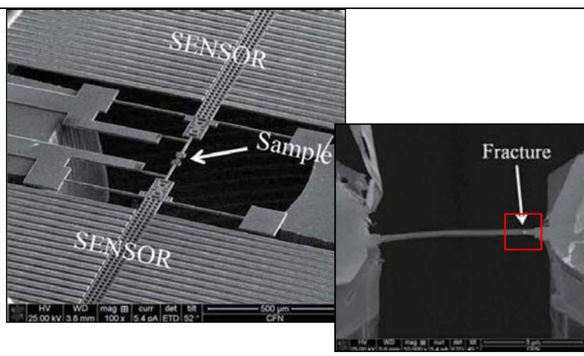
**Figure 5: Example of research highlights over a few different subject areas from external NNIN users.**



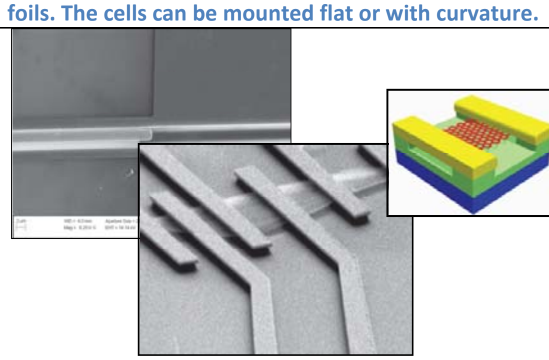

**a) Persistent Currents in Normal, i.e., Non-Superconducting Structures (Prof. Jack Harris, Yale University); The feasibility of observing persistent currents in a lossy disordered conductor was first predicted nearly thirty years ago. This quantum mechanical effect can only be observed in extremely small structure. These have been fabricated for the first time at NNIN and the effect demonstrated.**




**b) Thin Silicon Single Crystal Solar Cells (AstroWatt Inc.): Crystalline silicon solar cells comprise the largest segment of the PV market, but are based on thick substrates associated with a higher cost. Using small but optimal silicon thickness can reduce costs substantially and enable new applications due to flexibility of thin crystalline silicon. AstroWatt has developed a novel cost-effective process to make flexible 30um crystalline silicon wafers. This technology has also been demonstrated for other substrates such as Germanium and GaAs. Back-contact and hetero-junction solar cells have been fabricated on these foils. The cells can be mounted flat or with curvature.**




**c) MEMs Platform for SEM and TEM in situ Tension Experiments (Prof. H. Bau, U. Pennsylvania): An integrated MEMS device capable of real-time in situ SEM and/or TEM observation and quantitative measurement of the deformations on nanoscale samples has been fabricated and employed for *in situ* study of deformation phenomena. The group recently demonstrated the functionality of the MEMS device (top) with a nanoscale gold leaf sample that was integrated on top of MEMS device with a platinum welding technique. The MEMS device is employed to deform the platinum welded and focused ion beam (FIB) patterned gold leaf samples within the desired working range, as evidenced by the fracture noted in the SEM image.**



**d) Graphene NEMS Electrical Transducer (Prof. James Hone, Columbia University); Graphene mechanical resonators for high-speed electrical readout have been fabricated. These structures also allow the extraction of some fundamental graphene properties. The use of exfoliated graphite avoids the chemical contamination associated with the fabrication and thereby allows measurement of the intrinsic material properties. The pre-fabricated chips also employ a local gate that is better suited to RF operation.**
**This is one of many graphene related projects occurring at NNIN.**

Table of Contents

## Contents

## *Table of Figures*

# 1.0 Introduction to the Report

This report summarizes the efforts and progress over ten months during the $7^{th}$ year of the operation of the National Nanotechnology Infrastructure Network (NNIN) - the period from March 1 of 2010 through Dec. 31, 2010. This is the $2^{nd}$ year following the renewal of the network for its second five year term. The renewal took place with several major changes taking place in the network – in new sites joining the network (Arizona State, Colorado and Washington University in St. Louis), and in new technical and broader outreach initiatives that drew on the first five years' experience. The technical initiatives included enhanced and broadened emphasis in technical focus areas with major intellectual challenges in science or that needed concerted effort in technology development and engineering to address societal challenges. These technical directions included hard-soft interfaces for both biology and general engineering, energy, precision sciences, geosciences with a focus towards ocean and environment by leveraging sensors and systems development, environment and health, and in supporting through computation and modeling advanced interdisciplinary research such as by stronger connections to experimental research and building of open repositories for trusted information in support of advanced theory. The broader outreach initiatives included a national emphasis focusing on education and outreach, and societal emphasis, that drew on the network's unique strengths – its diverse technical capabilities afforded through the laboratory and technical personnel, its unique user community with technical diversity and unparalleled reach as the largest community of nano-oriented researchers, and the academic strength and geographic reach that it can leverage through its place in the national research and development pursuit. These newer efforts in educational and outreach activities in education: development of an international perspective in national student community, in helping open and explore new science and engineering frontiers through advanced symposia and workshops, and in development of societal and ethical consciousness through citizenship building and research studies to assess implications of nanotechnology, drew on the reach and the resources of the network.

The new sites are now thoroughly integrated: practicing and participating throughout our networked activities in research support and broader outreach. The newer technical, educational, SEI and outreach efforts have now been practiced for two years with very significant impact.

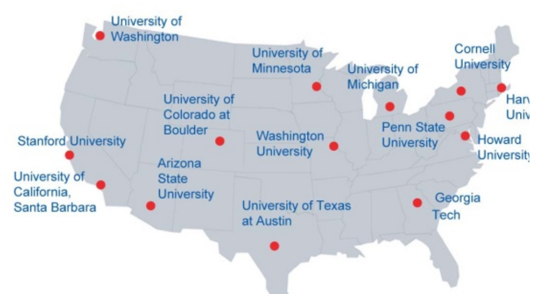
This report documents activities and highlights of the 2010 year. It includes statistics of usage and particularly focuses on progress and activities that NNIN initiated for renewed term. *Earlier reports have described NNIN functions and operations extensively and these will not be described here in detail.*

NNIN is funded via a cooperative agreement between Cornell University and NSF, which commenced on March 1, 2009. The current award period extends through Feb. 28, 2014.

# 2.0 NNIN Overview

The National Nanotechnology Infrastructure Network (NNIN) is a collective of fourteen university-based facilities with the mission to enable rapid advancements in nanoscale science, technology and engineering through open and efficient access for fabrication. It provides facilities-based infrastructure resource that is openly accessible to nation's students, scientists and engineers from academe, small and large companies, national laboratories, and others. It enables the reduction of ideas to practice by providing the capacity

*Figure 1: Map of location of NNIN Sites.*

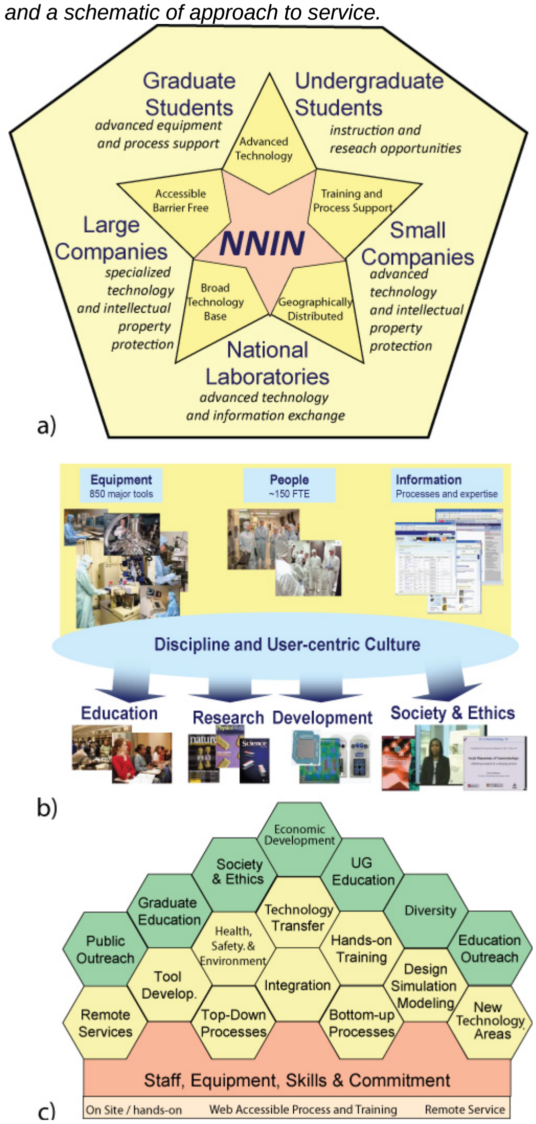


to explore materials, structures, devices and systems through access to tools, training and specialized knowledge for operating tools, through hands-on and remote operation, and through learning from diverse disciplines – all at affordable cost, minimum barriers and a few weeks of latency. NNIN also supports this experimental effort and other independent interdisciplinary theoretical effort through computational resources where the emphasis is on modeling and simulation in support of advanced scientific problems of nanoscale via open and tested software, hardware basis information, and in-depth support from advanced practitioners.  NNIN also leverages its infrastructure resources and geographic and institutional diversity to conduct other activities with broader impact: in education, in enhancing diversity in technical disciplines, in societal and ethical implications of nanotechnology and in health and environment.

## 2.1 Approach and Usage

NNIN's approach for supporting research and development has been to focus efforts on serving the external user and to use resources provided by NSF to predominantly fund the staff that trains users, assists them with their research and development tasks, and maintains the equipment and process resource. It is this staff, made possible by NSF funds and their leverage that helps users effectively utilize the large instrument set of NNIN sites.  Resources are optimized by connecting specific technical leadership offerings at a site to the intellectual strengths of the home institution, thus offering the most advanced knowledge and instrumentation to the user. When coupled with geographic diversity, this community approach also enables balanced and broad outreach.

*Figure 2:  Overview of NNIN operations. Its community, resources and a schematic of approach to service.*




The network is focused on providing infrastructure to support nanotechnology research by "outside users" — students and professionals from institutions outside of NNIN. In NNIN's view, infrastructure consists of much more than advanced equipment. While an extensive set of state-of-the-art equipment is a necessary condition it is not sufficient for the operation of an effective user facility. Key to NNIN operation and thus a key part of the "infrastructure" are the committed staff resources to enable effective use of nanotechnology equipment and a focus on service. NNIN's group of facilities are committed to this culture and operate as an organization supporting and complementing each other so that together  the network can be effective across the breadth of disciplines and geographically.

NNIN enables researchers, experienced and novice, by sharing with them the breadth of tools and the intricacies and knowledge of integrated processing where numerous materials and environmental interactions occur, and by focusing resources to help the users complete projects rapidly. Essential to efficient and productive operation is training of users on a large variety of equipment, maintaining the equipment for high uptime, supporting the users by sharing knowledge and previous experience, and keeping the facilities open 24 hours a day. Projects can be simple, requiring only one step or access to one advanced instrument; others can be very complex, requiring integration of multiple process steps and the use of novel materials. Openness to new materials is also a key feature on NNIN facilities. Nanotechnology extends to all forms of condensed matter and fabrication technology in order to build structures, devices, and systems. The ability and willingness to process new materials is critical for many emerging applications of nanotechnology, and is particularly critical at this moment of time where problems and research challenges related to energy and bio-sciences expand the materials of interest in science and engineering. A broad array of techniques applicable to a diverse palate of materials is necessary and is made available through NNIN facilities.

Our approach for achieving the objective of effective and efficient project execution is

- A true practice of openness at all sites based on serving external users,
- Making available state-of-the-art equipment resource, distributed across sites, and supported by a high level of technical staff expertise,
- Commitment to technical excellence that focuses on bringing key instrumentation and knowledge and training to users,
- Effective and leveraged use of scarce resources made possible by a critical mass of users engendered by successful projects and visibility of the network,
- Geographically distributed resources with distributed technical responsibilities, building upon the research and technology strengths of each site while serving the broadest community, and
- A synergistic set of local and national activities to support education of users, potential users, human resource development, and provide public outreach.

Each NNIN site has technical area responsibilities that are tied to the technical area strengths of the institution. NNIN sites, thus, do not provide identical capabilities but do provide a set of common widespread fabrication techniques *together with specialized technical area capabilities*. This allows one to provide world-leading expertise that is unique to each site based on its history, interests of the local faculty and resources. The network is a distributed set of laboratories, each with distinctly local flavor, but all working to a common goal and with a common approach. This shared vision is critical to the operation of the network. To achieve this vision, all sites have committed to the following common principles:

- Open and equal access to all projects independent of origin,
- Single-minded commitment to service of external users,
- Commitment to support interdisciplinary research and emerging areas,
- Commitment to deepening social and ethical consciousness,
- Facility control, not individual faculty ownership, of instruments and other resources,
- Openness to new materials, techniques, processes, and applications,
- Commitment to maintaining high equipment uptime and availability,
- Commitment to comprehensive training and staff support,
- Facility governance dedicated to national networked support independent of interference from other local organizations, and
- Commitment to no intellectual-property barriers.

These principles are critical to NNIN's operational success; they separate NNIN facilities from other research facilities which try to support user access as a secondary rather than a primary mission. This approach also avoids any conflicts of interest that arise in conduct of research when multiple investigators are pursuing similar directions. These principles have served NNIN well and have allowed it to make the unique and large-scale contributions as a successful national infrastructure resource.

NNIN efficiently utilizes its resources by tying intellectual strengths of a university to leadership responsibilities for serving related disciplines. This assures that the state-of-art instruments and advanced knowledge, experience, and approaches (including processes and the idiosyncrasies that only time provides) is available to external user and the local university users also benefit. The table shows leadership and contributory responsibilities of the sites within the network.

**Table 1---NNIN sites and technical competencies and leadership areas.**

**L=Leadership, x=assigned technical areas**

| | Bio & Integrated Systems | Chem. & Molecular-Scale Tech. | Electronics, Optics & MEMS | Bio & Life Sciences | Materials & Physical Sciences | Computation | Geo-Sciences | Man'f Res. Support/Tool Dev | Remote Usage Support | Inorganic-Organic Interface | Energy | Precision Sciences & Engineering | Environment & Health | Society & Ethics | Education | Diversity Outreach |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cornell** | x | x | L | x | L | L | x | x | L | x | x | L | | L | L | x |
| **Stanford** | x | x | L | x | L | L | x | x | L | x | x | x | x | L | L | x |
| **Georgia Tech** | x | | x | L | | | x | | x | | | | | x | L | L |
| **Michigan** | L | | x | x | | L | L | | x | x | | | | | x | x |
| **Harvard** | x | L | x | | x | L | | x | | | | x | | | x | x |
| **UCSB** | | | x | | L | | | | | x | | x | | | L | L |
| **Minnesota** | | | x | | x | | x | | x | | L | | | | x | x |
| **Penn State** | | L | x | | x | | | x | | x | | | | | x | x |
| **Texas** | | L | x | | | | | L | | | | | | | x | x |
| **Washington** | | | x | L | | | L | | | | | | x | x | x | x |
| **Howard** | | | x | | x | | | | | | | | | | x | L |
| **ASU** | x | | x | x | | | | | | L | | | | | x | L |
| **WUStL** | | x | | | | | | x | | | | | L | | x | L |
| **Colorado** | | | x | | x | | | | | | L | L | | | x | L |

Together, these practices have established NNIN as a model shared laboratory environment that embraces interdisciplinary research and builds upon the nanoscience and nanotechnology expertise resident at each of our member sites. This infrastructure support for nanotechnology research enables NNIN to play a leading role in the development of the scientists, engineers and high-technology work force of the future. Through these activities and a thrust in examining the societal and ethical implications of nanotechnology, we directly impact the national scientific landscape that extends beyond the scope of nanotechnology itself.

## 2.2 Practices for User Support

NNIN practices to support and train users and to bring in new users continue to evolve with learning and experience. External user support, training, and procedures are the focus of this approach. This in turn benefits the internal users because of the efficiencies created. The procedures are however not simple to implement in a traditional university environment where multiple interests co-exist. Through the leadership of NNIN derived from its evolving experience, and their documentable impact – locally and nationally, the participating sites in NNIN have adopted, implemented, and embraced these methods. This section summarizes the NNIN practices and mechanisms implemented by NNIN to enable effective research and development support.

### 2.2.1 User Facilities

The facilities of NNIN are resource facilities, i.e., the primary mission of NNIN and its individual sites are to facilitate the research of others.

This is accomplished by providing equipment, processes, staff support, and instruction to all feasible projects. *The NNIN sites are specifically not research centers and NNIN is not a research program.* This distinguishes its approach and effort from other center-based programs, including STCs, ERCs, NSECs, MRSECs, etc., which are primarily research centers. While the facilities of these research centers may be available to some collaborators, they are primarily maintained to support the research mission of the center; furthermore, such research centers rarely have the staff or user support mechanisms in place to assist users from other unaffiliated research programs. The NNIN facilities thus do not have a particular research thrust or a portfolio of research thrusts. NNIN does not fund research at the site by resident faculty or staff (except in society and ethics thrust). Similarly, NNIN does not directly fund user projects from outside users. The user base thus defines the direction of their research in NNIN, and we avoid the conflicts that arise between conducting research and supporting research through this clear distinction. At most NNIN universities there are resident research programs —NSECs, MRSECs, STCs, ERCs, etc., as well as non-NSF centers — which use the facilities heavily and provide critical knowledge and information. *These programs, related "research centers", and their associated students provide much of the technology base, process development, and process characterization at each site, which is critical to the success of diverse user projects.* A prime tenet of NNIN is, however, that all users are equal and the facility is equally open to all. NNIN sites are expected to clearly separate research tasks from the user facility tasks so that even researchers from competing research programs have fair and equal access to all site technology. The NNIN facility staff is distinct from any associated research staff. This separation is a cornerstone of NNIN operation and distinguishes the NNIN from other organizations.

*NNIN also removes intellectual property concerns by placing the responsibility for protecting confidential information on the user.* They are expected not to share information that they wish to protect for patents or as trade secrets. Being academic facilities, at least within the academic community – internal and external– NNIN fosters an environment of sharing so that researchers can focus on their own specific interests, rather than duplicating work or uncovering knowledge known to another practitioner.

### 2.2.2 NNIN Project Support, Process Support and Training

NNIN facilities are primarily hands-on facilities. Users are trained by the staff to become self sufficient. NNIN also serves users remotely without the necessity of a working visit to the site. These are for projects involving a selection of reproducible and specialized processes and process sequences that are essential to a variety of tasks (thin low stress membranes, selective etchings, deep etches, coatings, fine-line lithography, etc.) and don't themselves involve new research or development. These tasks can be performed remotely by a NNIN staff member. NNIN, however, does not operate as a foundry of complex integration. The execution of a complex multi-step process sequence is itself a research project and performed by the user. Most users, from academia or industry, are performing research and development and wish to be part of the hands-on process of research - to learn from the staff, and become self sufficient.

Each site is responsible for providing sufficient staff resources to enable comprehensive training and support for external research projects. Currently, NNIN trains approximately 2000 new users per year, with a total of over 5700 different users taking advantage of NNIN laboratory facilities each year. Safety training, including a component devoted to development of societal and ethical consciousness, is mandated for all users prior to any activity. Each external user project is assigned to a staff mentor who is the primary contact for the technical support. Instruction in all phases of nanotechnology is provided as necessary in addition to direct equipment instruction. The NNIN staff act only as facilitators; the technical and intellectual direction of each project remains with the user. As projects progress, users become more independent of NNIN staff support, many to the point of being self-sufficient. NNIN staff remains available, however, to provide support as necessary.

Accommodating large numbers of new users arriving weekly and training them to operate safely and creatively in a shared-facility environment is the most critical aspect of network operation. With a high level of training and process support delivered by a dedicated professional staff, complex technologies such as e-beam lithography and complex multi-step integrated processing procedures can be made available to a large user community in an efficient and timely manner. At the same time, new techniques and processes, developed either by the staff or by the user community, can be efficiently and effectively made available for the mutual benefit of all users, at the site, and across the network.

## 2.3 Activities Overview for 2010

2010, as the second year following renewal with its new initiatives, has been a very active year where, with the integration of new sites and the experience of the first year of the new initiatives, the network executed at full strength. 2010 also brought to completion and fruition the expansion and renewal of the equipment infrastructure of NNIN made possible by American Recovery and Reinvestment Act (ARRA) funds.

While the rest of this report will explain in more detail, some of the salient milestones of the diverse network activities included:

a. **Network usage:** The network usage is increasing in the high single digit rate per year and over the 2010 10 month period, 5405 users employed the resources. The usage is broadly distributed in disciplines. During this 10 month period 1897 new users were trained in the use of a large instrument set. Average costs incurred by academic users, who came from 188 universities, is below \$3000 for the 10 month period (lower than \$2000 for external academic users) for in excess of 100 hours of equipment access. This cost continues to be an affordable sum for research projects. Over 330 small companies and 58 large companies, with over 800 industrial scientists, are using the facilities for their research and development efforts. The graduate student community of 4200 users of NNIN reflects between 15 and 25% of experimental science and engineering student community that potentially needs the type of resources NNIN provides.

b. **Research and development impact:** The network's contributions are reflected in over 2500 publications that appeared over a year-long period and collected in July, 2010. Highlights of the research and development span the breadth of intellectual interests. Examples include fundamental measurements such as of single phonons, persistent currents in normal metals, attonewton measurements of dielectric fluctuations, mechanical control of spin states in single molecules, single photon sources for quantum explorations; biological applications such as use of single-walled nanotubes for DNA sequencing, use of nanoporous membranes for hemofiltration; energy applications such as self-pumping and self-breathing fuel cells, thin crystalline as well as nanowire solar cells and information technology related applications such as MEMS based mobile projectors, and new forms of phase transition memories.

c. **Advanced Scientific Computation and Modeling:** In excess of 100 advanced research users working at the limits of discipline and at interdisciplinary boundaries are employing the knowledge of the NNIN computation staff and the one-of-kind academic software available from NNIN. Their effort is reflected in 27 publications in leading journals – Nature Chemistry, Nano and Physical

Review Letters, etc. The cumulative impact of NNIN computation effort since its start in 2004 is reflected in about 11 citations per publication over 120 publications, with an h index of 22. A user, Zoe Boekelheide, graduate student at UC Berkeley, won the 2011 Group on Magnetism and Magnetic Materials (GMAG) Dissertation Award sponsored by the American Physical Society for her work on the effects of nanoscale structure on magnetic and transport properties of chromium and chromium-aluminum alloys. The virtual vault, a trusted repository of critically important but difficult to obtain scientific information, now includes over twelve different pseudopotential databases, ten pseudopotential generators, four pseudopotential generators, and links to key references on pseudopotentials.

d. **Education and outreach:** The broad portfolio activity encompasses the spectrum of age group and technical knowledge. Through the diverse events, NNIN reached nearly 34000 individually during the 2010 year.

    i. **Symposia and Workshops:** NNIN organized three major symposia during the 2010-11 period where leading practitioner and visionaries assemble for talks and discussions of challenges and in defining future directions. The symposia subjects were Nanotechnology and Energy held at University of Colorado, Inorganic/Organic interfaces in Health Sciences at Arizona State University, and "Challenges Beyond Limits of Moore's Law" that was organized in Arlington in close proximity of NSF with NSF support. In addition, NNIN organized numerous workshops with technical education objective.

    ii. **Nanooze** is a children's magazine, a website resource, and a hands-on museum-quality exhibit for elementary to middle-school age children. 8 issues of the print edition are now available and nearly 100,000 copies distributed by direct mailing upon request. The Exhibit opened in February 2010 at the Innovations Center at Epcot Center at Disney World and is being visited by hundreds of thousands of visitors each year.

    iii. **REU** (Research Experience for Undergraduates), a hands-on nanotechnology research experience across the breadth of disciplines had 80 participants across the network.

    iv. **iREU** (international Research Experience for Undergraduates), a summer research program at National Institute of Materials Science (NIMS) in Japan, Forschungszentrum (Helmholtz Institute, Jülich) in Germany, and IMEC in Belgium had 19 undergraduate students from across the nation participate in a second research experience under close supervision of a senior scientist

    v. **iWSG** (international Winter School for Graduate Students), a technical and global awareness activity in which a technically advanced emerged area is taught internationally together with a society and ethics component with exposure to third world environment. The 2010 edition was taught at Indian Institute of Science in Bangalore by five USA faculty. 13 nationally selected graduate students participated together with more than 100 students from across India.

    vi. **iREG** (international Research Experience for Graduates), a reciprocal program of partnership with NIMS brought 5 Japanese graduate students and were hosted at NNIN laboratories for a summer research experience. Georgia Tech, University of Michigan and University of Texas participated in this year's program. The costs of the travel, housing, and stipend for the participating students are borne entirely by NIMS.

    vii. **LEF** (Laboratory Experience for Faculty), a summer REU-like program for under-represented faculty or faculty at under-represented serving institutions had 9 participants hosted at Georgia Tech, Stanford, Michigan, University of Washington, Cornell, Texas and Howard. This program helps the faculty establish viable research program and provides a nanotechnology experiences which can be incorporated into their classroom environment.

viii. **Nanotechnology Showcase** is a day long event consisting of lectures and hands on experience activities designed for increasing awareness among underrepresented undergraduates. NNIN held a Showcase at Society of Hispanic Professional Engineers during the past year reaching more than 200 undergraduate students.

e. **Societal and ethical implications of nanotechnology:** Our SEI effort participated in the training of over 1900 new users through discussions, presentations, and training modules, reaching the community of new NNIN users. NNIN also provided travel grants to external researchers for leveraging NNIN's unique community in SEI studies. C. Mody of Rice University is studying nanoscale research communities and interdisciplinarity through a look at NNIN users' perceptions. E. Fisher is exploring the integration of SE considerations in nanoscale research. In addition. 8 publications discussed the results of SEI research conducted by NNIN SEI researchers. SEI also participating broadly in the network's educational activities and conducted a workshop at Washington University in St. Louis.

Details of these accomplishments as well as other activities are given in subsequent sections of this report and in some cases in the individual site reports.

### 2.2.1 Facilities Expansion

Significant facility expansion and construction, a near doubling of space, was completed at University of Colorado during this period. Washington University at St. Louis, has also completed the renovation and equipping of new space devoted to environment and health studies through creation and analysis of impact of nanoparticles and other nanoassemblies. At Cornell University, equipment and resources formerly used in support of nanobiotechnology are now fully integrated within CNF's cleanroom space. Extensive new facilities at Penn State facility are nearing completion. Significant activity took place at Georgia Tech and Michigan in fully occupying and integrating their recently built facilities. Since 2004, nine major facilities expansions or constructions have taken place at NNIN sites. In total, eight entirely new facilities (Cornell, UCSB, Harvard, Michigan, Washington University at St. Louis, and University of Colorado, Georgia Tech; PSU under construction) represent an investment by the universities and state governments of a fair fraction of a billion dollars. The affiliation with NNIN is an important force in justification of these expenditures by state and universities since sustainable operations of the resources becomes possible through the critical mass of users that come via NNIN participation. NNIN is a key factor in the business model that makes these facilities affordable. While these expenditures are made to enhance the local university's capabilities and stature, NNIN and its users receive enormous benefit from this significant investment in infrastructure.

### 2.2.2 New Equipment-ARRA

Equipment sustainability and acquisition of new capabilities has traditionally been a major challenge to facilities of NNIN. Nearly all of the funds that NNIN receives from NSF and the user fees are employed for staff who train and help users and maintain equipment, and towards consumables. The traditional NNIN route to equipment acquisition is through donations from companies, gift funds, opportunities local to universities, and national competition. This route usually works in bringing exceptional novel and new capabilities to sites, but not for traditional workhorses or replacement of old tools. NSF, as part of ARRA, provided NNIN with $10M of funds for equipment acquisitions. These funds were made available in summer of 2009. The methods and rationale for allocation of these funds to the NNIN sites have been described previously. Briefly, NNIN sought to provide funds for those core pieces of equipment that while providing necessary capabilities would be hard to fund via a stand-alone proposal.

In the end, the 10M$ of funds was allocated to the NNIN sites for the purchase of 46 pieces of identified equipment. NNIN sites, working together, were able to leverage these funds in buy-out to extract significant discounts through coordinated negotiations, allowing the purchase of several additional pieces of equipment (full or partial) with the ARRA funds.

**Table 2: ARRA purchases**

| | | | |
|---|---|---|---|
| 1 | Cornell | Advanced High Resolution Pattern Generator | Available |
| 2 | Cornell | Contact Mask and Bond Aligner | Available |
| 3 | Cornell | Expanded Range Film Thickness Measurement | Available |
| 4 | Cornell | Ion implanter Computer Upgrade | Available |
| 5 | Cornell | Atomic Force Microscope | Available |
| 6 | Stanford | Plasma Enhanced CVD System | Installation |
| 7 | Stanford | Electron Beam Evaporator System | Available |
| 8 | Stanford | Flexible RF/DC Research Sputtering System | Available |
| 9 | Stanford | Versatile Atomic Layer Deposition Tool | Installation |
| 10 | Michigan | Inspection SEM- | Available |
| 11 | Michigan | Image Reversal Oven | Available |
| 12 | G Tech | Monochromated small-spot X-ray Photoelectron Spectrometer (XPS) System. | Available |
| 13 | G Tech | Plasma Enhanced Atomic Layer Dep. System | Available |
| 14 | GTech | Confocal Microscope | Available |
| 15 | Penn State | Advanced Optical Microscope | Available |
| 16 | Penn State | Electroplating System with full wafer capability | March 2011 |
| 17 | Penn State | Stylus Profilometer | Available |
| 18 | Penn State | Ion Beam Assisted and Conventional Sputter Deposition chamber for existing sputter tool | May 2011 |
| 19 | Penn State | One Atmospheric and Two LPCVD Stack | May 2011 |
| 20 | U. Minnesota | Sputtering System | Installation |
| 21 | U. Minnesota | High Throughput RIE | Installation |
| 22 | U. Minnesota | High Resolution FE-SEM (refurbished) | Available |
| 23 | UCSB | Field Emission SEM for Insulators | Available |
| 24 | UCSB | Spectroscopic Ellipsometer | Available |
| 25 | UCSB | Xenon Difluoride Etching System | Available |
| 26 | U. Washington | Sputtering System | Available |
| 27 | U. Washington | Reactive Ion Etch System | Installation |
| 28 | U. Washington | Maskless Photolithography Tool | Available |
| 29 | U. Washington | Rapid Thermal Annealer | Available |
| 30 | Harvard | Sputtering System | Available |
| 31 | Harvard | Microfluidic Lithography Station | Available |
| 32 | Harvard | Plasma Enhanced CVD of Diamond | Available |
| 33 | Howard | Surface Profiler | Available |
| 34 | Howard | Spin Coaters (x4) | Available |
| 35 | Howard | Contact Mask Aligner | Available |
| 36 | Howard | Field Emission SEM | Available |
| 37 | Arizona State | Optical Contact Aligner (photolithography) | Available |
| 38 | Arizona State | Plasma CVD | Available |
| 39 | U. Colorado | ICP Deep Silicon RIE Tool | Available |
| 40 | U. Colorado | Photomask Pattern Generator | Available |
| 41 | U. Colorado | Maskless lithography Tool | Available |
| 42 | Wash. U. St.L. | Particle Image Velocimetry (PIV) | Available |
| 43 | Wash. U. St.L. | Particle Characterization incl. zetapotential | Available |

| | | | |
|---|---|---|---|
| 44 | Wash. U. St L | ICP-MS | Available |
| 45 | U. Texas | Deep Silicon Etch | Available |
| 46 | NNIN | Mobile SEMs for Education (2) + 1 EDX detector | Available |

These funds were allocated in 2009. Purchase orders were placed during 2009 and early 2010. During this FY10 period most of the equipment arrived and was installed and is now operating in support of NNIN users. The final few pieces of ARRA funded equipment will arrive during this quarter. The Penn State equipment, for example, is being installed directely into the new facility which is being commissioned this quarter. Equipment acquisitions at the individual sites are discussed in the site reports in section 7.

## 2.3 Examples of Scientific Impact from 2010

The over 2500 publications resulting from work made possible by NNIN encompass the breadth of engineering, and physical and life sciences where small scale brings exquisite disciplinary and interdisciplinary problems of materials, structures, devices, systems. A publication list over the period July 2009-June 2010 is available as supplementary material to this annual report. These are all available from NNIN's website and they range from fundamental measurements, to molecular and supra-molecular scale structures where technology and devices are practiced, and applications where significant integration is brought together in physical and life science and engineering disciplines.

Some examples that show the breadth of the activity's impact in sciences and engineering are shown in Figure 3. Figure 3(a) summarizes persistent current measurements in a lossy disordered conductor. This persistent current is similar to the net orbital angular momentum of the electrons. For this persistent current to be appreciable, the circumference of the ring must be of the same order of magnitude as both the electron phase coherence length in the metal and the thermal length, both of which are on the micron size scale for milli-Kelvin temperatures. The persistent current in a normal metal ring can only be observed when the ring is closed, meaning that a direct current measurement is not possible. Since the ring is small, the magnetic moment associated with it is small. This moment can now be measured using micromechanical cantilevers with metal rings integrated near the cantilever tips which act as sensitive torque magnetometers. Prof. Jack Harris of Yale University conducted this research.

Figure 3(b) summarizes quantum ground state measurement of mechanical system, i.e. a single phonon measurement. This, until now, has been a long-standing challenge, hindered by the difficulty of cooling a mechanical mode to its quantum ground state. The temperatures required are typically far below those attainable with standard cryogenic methods, so significant effort has been devoted to developing alternative cooling techniques. Once in the ground state, quantum-limited measurements must then be demonstrated. In this work, Prof. Cleland, using conventional cryogenic refrigeration, cooled a mechanical mode to its quantum ground state by using a microwave-frequency mechanical oscillator—a 'quantum drum'—coupled to a quantum bit, which is used to measure the quantum state of the resonator. This method shows the control of the creation of single quantum excitations (phonons) in the resonator, thus taking the first steps to complete quantum control of a mechanical system.

Figure 3(c) shows a recent NY Times article highlighting work in retinal implants, particularly an effort by Prof. Wyatt of MIT conducted in NNIN. This work aims to restore useful vision to patients who are blind with degenerative retinal diseases whose major causes are retinitis pigmentosa (a primary cause of inherited blindness) and age-related macular degeneration (the leading cause of blindness in the developed world). Both of these diseases cause the eventual destruction of the photoreceptor cells in the retina, leaving intact the ganglion cells which transmit electrical impulses (and hence visual information) to the brain. The ganglion cells may be stimulated, however, with biphasic current pulses from a microfabricated electrode array. The new generation of these structures now allows wireless monitoring of the electrode voltage waveforms.

Figure 3(d) shows the use of single walled carbon nanotube, used as a nanopore in an electrochemical cell, where the current can be measured during transport through the tube. The structures are assembled using soft materials, provide reservoirs for the channels to be connected for transport, together with the means for electrical measurement. The approach offers new routes to controlling translocation of molecules such as DNA. This work was joint research from Columbia, Oakridge Labs, and ASU.

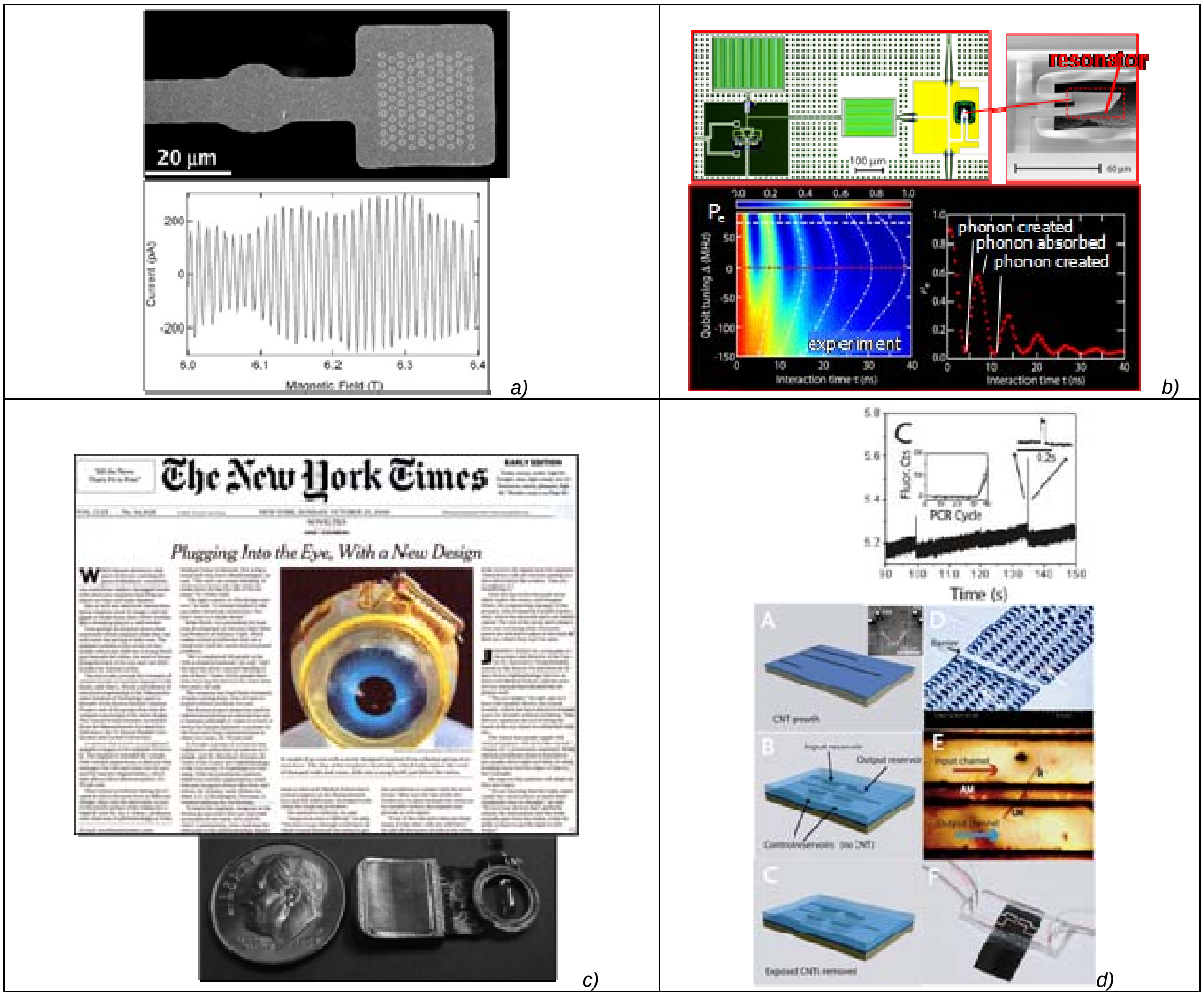



*Figure 3: a) Measurement of persistent currents in lossy disordered conductors, a quantum effect that becomes observable when phase coherence length and ring circumference are close to each other, has now been measured by using a highly sensitive torque magnetometer (Science, 326(2009). (b) shows single phonon measurements – i.e. a quantum demonstration in a mechanical system made possible by coupling a quantum state of the resonator to a quantum bit (O'Connel et al., Nature, 464 (2010) (c) shows progress in retinal implant development where ganglion cells can now be reproducibly stimulated, and wirelessly monitored. This work continues to be studied clinically and is being conducted by Prof. Wyatt of MIT. (d) the use of single walled carbon nanotube as a pore that enables sequencing of large molecules such as DNA through electrical current measurements in an electrochemical cell. (Liu et al., Science 327 64 (2010).*

## 2.4 Network Management

As a large group of university based laboratories in a very diverse technical area encompassing nearly all the areas of science and engineering serving a user community spanning academia, industry and national laboratories, and a multifaceted outreach mission, a cohesive, responsive and stream-lined management is essential for the NNIN to achieve its network goals and for the standards for operation and support of users to be maintained. Management is responsible for coordination of intra-network activities and for various levels of reporting to NSF, NNI, and others. The management structure of NNIN also has to take into account the large number of network university sites, the individuality of universities and their environment and yet has to be flexible, responsive and adaptive to the evolving environment of nanotechnology research. Our management structure and procedures follow the format outlined in the NNIN proposal.

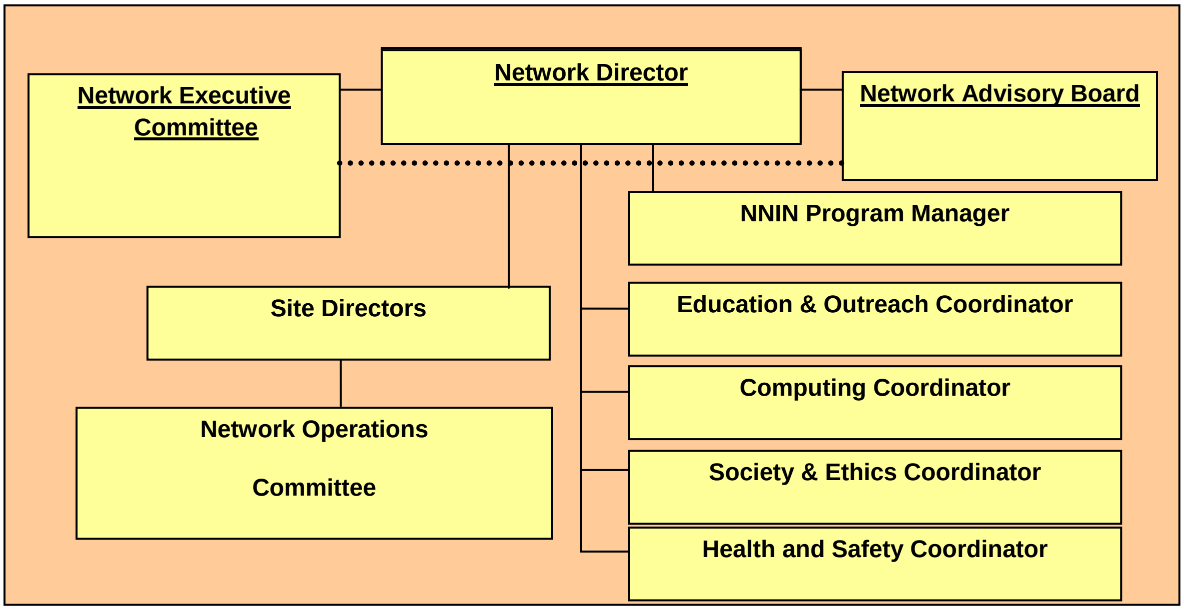



*Figure 4: Network Management Structure.*

Figure 5 shows the broad outline of the organizational structure. Currently, Prof. Sandip Tiwari, Cornell University, the NNIN Network Director, is the point of contact with NSF, and is responsible for implementing the network policies and program. Dr. Lynn Rathbun, Cornell University, serves as the NNIN Program Manager coordinating the daily activities and communication with network sites.

Four Network Coordinators are responsible for the broad outreach activities areas across the network.

- Education & Outreach: Dr. Nancy Healy, Georgia Tech,
- Society & Ethical Implications in Nanotechnology: Prof. Katherine McComas, Cornell,
- Computation and Modeling: Dr. Mike Stopa, Harvard, and
- Environment, Health and Safety: Dr. Dong Qin, Washington University at St. Louis

For the purpose of implementation of the program and policies, the Network Director and the Program Manager interact directly and regularly with the site directors and the coordinators of thrust activities. The Site Directors are responsible for the operation of individual sites. A complete list of Site Directors is provided in Appendix. The network management hosts a conference call with the Site Directors as a group at least once every two months.

The Network Executive Committee (NEC), chaired by the Network Director, sets the vision, policies, operating procedures, evolution, and manages the allocation of the NNIN resources. NEC has 3 permanent members — the Network Director and the site directors at Cornell and Stanford — and 3 members elected from the other sites. The Network Coordinators also participate in the Network Executive Committee discussions. The NEC meets monthly by conference call, or more often, if necessary.

For 2010, the Network Executive Committee consisted of

- Prof. Sandip Tiwari
- Prof. Dan Ralph (Cornell University)
- Prof. Yoshio Nishi (Stanford University)
- Prof. James Meindl (Georgia Tech, term expires 2011)
- Prof. Steve Campbell (University of Minnesota, term expires 2012)
- Prof. Mark Rodwell (UCSB, term expires 2012)

In 2011, Prof. Khalil Najafi was elected to replace Prof. Jim Meindl. Prof. Roger Howe has also replaced Prof. Yoshio Nishi as the Stanford site director and as a member of the network executive committee.

The Network Director and the Network Executive Committee receive advice from the Network Advisory Board (NAB), an independent body of leaders and thinkers of the disciplines and communities that the network serves. The NNIN advisory board represents eminent scientists, engineers, and administrators. The advisory board members are a cross-section representative of the nanotechnology user areas and are individuals with stature, experience and independence that can help the network evolve through critical advice and guidance of programs, activities, vision and future directions.

The members of the Network Advisory Board are:

**Dr. Samuel Bader**; Assoc. Div. Director, Materials Science Division, Argonne National Lab

**Dr. Carl Kukkonen**; CEO, ViaSpace Technologies

**Prof. George Langford**; Dean of College of Arts and Sciences, Syracuse University

**Dr. Jim McGroddy**; Retired Senior VP, Research, IBM

**Prof. Hans Mooij**; Chairman, Kavli Institute of Nanoscience, Delft Univ. of Technology

**Prof. Paul Peercy**; Dean of Engineering, U. Wisconsin

**Dr. Kurt Petersen**; Entrepreneur and consultant

**Dr. Tom Theis**; Director of Physical Sciences, IBM Research

**Prof. Vivian Weil;** Director, Center for the Study of Ethics in the Professions, Illinois Institute of Technology, Chicago

The advisory board meets, in person, at least once a year, by conference calls, and is consulted by phone and group email by the NNIN Director at critical times.

## 2.5 Network and Site Funding-Year 8 (2011)

NNIN has been funded by a primary cooperative agreement between NSF and Cornell University at the level of $17.0 M for years 6-10. Almost all of these funds are distributed to sites for local programs. Some funds are retained at the NNIN office for management. Other funds are retained at the NNIN office for network programs. The majority of those funds are either spent directly on programs or distributed to sites as supplements to execute national programs at the local sites.

The budget is outlined in Table 3.

| Table 3 NNIN Annual Funding by Site | Year 8 baseline budget |
|---|---:|
| Cornell | $2,675,000 |
| Stanford | $2,675,000 |
| Georgia Tech | $1,590,000 |
| Michigan | $1,275,000 |
| UCSB | $875,000 |
| Harvard | $825,000 |
| U. Minnesota | $775,000 |
| Penn State | $750,000 |
| U.Washington | $725,000 |
| U. Texas | $700,000 |
| Howard Univ. | $550,000 |
| Arizona State | $500,000 |
| U. Colorado | $500,000 |
| Wash. Univ. in St. Louis | $500,000 |
| Network Coordination | $372,855 |
| Network Activities and Programs (central) | $1,712,145 |
| | |
| Total | $17,000,000 |

This budget distribution currently remains the same as for the prior year. Depending on the outcome of the year's activities, execution on commitments, and network's activity evolution, the budget distribution can change from year ot year and have in the past.

The NNIN Activities budget is for network-scale activities, including participant support for various programs (REU, iREU, LEF, iWSG, Showcases), network booths at outreach activities and professional meetings, support of Symposia and Workshops, Advisory Board and Annual Meeting, etc. Much of this budget is sub-awarded to sites annually. The mix of activities funded under this budget changes annually based on new initiatives and feedback on existing programs and initiatives. Retaining these funds at the network level, at least initially, gives maximum flexibility in meeting the changing program needs.

A more complete explanation of funding and program allocation is given in the Budget Justificaiton for year 8 funding supplied to NSF.

## 2.6 Network Performance

For NNIN to deliver the greatest possible value to the national user community and the nation, it is essential that the network be a dynamic organization that rewards performance and systematically adapts to changing circumstances and emerging opportunities. During formation of NNIN, we committed to making funding allocations yearly based on productivity metrics and on the basis of leadership contributions in research service in areas of assigned responsibilities and the other NNIN thrust areas. A balanced evaluation requires understanding of responsiveness to user needs, the quantity and quality of output from the individual sites, the needs of different types of usage, and the changing requirements of new and rapidly developing fields. Sites are expected to allocate resources in accordance with the assigned focus areas and are held specifically accountable for success in those areas.

We distinguish experimental R&D usage, i.e. research usage, from educational usage that is in support of our broader outcome objectives. Research usage is in support of a specific research task, supported by research funds whose end result are publications for academic users, or new technology and commercialization-oriented development for the industrial users, and new knowledge for both. Educational and other broader area usage has as its goals training or knowledge dissemination. Technical workshops that we conduct, e.g., are in educational usage. On the other hand, an external user, who comes to facilities, gets trained and uses resources to accomplish their own technical tasks, is a research user when we count in our user statistics for experimental support.

We also collect statistics related to Scientific Computation and Modeling activities separately because of the different nature and needs of this activity.

Evaluating performance in this context is a complex task since it must balance between the nature of the activity and its requirements and needs and an appropriate evaluation of the contribution. Research user support and educational user support require different resources and scientific computation users also require a very different type of attention and support. Similarly, within research user support activity, different tasks may require different level of time and intensity of commitment from staff as well as of the level of complexity of instrumentation. Thus, data needs to be looked at in a variety of ways in order to assess the performance. In addition to quantitative measures, a qualitative evaluation of the enabled research also sets a different context of performance evaluation. Impact of the activity is also critical, and hence quality and quantity of research contribution enabled by site activities, particularly in the area of site focus, is an important consideration in performance evaluation. NNIN focuses on collecting information that helps with forming a balanced and relatively complete picture of the network operation. For research quality, this includes collection of highlights of research and development, related publications and presentations, the impact of the scientific research, as well as quantitative measures that look at research and educational user service.

A list of publications resulting from network efforts during a one year period is attached to this report together with research highlights.

The different components of the NNIN mission - research-user services, computation and web-based services, education and outreach, and the societal and ethical thrust - each requires separate measures to evaluate productivity, quality of contributions, and user satisfaction.

NNIN sites also vary considerably in size and scope of effort related to NNIN. Consequently, the level of funding and the resultant expectations vary accordingly with the following guidelines:

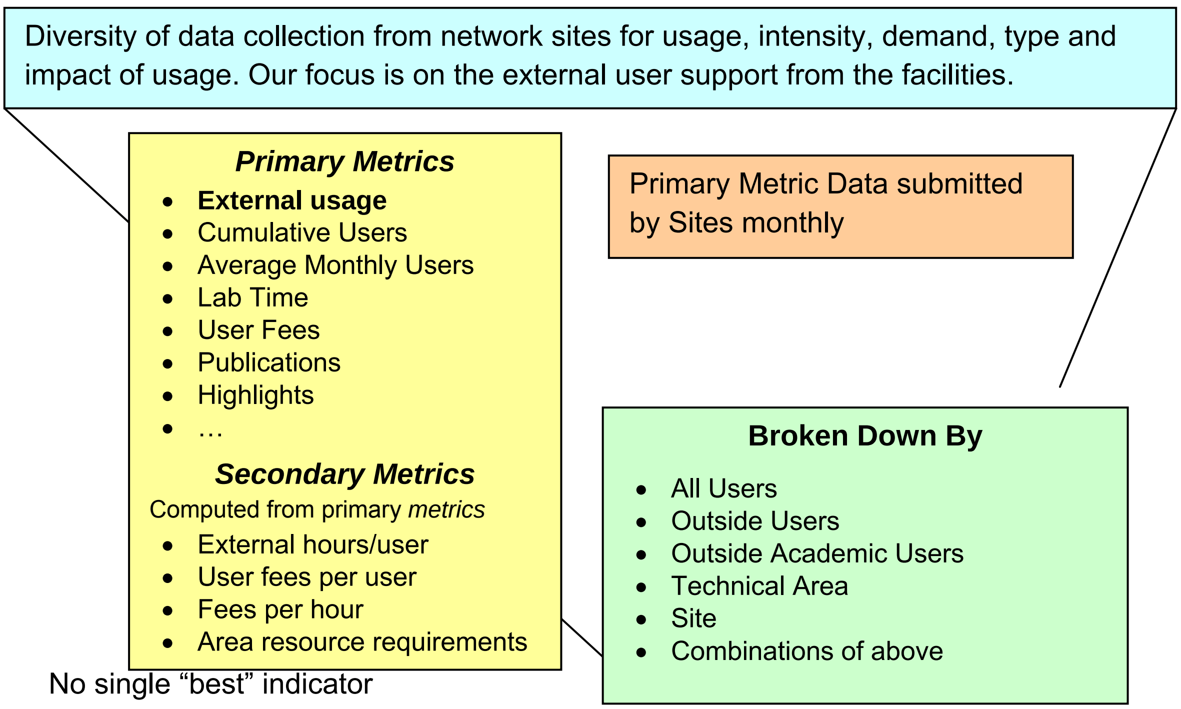
- The range and volume of service that each site can, now and in the near future, provide to outside research users in specific technical areas assigned to it;
- The infrastructure needs of the technical focus areas that are supported by each site;
- The infrastructure needs for the educational efforts and educational user activities — activities that are different in character than research support activities;
- The level of responsibilities and range of activities that each site undertakes with regard to the NNIN education and outreach thrust, the computing and web-infrastructure thrust, and the societal and ethical issues thrust.

In the following, we summarize the performance of the network and the sites.

Figure 5 shows some of the major elements of the information collection. Since each user and each site is different, none of the metrics tells a complete story in itself. In particular, aspects of the quality of the research or the quality of the customer service are not captured well by any of the quantitative metrics. It is also acknowledged that the scope and type of use varies significantly from site to site, and that some types of users/fields have significantly different use profiles (e.g. a simple characterization or thin film deposition user vs. a user doing complex process integration for a MEMS or electronic device).

The information summarized here is for experimental research lab usage only. These are related to the projects where a user is trained and performs independent research, uses the variety instruments in the laboratory, and is the primary focus of the network research support activity. This data there does not include any educational "user", people who attended workshops, and other significant activities, or local students taking using any resources for class-room learning, etc. These statistics do not include Computation and Modeling Users; although a significant number and requiring close work with our Computation Domain Experts, and doing in theory what we also do in experiments, they are evaluated separately as this is a distinctly different use available only at four sites currently.

*Figure 5: Approach to collection of information by the network.*




Primary usage data is submitted monthly by each site to NNIN management. All graphs are subject to the accuracy of the data supplied by the sites.

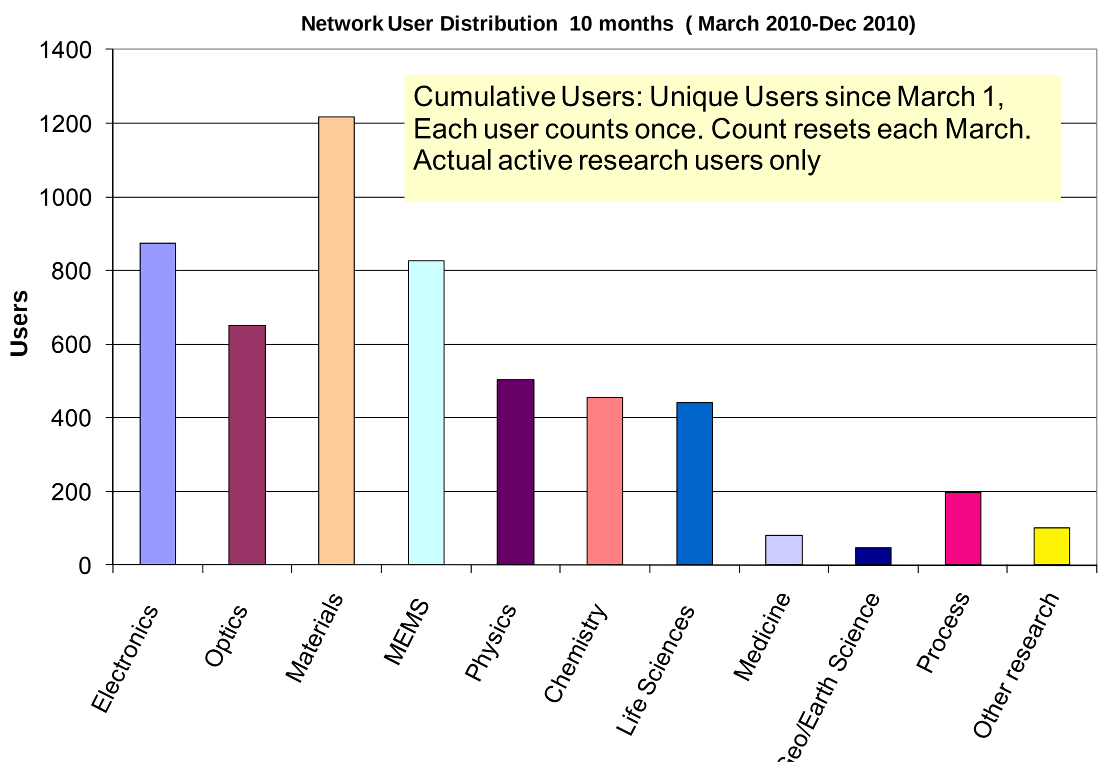
Unless otherwise noted, all data is for the 11 month period March 2010-Dec. 2011. Data will be updated after Feb. 28, 2011 to reflect the full year.

Persons exclusively using NNIN Computation resources for scientific simulations are not counted as part of the NNIN Users. We collect that data separately. As used here, "users" refers to laboratory users only.

### 2.6.1 Program Breadth

NNIN's mission in support of experimental nanotechnology is over diverse technical areas, from complex fabrication of structures such as in MEMS, biosciences, optics and electronics, to synthesized molecular scale structures and creation of materials assemblies for advanced studies. Figure 6 shows the distribution of users by field (10 months, cumulative users) across the network. Overlap between technical areas is inevitable and many users could be assigned to multiple categories. None the less, the broad coverage of nanotechnology subareas is apparent. Materials is a broad category when specific engineering application is not intended; it is the largest in usage and users from Chemistry, Physics and Materials Sciences are usually pursuing projects in this category. GeoSciences is an area where usage is increasing with outreach effort on our part and increasing interest and recognition in the community. NNIN continues to place an effort in building up usage in this area. Our focus is on leveraging sensors and microsystems knowledge to help the scientists and engineers in water and environment related community. A symposium was held at University of Michigan in 2010 resulting in collection of a number of ideas jointly developed by geoscientists and NNIN users that will be catalysts. During this past year this has been followed with joint proposals for projects to demonstrate applicability and other independent efforts.

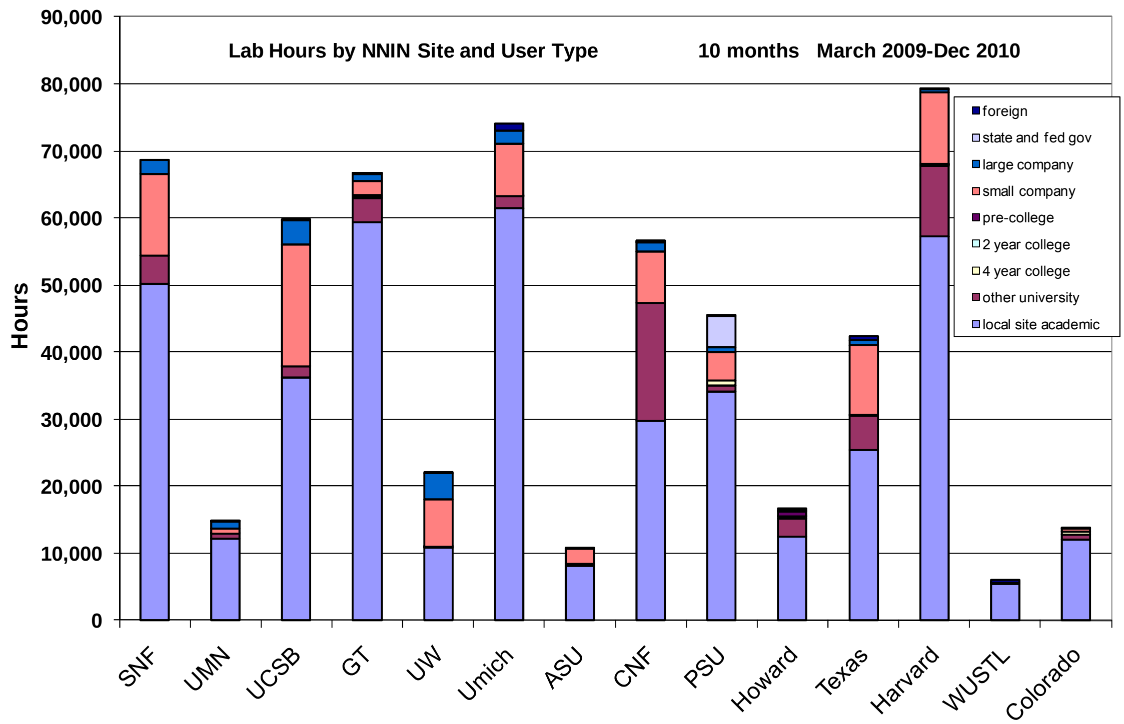
*Figure 6: Network User Distribution by Technical Area.*



## 2.6.2 Lab Use

Laboratory hours are counted by one of two means at NNIN sites; either direct use equipment time, or clean room time. The former does not include lab use for non-charged equipment or other general lab time but does count multiple simultaneous equipment use. The latter counts just time in the lab, which could be used for a single piece of equipment, or multiples or none. Thus, while there is correlation between the two measures, they are different in between sites. We accept this variation in counting methods as part of the uncertainty, and have not standardized to one approach because of the expense and time involved and questions that will still remain – sites have numerous essential equipment that incur no charge while a clean room in itself provides ability to access a large number of tools simultaneously. However, laboratory hours are an important way to track intensity of laboratory activity at each site and across the network.

*Figure 7: User Lab Hours by NNIN Site. Note different sites count hours in different ways – equipment time where equipment has charges associated with it, or clean room time.*



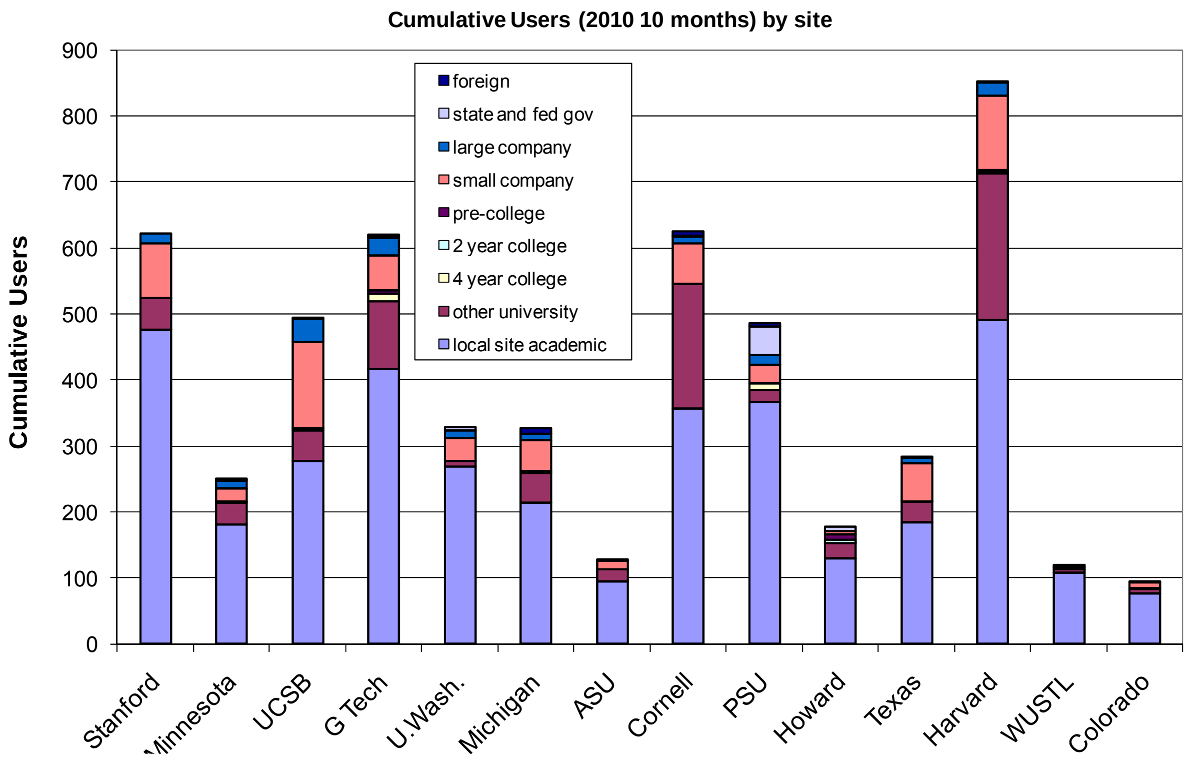

The chart in Figure 7 represents total lab hours during the 10 month period (Mar. 2010-Dec. 2010). The size of each NNIN facility and its associated funding varies significantly and each includes different amounts of "associated" facilities (.e.g. characterization facilities). Nonetheless, they reveal information about the size, scope and character of each laboratory's activities when looked together with user numbers and their antecedents in academic (local or external) and industrial research. The activity at all laboratories is dominated by local usage. The local users are a vital foundation and critical element of the facilities. The local users develop the processes, provide quite often the initial impetus for new technology development, and provide the rigor and reproducibility that becomes the knowledge and training foundation for the external user.

### 2.6.3 Cumulative Annual Users

Cumulative Annual Users is a primary user counting metric employed by NNIN; this is often just referred to as "users". This is each unique experimental research user counted once during the time period, using March as the starting time for every yearly cycle. This number monotonically increases during the year, reaching the maximum at 12 months (at the end of February of NNIN funding calendar) when the counter is reset for the next year. This measures the number of different people that the site has served; a user who visits once counts the same as one who visits many times over the year.

Figure 8 shows the distribution of users across the network by site and institution type. This figure can also be contrasted with the chart for laboratory hours (either laboratory time or equipment time) (Figure 8). Cornell and Harvard reflect a large and good balance between internal and external users, with Stanford, U. Minnesota, UCSB, Texas, and Georgia Tech also showing a significant amount of external usage. There is considerable variation in the number of users and in their distribution between sites, and this should be considered together with the technical focus responsibility area at the specific site. In this metric, each user counts the same regardless of whether he/she uses the facility 4 hours per year or 400 hours per year. To gain a fuller picture of the effectiveness of each site one has to look at other metrics, such as intensity of usage, as a supplement to this information.

*Figure 8: Cumulative Users at each site. (March-Dec)*

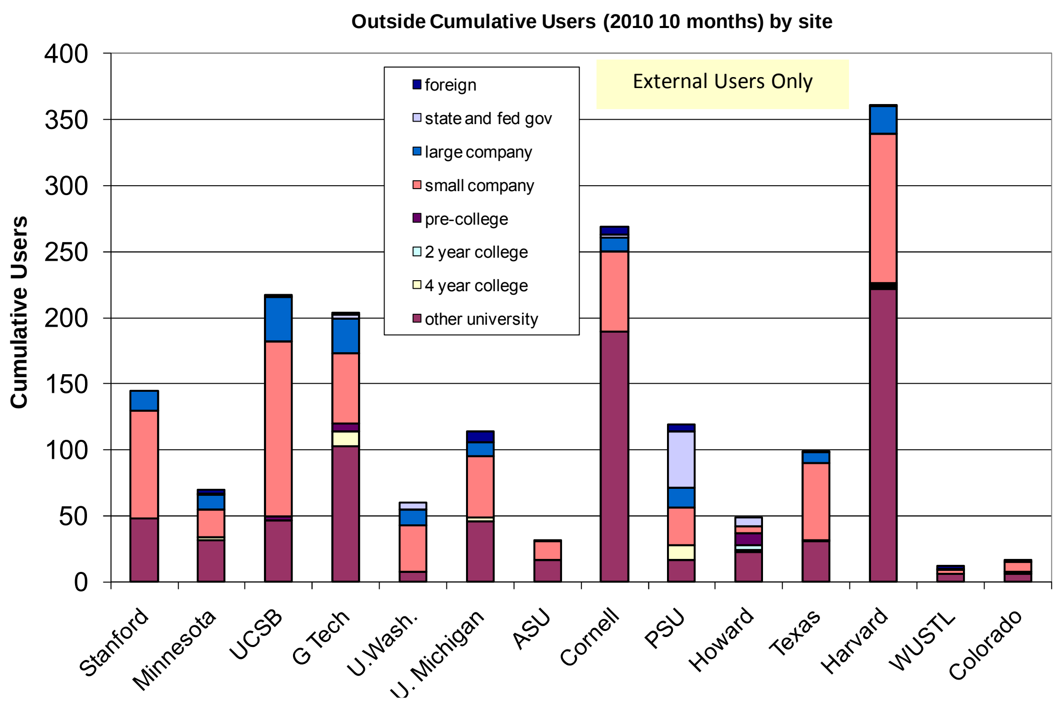



As discussed in the introduction, NNIN's effort is organized around the theme of serving the external user – a focus we believe leads to crucial benefits in quality, efficiency, and local community and external community effects that are essential to bringing the maximum benefits to progress in nanotechnology from an infrastructure.

External users are the most important component of the NNIN effort together with the focus on external users in assigned areas of technical responsibility within the network. This enables effective use of limited funds with the maximum efficiency in equipment usage and delivery and sharing of critical technical knowledge and expertise.

Figure 9 show the distribution of outside (external) users only, i.e. local site users have been removed for clarity. Nearly all sites continue to make progress towards the objectives. Five major sites of the network, Cornell, Stanford, UCSB, and Georgia Tech, and Harvard all have 150 or more outside users each in the 10 month period, with both academic and industrial users benefiting from the network.

*Figure 9: NNIN Outside Users by Site.*



Building up usage at a site is a multiyear enterprise based on network and site outreach and user successes that reinforce confidence in the site's capabilities. Particularly for the new or smaller sites, it takes considerable time to grow effective and sustainable usage and vibrant user base. The new sites to the network are the ones with the smaller usage and it is important to also view the progress in network usage since the inception of NNIN in 2004. Figure 10 shows the trends in usage of the network at the sites. In this figure, the data for current year is for a 10 month period. The larger sites, in general, are operating at or near saturation, given current resources and user base tied to specific technical directions and their equipment needs, and limits to user support that is critically dependent on the technical staff who assist and train the users and maintain the equipment. This user number is also tied to the type of needs, its usage needs in equipment and in staff, and the intensity, i.e. hours of usage per user.

*Figure 10 NNIN users by site in a multi year comparison.*

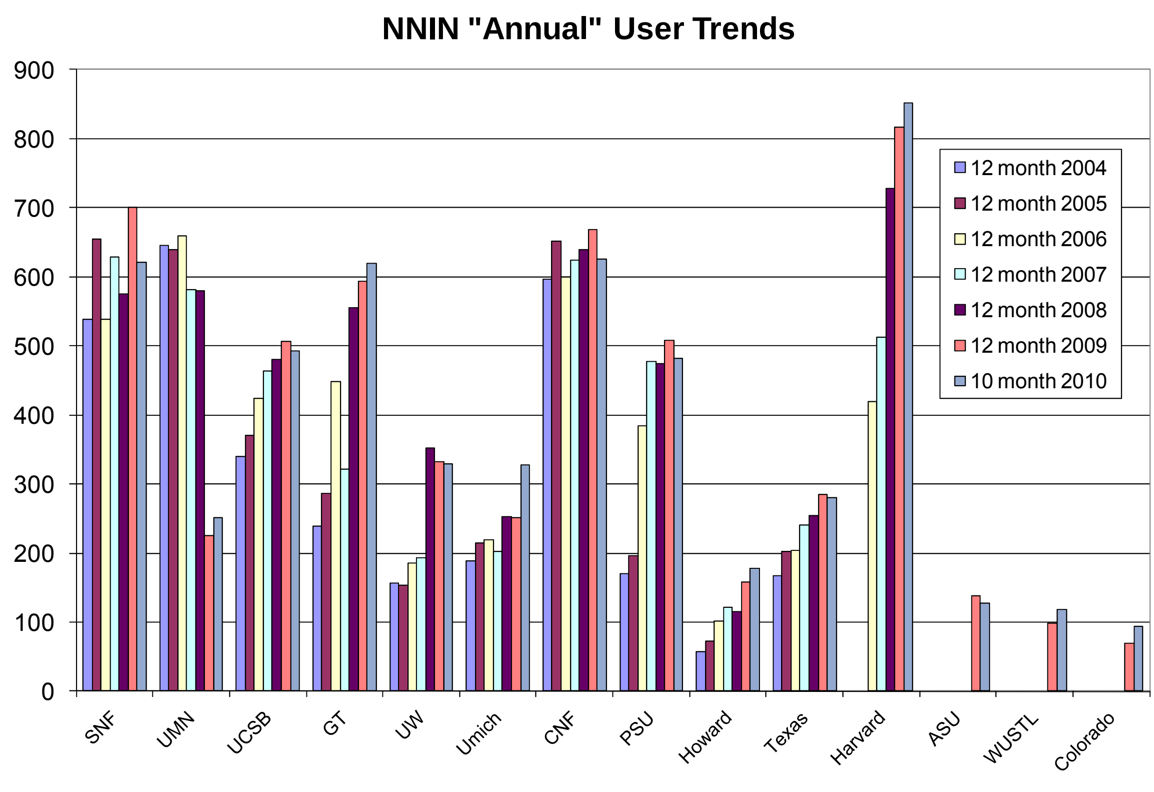
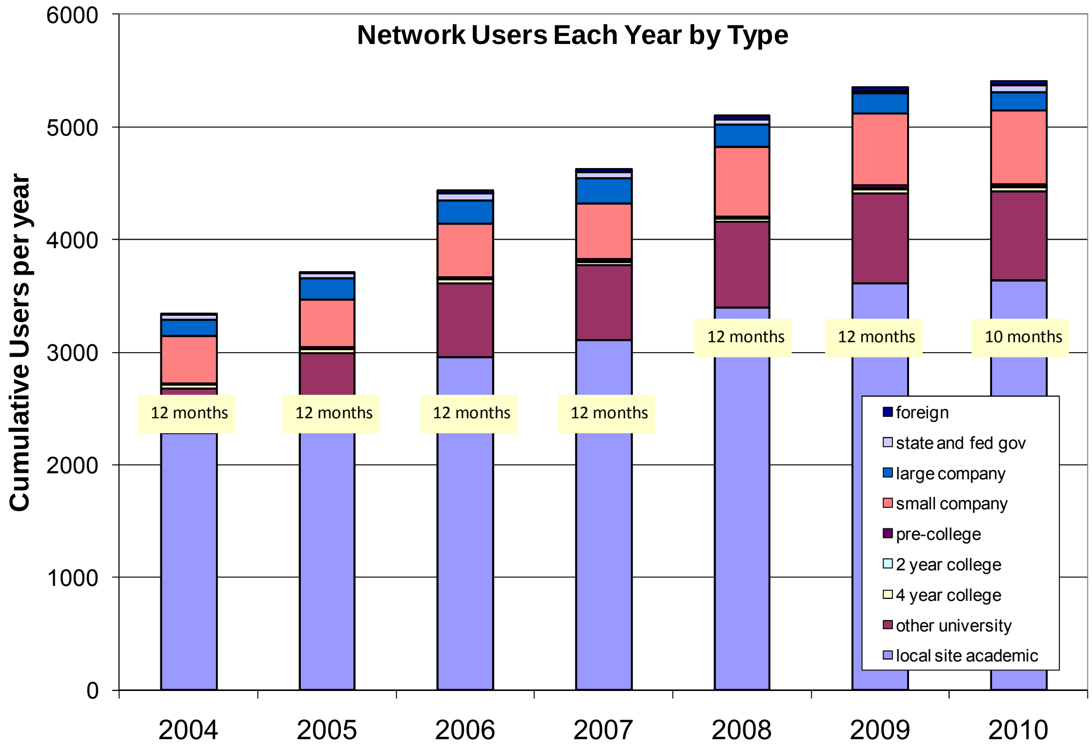


Figure 11 shows the type of usage – local and external academic, and industrial. It shows a continuing increase in network usage across all types over the 7 year history of the network.

*Figure 11: Network wide research usage by year.*

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## 2.6.4 Average Monthly Users

Usage needs to be looked at from a variety of perspectives as remarked earlier. The metric of average monthly users, i.e., number of unique users each month, e.g., is indicative of "how busy" a site is (Figure 12). The larger NNIN sites also show a larger number of average monthly users. Figure 13 shows this demand from external users, the user populace that NNIN places its emphasis on.

*Figure 12: Average Monthly Users.*

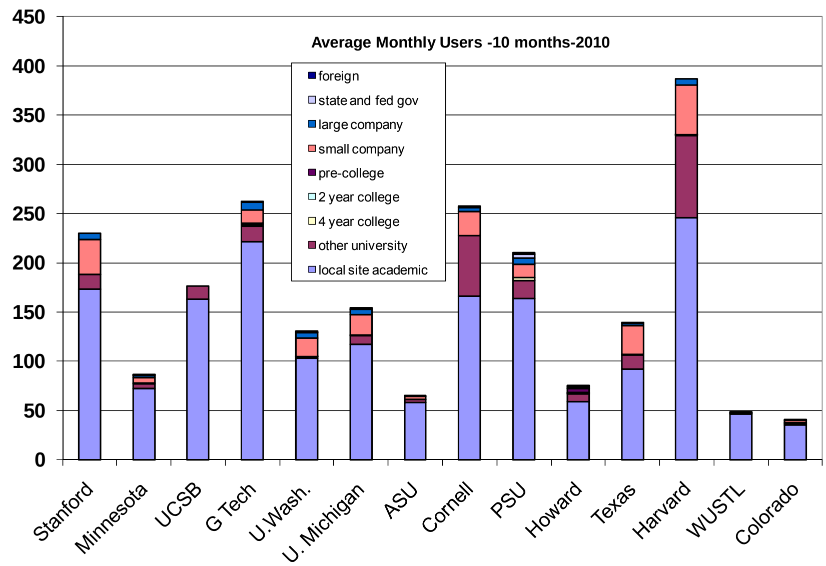
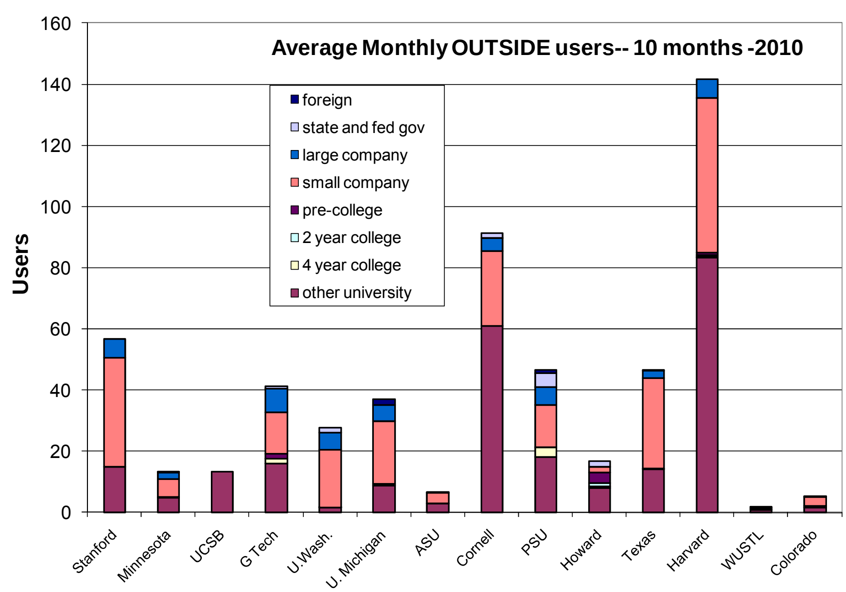


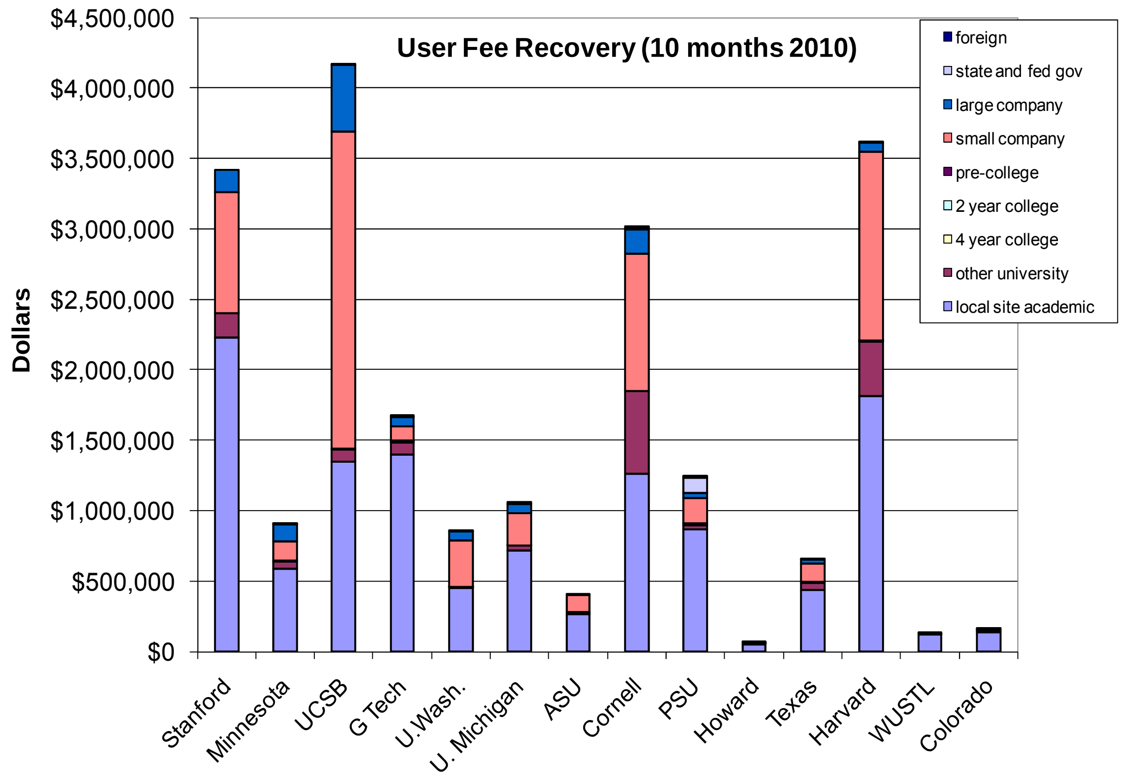

*Figure 13: Average Monthly Outside Users*



## 2.6.5 User Fees

Lab use fees supplement the NNIN funding at all sites. In addition, some sites have additional sources of funds from the university and/or other resources to strengthen the research and sustain the community resource. Fees are charged on per user or per hour basis with the exact structure varying by site. The user fee rates at each site are set at local discretion following the federal and university regulations for cost centers. Some of the NNIN site programs are connected to existing and sometimes larger facilities and programs. As such, no attempt has been made to standardize fees across the network since cost structures are different at different locales. NNIN only expects that external academic users receive the same rate as local academic users, and that NSF funds be allocated to support open academic usage. Thus, industrial users pay the full cost of usage, while the academic users benefit from lower costs that the NSF support makes possible. In short, academic fees cover the incremental costs of operation while the industrial users are charged at higher rates to reflect full cost recovery and reflecting effort that does not compete with commercial enterprises.

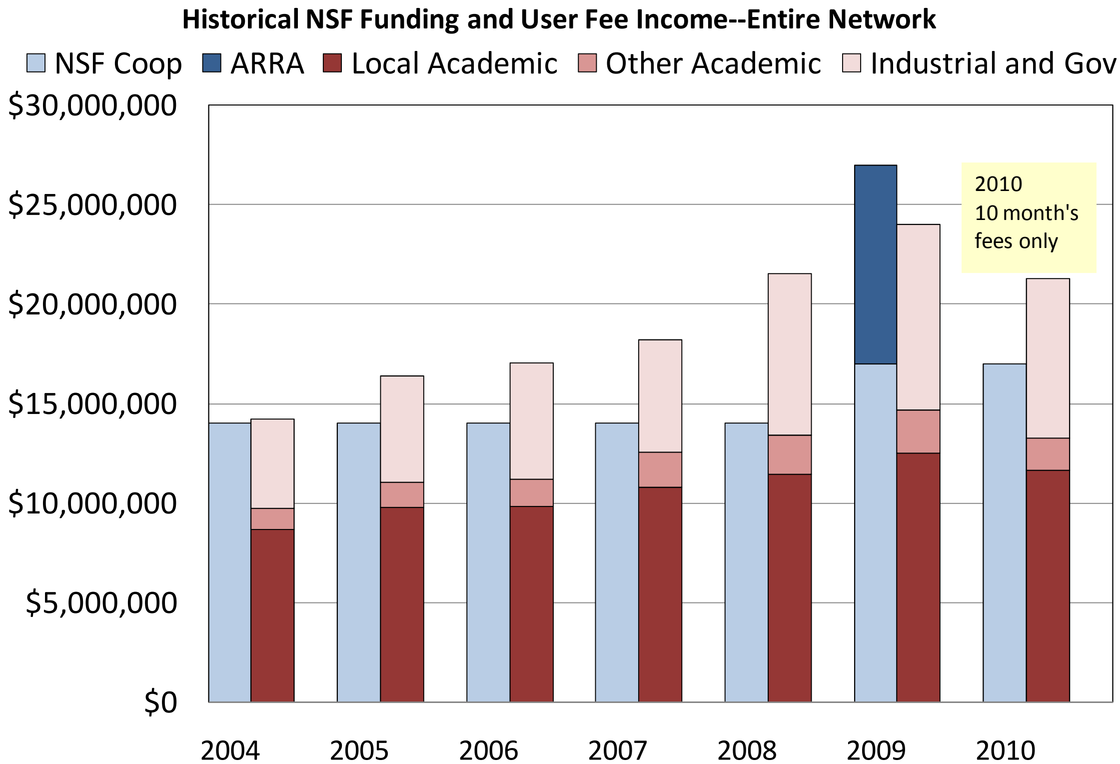
*Figure 14: User Fee Recovery by Site and Type for 10 month period of 2010.*




User fees provide a mechanism for allocating costs to different activities. The NNIN mission is to make successful research and development happen through open and effective usage of these facilities by the national user community. NNIN funds largely pay for the staff and training infrastructure required to support this outside user effort and not for operation of existing facilities. The level of expense recovery obviously varies with the size of the user base as well as the type of user, e.g. industrial users are an important source; examination of total fee recovery yields little new information. The amount of user fees collected at each site is shown in Figure 14 (10 months). There can be several explanations for low fee recovery from outside users, among them: a) low number of outside users, and b) low average level of use by outside users. At least four sites, however, show that company usage is an important component of achieving their sustainability. In particular, it points to the large relative small company fee recovery at UCSB.

Figure 15 shows the overall high leverage of the NSF investment over the years. Each dollar of the NSF cooperative agreement is more than matched by user fees. Both user fees and the NSF support are critical to operation of NNIN.

*Figure 15 Two of network's major sources of funding: NSF (NNIN Main Cooperative agreement and ARRA only) and user fees.*



One of the requirements of a successful user facility/network is that it be affordable. This is particularly critical for academic research where the effort is paid largely by various government grants. Because of the economies of scale and the critical mass of users, NNIN is able to keep academic use charges low. Figure 16 compares the local academic (NNIN institution) and outside academic average user fees per user over the 10 month period (total academic fees/ total # of academic users).

*Figure 16: Average academic user fees for local and external academic users.*

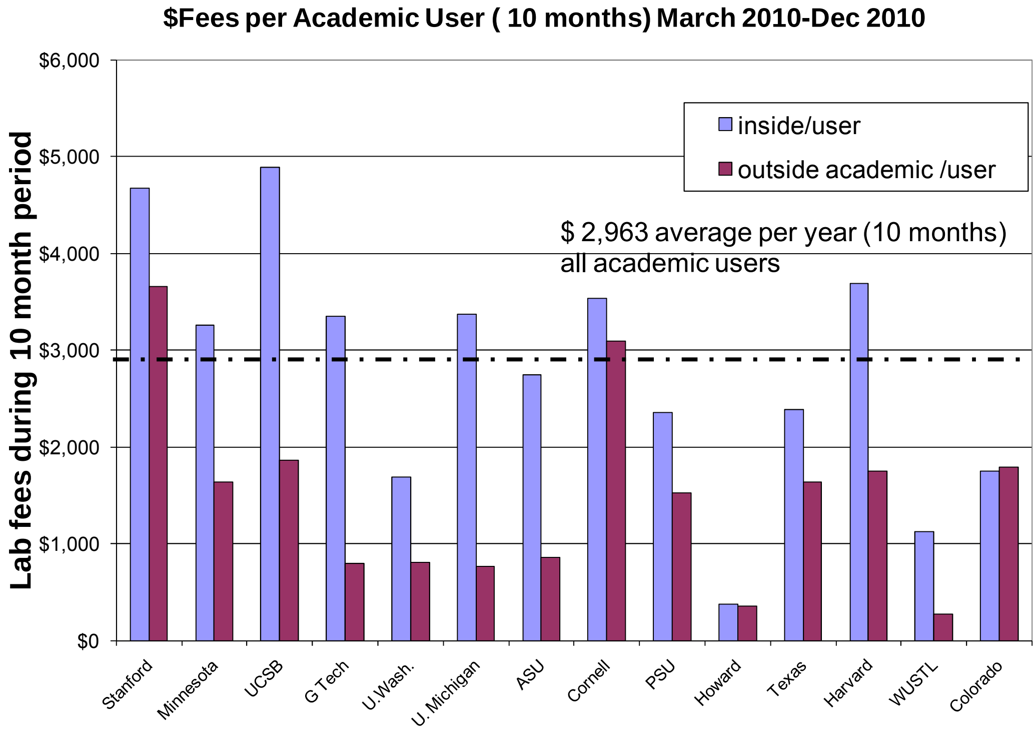
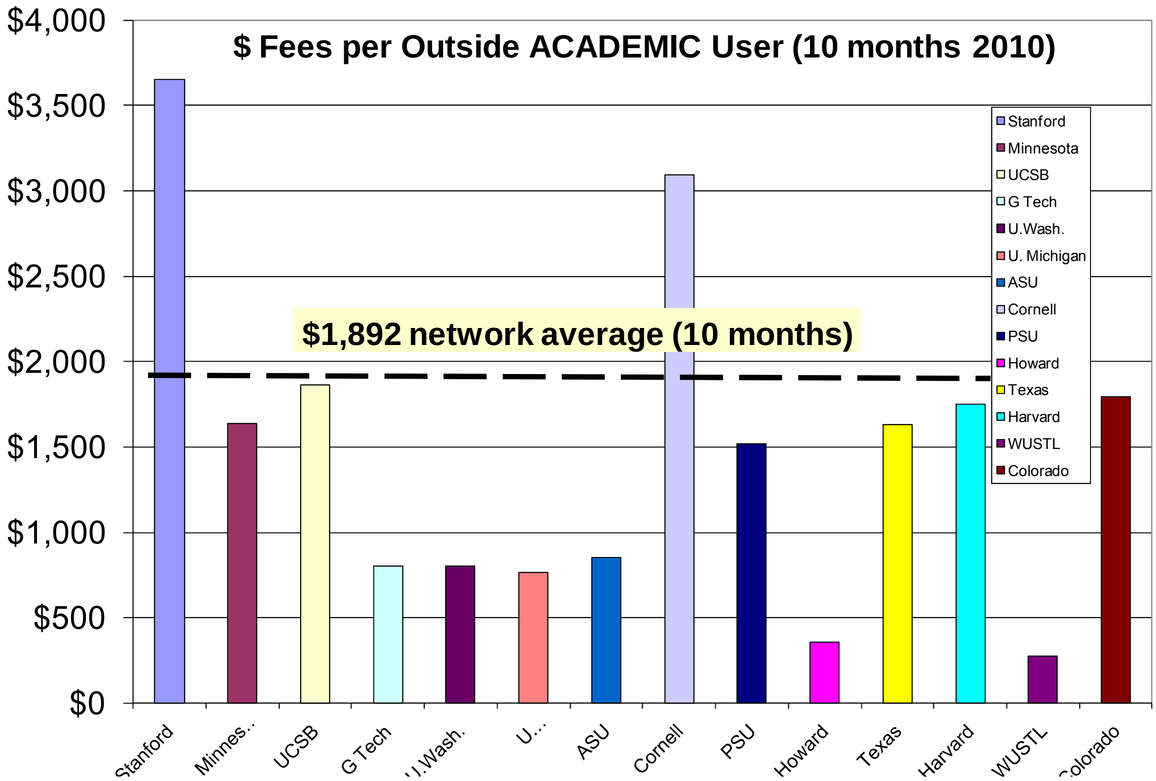


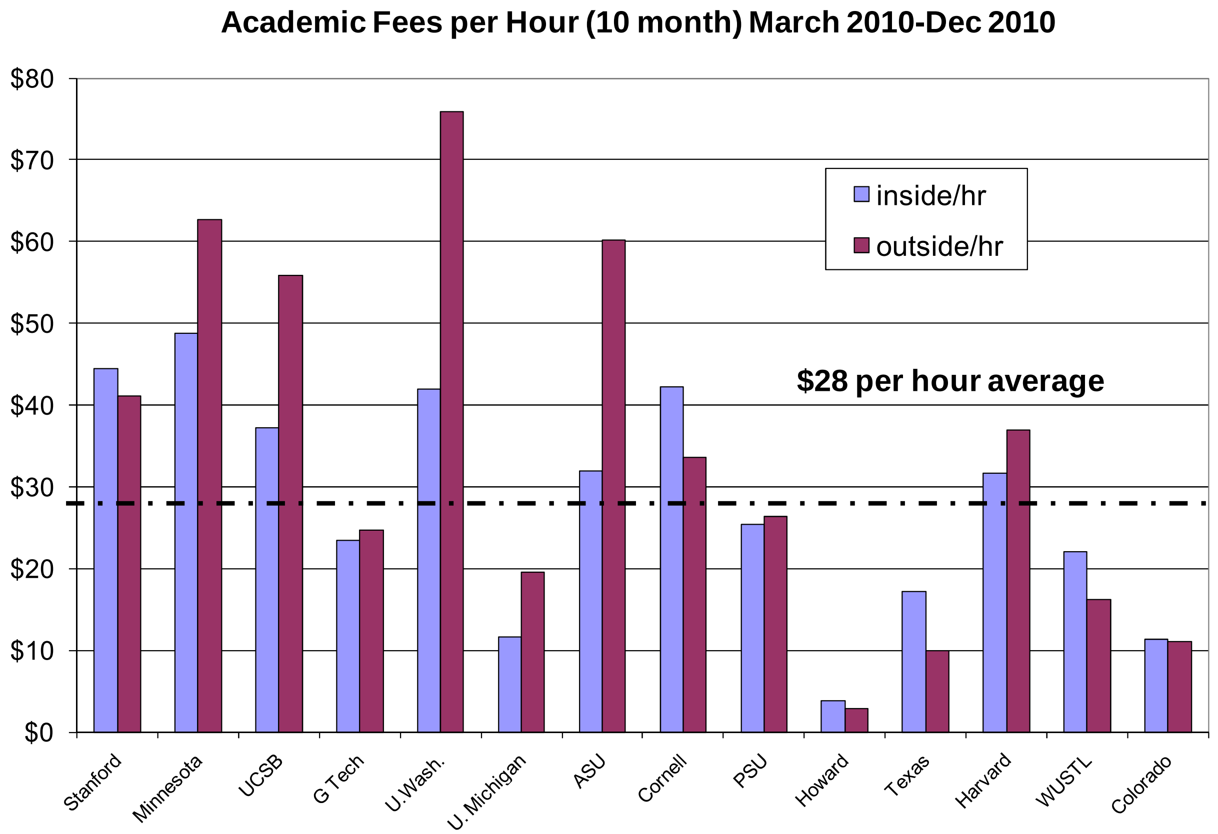
Figure 17 shows the average user fees per user for outside academic users By NNIN mandate, local users and outside users pay the same rates for use; the variation from the total for all academic users reflects different levels and types of usage and intensity of that usage. While there is some variation between sites, the most striking part is that the average external academic user paid near $2000 during the 10 month reporting period. This is an average; many heavy users paid significantly more, and many users paid significantly less. Figure 17 and 18 together also show that the usage recovery from internal academic user is about twice that of external academic user, and for sites an important component of their sustainability.

*Figure 17: Average fees for Outside academic users.*



Similarly, average fees per hour (Figure 18) are clustered around $30 per hour, a quite reasonable and accessible fee for high technology equipment.

*Figure 18: Average academic fees per hour at NNIN facilities.*

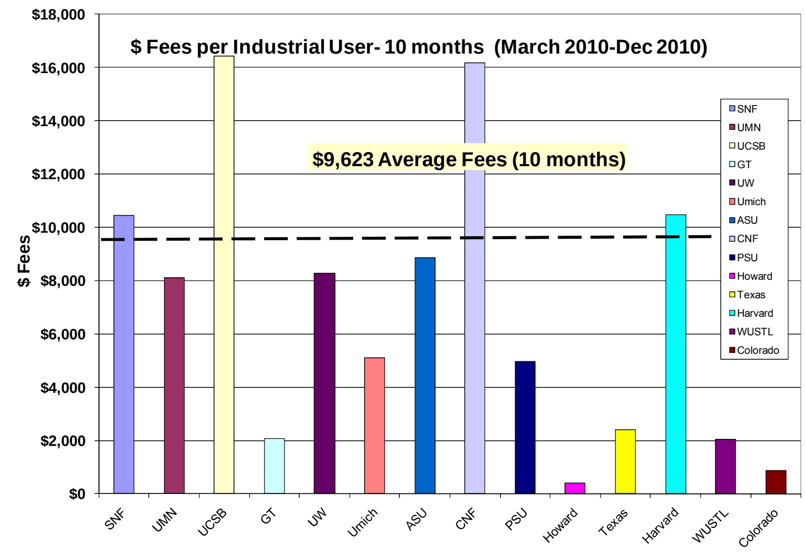



The point of these figures is not any individual variation, either between sites, or between local and outside users at a given site; there is far too much variation in complexity of projects and the available equipment sets to draw those conclusions (although actually most use falls in the $20-40 per hour range, a quite tight and reasonable result). One should thus not conclude that one site's fees are too high or too low from this data – a larger fraction of user of expensive tools, electron beam lithography or deep ultra violet lithography can skew this data. In addition, there are certainly individual users who are at both 4x the average and 1/4 the average, i.e. there is a broad distribution.

It does show, however, that access to NNIN facilities for an "average" user is quite affordable. The full out average over all sites for all academic users by being near $3000 is quite within the budget of most research grants.

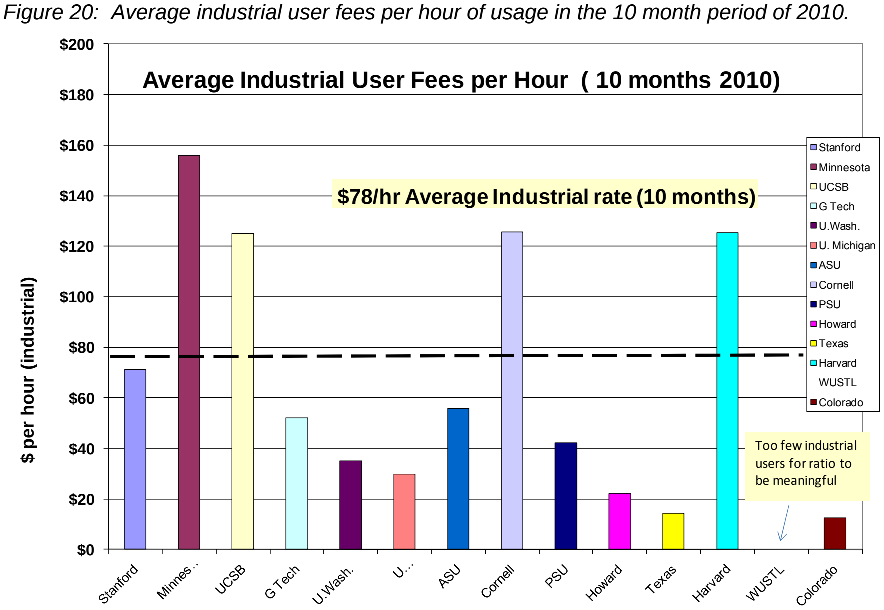
In contrast, the average cost for an industrial users (small and large company) is $9623 for the 2010 10 month period (Figure 19) or approximately $78 per hour (Figure 20), again with a broad distribution both within sites and across sites, but extremely manageable for the complex resources that the NNIN sites provide to the industrial users. Again, the equipment use profile varies significantly across the sites

*Figure 19: Average Industrial User Fees by Site.*




resulting in some of the intra-site variation. The major point is that equipment resources are affordable and accessible.

*Figure 20: Average industrial user fees per hour of usage in the 10 month period of 2010.*

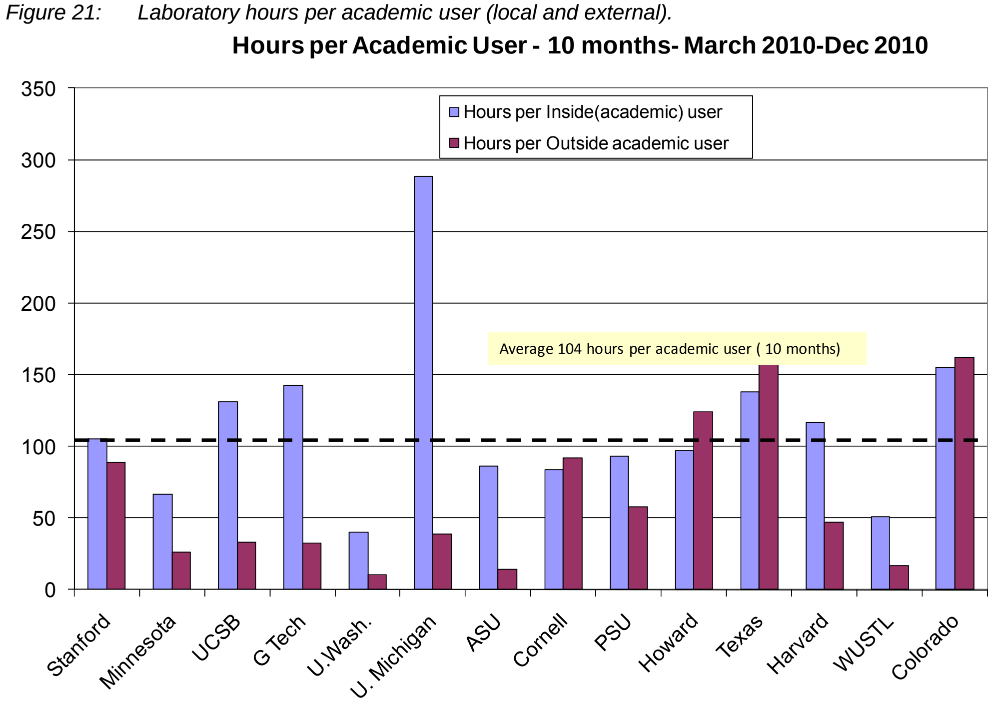



For outside users we do not believe that the relative costs of NNIN facilities are a major factor in selection of a facility. Technical capabilities of the sites, technical alignment with the users requirements, and geographical considerations are significantly more important considerations.

### 2.6.6 Hours per user

Hours per user is a particularly enlightening metric as it reflects intensity of use with the caveat that different sites collect data on hours of usage based on either use of those instruments that have charges associate with them (a fraction of the facility set) or clean room time. A site can more easily sustain a large number of users doing small processes than a similar number of users doing complex processing. Hours per user is an average secondary metric, gathered by dividing lab hours in a particular category by the cumulative annual users in that category. Average usages of 100's of hours per user would indicate a facility with more complex processing and a concomitant larger impact upon the facility and its resources. A hundred hour of usage is more than a couple of weeks of dedicated effort by the user. Average usages of <25 hours indicate a group of users who place a significantly smaller burden on the facility. That use may still in fact be critical to a given project but it requires fewer resources to support incrementally. Results across the network, for both internal and external academic users, are shown in Figure 21. It is obvious that there is considerable difference between sites in the intensity of use by an "average" user. Note, in some cases, this derived metric is the ratio of two small numbers and thus the metric is less enlightening for sites with a small number of users. In most cases, intensity of use by internal users is higher than external users reflecting the higher availability for routine and unplanned use.

*Figure 21: Laboratory hours per academic user (local and external).*



## 2.6.7 New Users

Each facility is constantly accepting new users. This is part of the trend of growth and of turnover as projects succeed and graduate. New users require training, hand holding at least initially, and intense staff commitment during the initial periods of visit and start up. The number of new users is thus an excellent metric for measuring the demand for NNIN resources. Here (Figure 22) we show the number of new users trained in FY2010 by site. Note that at some sites (e.g. Stanford, Cornell, Harvard, Georgia Tech, Penn State, Texas)) average 3-6 new users (inside + outside) per week.

In addition, there needs to be a balance between new users and total users. Figure 23 shows the ratio of new users to total users in FY2010 at each site. A ratio too low could indicate a stagnant facility with little growth or replenishment. A high ratio hand could indicate a rapidly growing facility. On the other hand, a ratio too high could also indicate an excessive turnover often associated with short term low impact projects.

*Figure 22:: Training load for new users (internal and external).*

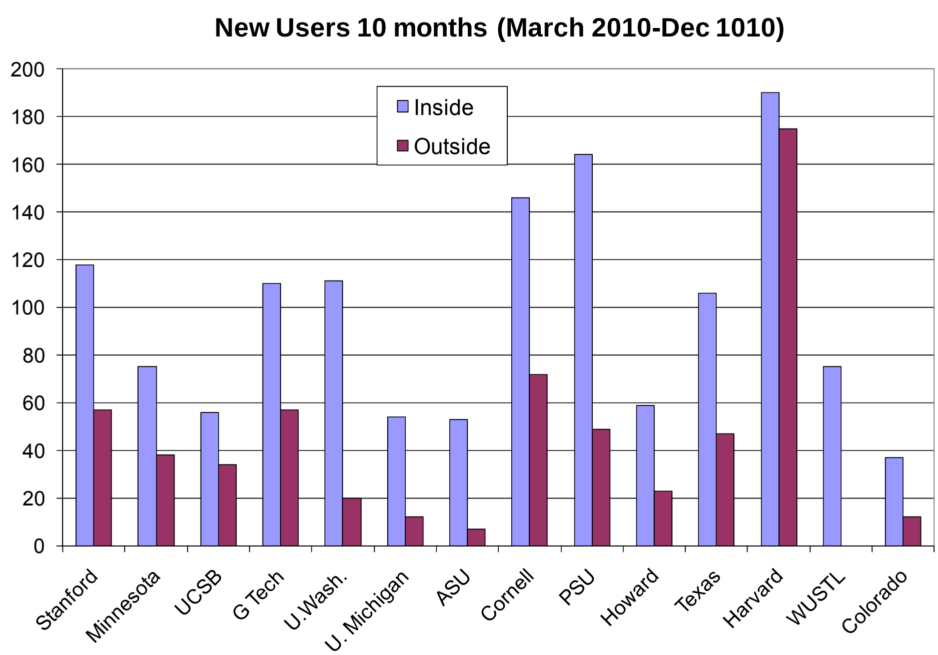
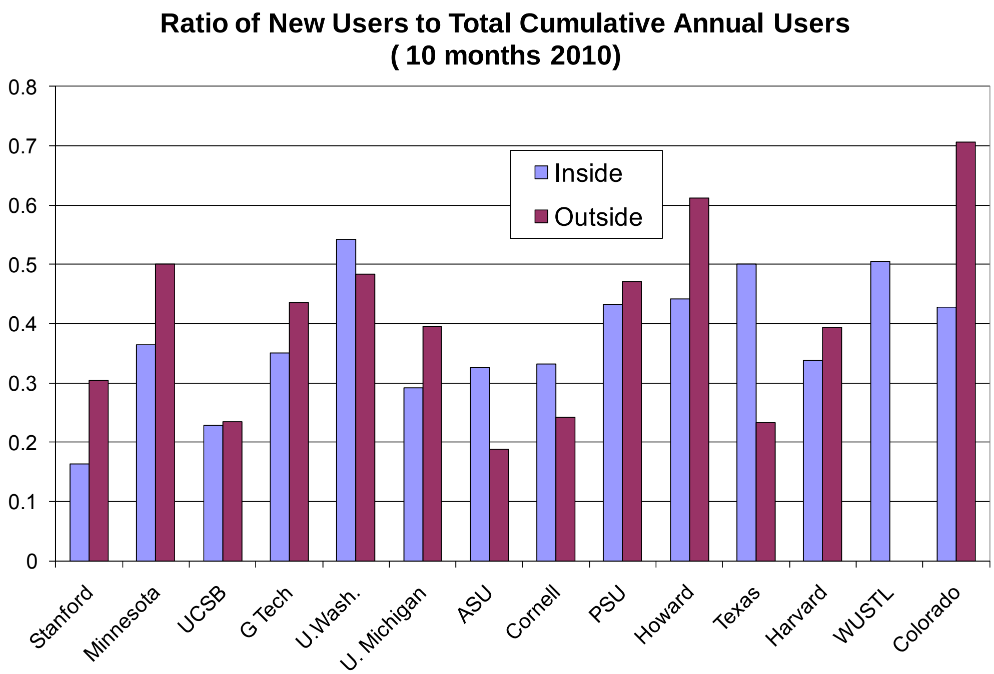


*Figure 23:  Ratio of New Users to Cumulative Annual users by site.*



# 3.0 NNIN Education and Human Resources Programs

## 3.1 Objectives and Program Challenges

In completing its seventh year of operation, the NNIN Education and Outreach (NNIN E&O) program continues to offer and strengthen numerous activities at the local, network, and national level. NNIN has as its goals a wide variety of educational outreach that spans the spectrum of K-gray, i.e. school aged children through adult professionals. NNIN has established the following goals for its network-based educational outreach and human resource development:

- Educate a dynamic workforce
- Support the spreading of benefits of nanoscale science and engineering (NSE) to new disciplines where it has meaningful impact
- Be a resource for all ages and educational background
    - K-12
    - Undergraduates
    - Graduate students
    - Post-docs, faculty, government/industry
    - General population

From these overarching goals, specific programmatic objectives have been established that impact national or local efforts. These include:

- developing and distributing activities to encourage K-12 students to enter science and engineering fields;
- developing resources to inform the public about NSE;
- developing activities and information for undergraduates regarding careers in nanoscience;
- developing tools and resources for undergraduates and graduate students that focus on teaching and learning and research;
- designing programs to ensure the inclusion of underrepresented groups;
- developing programs for technical workforce development; and
- developing programs and resources for K-12 teachers.

This report provides updates on our accomplishments and current programs that are both local and national in focus.

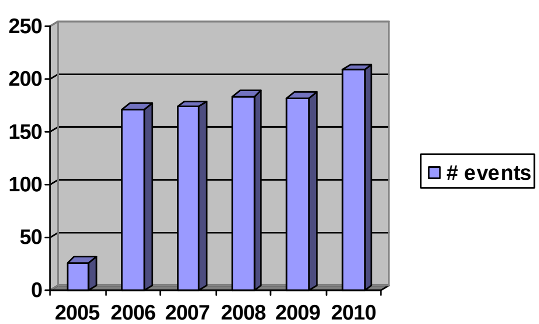
To attain each of the NNIN's education objectives, a variety of innovative activities has been defined, developed, and implemented. NNIN E&O components include network-wide programs to address needs at the national scale and more specific efforts for communities that are local to network sites. Table 3 illustrates the type of programs offered by NNIN and the scope across the network. The various facets of the NNIN E&O program are reviewed in following sections of this report.

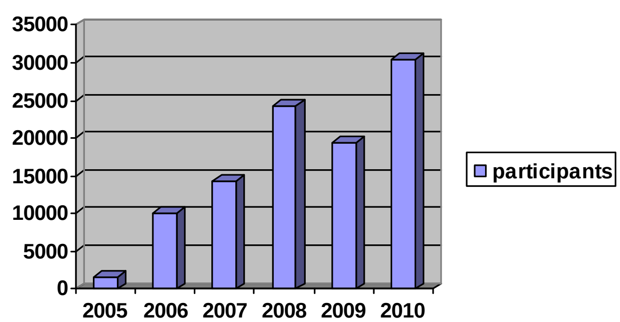
Table 4. Local and National NNIN education activities and program.

| | **Site Specific Activities** | **Network-wide Activities** |
|---|---|---|
| **Local Scope** | **Local Activities – Site Specific** | **Network Activities - Local Scope** |
| | Facility tours<br>Community days<br>Open house<br>Seminars/Public lectures<br>School programs<br>K-12<br>2 and 4 year colleges | User support & training<br>Diversity<br>K-12 education- school programs<br>Summer & after school camps |
| **National Scope** | **Site Activities - National Scope** | **Network Activities - National Scope** |
| | Workshops<br>Technical Training<br>Teacher Training<br>K-12 instructional materials<br>Hands-on demos & experiments<br>Undergraduate education | National Conferences & Meetings<br>Research Experience for Undergrads<br>Research Experience for Teachers<br>(NSF award)<br>NNIN Education portal<br>User support<br>Diversity<br>Open Textbook<br>*Nanooze* |

Figure 24 summarizes events that NNIN has conducted yearly since 2005 and reported through our web-based recording system. The graphs demonstrate how the program continues to maintain a high level of activity since we began collecting data on events in 2005. Figure 24 also shows that we maintain our capacity in the number of events offered across the network sites. In 2010, we directly reached more than 34,000 individuals. This number does not indlcude the NNIN education portal (http://www.education.nnin.org) nor the print version on Nanooze (~100,000).

*Figure 24: Yearly direct contact events offered by NNIN and NNIN sites locally and the number of participants in these activities.*




NNIN as a networked resource has geographic reach and technical strengths that are derived from the diversity of subject strengths and facility strengths, and within our universities the strengths arising form the collective of faculty and students. This national and diverse scope is unparalleled and not reproducible in any other center based programs. NNIN has chosen to place emphasis on deriving maximum impact from the strength of these resources. Our efforts use an approximate guide of 2/3 of our effort devoted to national reach and impact and 1/3 on local/state reach and impact.

## 3.2 Coordination and Collaboration

The challenges of any large-scale activity center on coordination and communication. Each NNIN site has a full-time or part-time education coordinator. The NNIN Site education coordinators have established a communications network which effectively allows us to refine our work plans, establish short and long-range plans, and ensure continuous communication and collaboration among the sites. The network coordination of NNIN E&O occurs from the Georgia Institute of Technology and Dr. Nancy Healy serves as the NNIN Education Program coordinator. She is assisted at the site by Joyce Palmer and Katie Hutchison. Communication methods include phone, e-mail, wiki, and face-to-face meetings.Large education programs are coordinated in cooperation with the NNIN Program Manager and assistants at Cornell.

The education site coordinators meet once a year at one of the NNIN sites for a minimum of two days. The NNIN E&O program has reached a point where sharing of ideas, approaches, and materials is a regular practice among the sites and often occurs outside our scheduled meetings. During the past year, the coordinators met at the University of Texas October 12-13, 2010. Minutes of all meetings are available. Coordinators also meet informally at various professional meetings/conferences and the REU convocation. An additional challenge is keeping accurate records of our activities and resources. Because of the wide variety of activities across the sites, it is important to know the types of activities, the duration, the impact in terms of numbers served, etc. In 2005, NNIN launched the Education Events Manager (EEM). All sites are required to regularly update the system by posting their events and activities. Tracking of events is done by Georgia Tech and Cornell which can monitor entries and use the system to generate reports.

## 3.3 NNIN Major National Programs: REU, iREU and RET

### 3.3.1 REU Program

The NNIN has developed, operated, and managed a highly successful Research Experience for Undergraduates (REU) Program in nanotechnology since 1997 (begun under NNUN). This program is a coordinated network activity which has ~-80 students participating each summer across 14 NNIN sites. In 2010 the NNIN management budget allocated funds to sites to assure a minimum of 5 students were hosted at each of the 14 sites for a total of 80 interns.

Our program offers a well-supervised independent research project for a 10 week summer period. While individual sites are responsible for daily project supervision, there is strong network coordination to assure a uniform program with high expectations. Our program features a central on-line application process for the entire network program as well as specified program expectations for projects, interns, project directors, and mentors.

The NNIN REU draws top quality participants from a diverse applicant pool. Due to the visibility and size of our program, we have been successful in recruiting a large number of women, minorities, and students from non-research institutions (non-doctoral granting). Our program remains a popular choice among students with 756 applications received in 2010. We have been committed to providing research opportunities to students who have the most to gain from the NNIN REU experience - 75% of the 2007, 69% of the 2008, 65% of the 2009, and 48% of the 2010 participants had no prior summer research experience. Table 5 shows the demographic make-up of applicants, participants, and their type of home institution for 2008, 2009, and 2010.

Table 5. Demographics of NNIN applicants and participants 2008-2010.

| 2007-2009 NNIN REU Program Demographics | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **# of applicants** | | | **Applicant Pool** | | | **# Participants** | | | **Appl. Success Rate** | | | **Participation (%)** | | |
| | **'08** | **'09** | **'10** | **'08** | **'09** | **'10** | **'08** | **'09** | **'10** | **'08** | **'09** | **'10** | **'08** | **'09** | **'10** |
| Overall | 553 | 625 | 756 | | | | 73 | 74 | 80 | 13% | 12% | 11% | | | |
| **Gender*** | | | | | | | | | | | | | | | |
| Women | 194 | 213 | 245 | 35% | 34% | 33% | 36 | 40 | 37 | 19% | 19% | 15% | 49% | 54% | 46% |
| Men | 359 | 412 | 505 | 65% | 66% | 67% | 37 | 34 | 43 | 10% | 9% | 9% | 51% | 46% | 54% |
| **Race/Ethnicity** | | | | | | | | | | | | | | | |
| Minorities** | 93 | 103 | 128 | 17% | 19% | 19% | 26 | 14 | 13 | 28% | 13% | 10% | 37% | 19% | 18% |
| Non-Minorities** | 399 | 446 | 550 | 72% | 81% | 81% | 45 | 59 | 61 | 11% | 13% | 11% | 63% | 81% | 82% |
| **Inst. Type*** ** | | | | | | | | | | | | | | | |
| Ph.D. Level | 376 | 406 | 506 | 68% | 65% | 67% | 50 | 52 | 57 | 13% | 13% | 11% | 68% | 70% | 71% |
| Master's Level | 81 | 114 | 101 | 15% | 18% | 14% | 12 | 10 | 15 | 15% | 9% | 15% | 16% | 14% | 19% |
| Bacc. Level | 94 | 85 | 119 | 17% | 14% | 16% | 11 | 11 | 8 | 12% | 13% | 7% | 15% | 15% | 10% |
| Assoc. Level | 2 | 18 | 24 | 0% | 3% | 3% | 0 | 1 | 0 | 0% | 5% | 0% | 0% | 1% | 0% |

* Not all report gender; * *Race/Ethnicity is only for students who reported this information – in 2010 76 did not report. +Carnegie Ratings: The Carnegie Foundation ratings of high education institutions are used as the measure of institutional size diversity. Some Ph.D. institutions may not offer advanced degrees in the sciences and engineering.

Of particular interest is the high number of female participants in the last three years. Female students participate at a much higher rate compared to the number of female applicants. Minority students for the last two years are participating at about the same level as the percentage of applicants. Prior to this, they participated at a higher rate in comparison to applicants including years 2005-2007. We are monitoring this number but believe it is because of the increasing applicant pool of students.

The NNIN REU program culminates with the NNIN REU Convocation which is a "mini" scientific conference attended by all site coordinators and REU interns. The 2010 convocation was held August 11-14, 2010 at the University of Minnesota. At the convocation, each student presents his/her research results to fellow NNIN REU participants and to staff and faculty who also attend. For many of our students, this is their first scientific presentation. We also simultaneously webcast these presentations which allows faculty, graduate student mentors, and staff from the sites, as well as any other interested viewers, to view the convocation To complete the program, all students write a research report that is published as the *NNIN REU Research Accomplishment*s. The archived webcasts and the *Accomplishments* are online at http://www.nnin.org/nnin_reu.html .

Each year we survey our interns as part of our program evaluation. We consistently receive very high ratings for our program including the quality of research, support by faculty and graduate student mentors, and technical training and support (among others). Table 6 highlights the technical components of our 2010 program (Likert scale of 1-5 with 5 being the highest rating):

Table 6. NNIN Participant post-program survey.

| NNIN Post Survey 2010 | | | | |
|---|---|---|---|---|
| **Question** | **Avg** | | **Question** | **Avg.** |
| Did the program offer you a substantial independent research project with a strong intellectual focus? | 4.23 | | How well did the program provide you with an understanding of the graduate research life? | 4.44 |
| Were you able to execute the research project using the available equipment and facilities? | 4.27 | | How well did the program provide you with an understanding of careers in nanotechnology? | 3.62 |
| Did you consider your project a "good" project- interesting, right scale, right complexity, etc. | 4.25 | | Did the program assist you in making future educational & career choices? | 4.27 |
| Were you reasonably able to complete the project? | 3.94 | | How likely is it that you will choose a career in nanotechnology? | 3.72 |
| Were you satisfied with how much you were able to complete, given the time constraints? | 3.97 | | How likely is it that you will go to graduate school in science/engineering? | 4.61 |
| Did you receive significant scientific interaction with the faculty member/ senior staff in charge of your project? | 3.97 | | Did the program assist you in developing presentation and writing skills? | 4.11 |
| Were you included in group meetings and seminars? | 4.41 | | Was the Convocation a worthwhile experience? | 4.20 |
| Did the program provide you with experience that allowed you to see the breadth of nanotechnology applications? | 4.19 | | Would you recommend the program to a friend? | 4.67 |
| How well did the program assist you in learning to use advanced equipment and processes in nanotechnology? | 4.19 | | How likely is it that when you return to your home campus that you will share your experiences with fellow students and faculty? | 4.68 |
| How well did the program assist you in understanding the scientific basis of nanotechnology equipment & processes? | 4.14 | | How do you rate the overall quality of the program? | 4.51 |
| | | | Did you think that your experience with the program was positive? Would you do it again? | 4.62 |

Table 7 Academic/Career paths

| NNIN REU Longitudinal Study | |
|---|---|
| Degree/Career | 1997-2005 |
| Doctorate | 50% |
| Master's | 25% |
| Baccalaureate | 11% |
| M.D./J.D./MBA | 14% |

Since its inception in 1997, the NNIN REU program has had nearly 900 participants. As noted above, the program began under the NNUN and expanded to twelve sites with the inception of the NNIN, and to 14 following renewal. The NNIN REU is a long-term investment in human resource development. The plans of those students who choose to go on to a research career plays out five to ten years after participation. In 2006, we began a longitudinal study to determine the educational and career path of interns who participated in the 1997- 2005 period of the program. This is an ongoing, labor-intensive study which has significance for not only the NNIN REU program but other undergraduate research programs.

We have chosen this time period because participants will have graduated from their home institutions and will have entered or completed additional education and/or entered into the workforce. Of the 450 participants from 1997-2005, 265 (59%) have completed the online survey. Academic and career results are shown in Table 6. Ninety-six percent of the respondents are in science and engineering and with approximatley 50% reporting their current position involves nanotechnology (broadly defined). The results presented in Table 6 have remained consistent as the number of responses has increased.

### 3.3.2 iREU Program

Each summer, NNIN provides the introductory research experience for approximately 80 students described above. The training and experience these students receive is excellent and they are highly sought by employers, graduate schools, and other internship programs. While they almost all perform well, from observations over the summer, it is clear that 15-25% are very high quality students and have an exceptional commitment and love for research and development.

In 2007, we established the NNIN international REU (iREU) to further the NSE experience of these exceptional individuals. NNIN established this program because we believe that globally aware scientists and engineers should be a priority in the 21st century. This program is only open to our prior year REU students – we are effectively using our REU program as a “filter” to select only the very best students for this enhanced research experience as determined by their activity during the REU experience. In 2010, we had three partners for this international program: the National Institute of Materials Science (NIMS) in Japan, the Forshungsentrum Jülich (FZJ) (a Helmholz Research Institute) in Germany, and IMEC in Belgium. Each of these sites hosted 9, 6 and 4 students, espectively (Figure 25, 26 and 27). We have supplemental funding from the NSF International Research Experience for Students program (IRES) for the five Japan participants.

Participants in 2010 included:

**Japan** (Figure 25)

- Scott Isaacson, University of Minnesota
- Isaac Marcus, The Cooper Union
- Denys Zhou, MIT
- Arolyn Conwill, Pomona College
- Athena Pan, Brandeis University
- Claire McLellan, Wake Forest University
- Sarah Connolly, University of Florida
- Mark Borysiak, The Ohio State University
- Axel Palmstrom, UCSB

*Figure 25: 2010 NNIN iREU Japan Participants: (Left to Right)-Scott Isaacson, Isaac Markus, Denys Zhou, Arolyn Conwil, Athena Pan, Claire McLellan, Sarah Connolly, Mark Borysiak, and Axel Palmstrom.*

**Germany** (Figure 26**)**

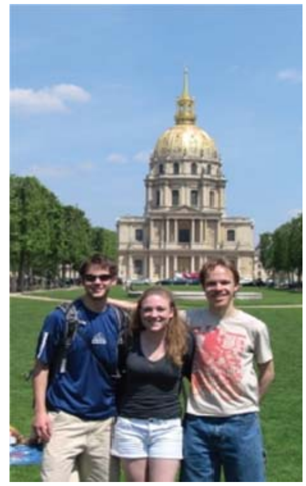
- Jacob Sadie, Clemson University
- Matthew Hershberger, Bethel College
- Vivian Feig, Columbia University
- Hamsa Sridhar, Harvard University
- Margaret Merritt, Brown University
- Devanand Sukhdeo, Columbia University

*Figure 26 2010 NNIN IREU participants in Germany (left to right) Jake Sadie, Hamsa Sridhar, Matt Hershberger, Vivian Feig, Dave Sukhdeo, and Margaret Merritt.*

**Belgium** (Figure 27)

- Nathaniel Hogrebe, University of Dayton
- Adam Kozak, University of Rochester
- Christine Burdet, NC State University

*Figure 27: NNIN 2010 iREU Belgium participants: Nathaniel Hogrebe, Christine Burdett, and Adam Kozak.*

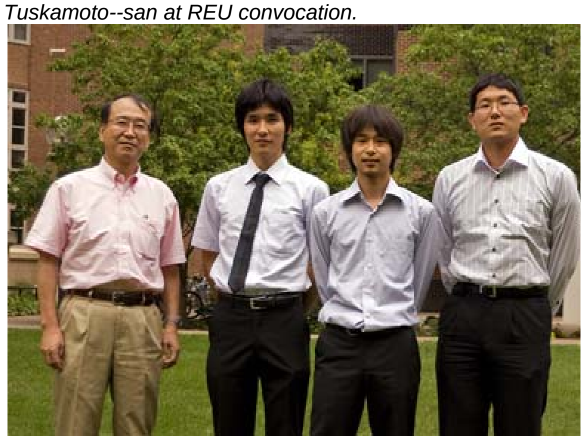


The students spent between 11 and 12 weeks (site dependent) at the international laboratories. NNIN provided the stipend, travel, housing, and food allowance. This program provides an excellent career growth opportunity for the participants. iREU interns have indicated that their prior NNIN REU experience allowed them to meet the challenges of a more advanced project, work in a different research environment, and live and work with colleagues from another culture. The participants indicated that they would be willing to pursue other international programs in their future education and career paths. The iREU also established important international linkages for the NNIN.

### 3.3.3 iREG-International Research Experience for Graduates

As an integral part of our relationship with NIMS Japan for hosting our iREU program, NNIN hosts a number of graduate students from Nanonet, the Japanese equivalent of NNIN, which is managed by NIMS. In 2010, 5 graduate students from Japan came to NNIN sites, two to Georgia Tech, two to University of Michigan and one to University of Texas.

*Figure 28: Furuya-san, Fujii--san, Watanabi-san and Tuskamoto--san at REU convocation.*



- Takashiro Tsukamoto, Tohoku University; worked at Georgia Tech with Prof. Ken Brown on the project **"Microfabricated Ion traps for Quantum Computation "**
- Kazutoshi Kubo, Nagoya University; worked at Georgia Tech with Prof. Ali Adibi on the project **"Development of Optimal Surface Coating Techniques for High-throughput, Dense-multiplexed Nanophotonic Biosensor Arrays in Lab-on-a-chip Applications"**
- Masaki Watanabe , Nagoya University; worked at the University of Michigan with Prof. John Hart on the project **"Carbon Nanotube Microsensors and Microactuators for Biomedical Microsystems"**
- Takeshi Uchinoumi, Kyushu University; worked at the University of Michigan with Prof. Wei Liu on the project "**Heterogeneous Integration of p- and n- type Nanowires for Complimentary Nanowire Circuits"**
- Hiromosa Fujii, The University of Tokoyo; worked at the University of Texas with Professor Brian Korgel on the project "**Solvent-based Deposition Processes for High-efficiency Photovoltaic Devices**"

Each of these students was at NNIN for 8-10 weeks during which time they were treated much like our REU students. In particular, they were integrated both socially and technically with the REU students, which added greatly to their experience. Unlike undergraduate REU students, these graduate students come with a significant prior skill set and focused interest. During this time they integrated into the appropriate research group, were trained in equipment and techniques, and contributed to both their own research project and the overall goals of the research group. Three of the students were able to participate in the NNIN REU convocation in Minnesota, further enriching their experience. They were joined by Kazuo Furuya, a senior scientist from NIMS and the Deputy Director of the Japan Nanonet program

In 2008, 5 students were hosted at Penn State (2), University of Texas, Harvard, and UCSB. In 2009, 3 graduate students from Japan came to NNIN sites, 2 to Cornell University and 1 to University of Texas. NIMS and Nanonet are highly pleased with the program and the interactions developed with this exchange. The goal of this program is much the same as iREU, that is, to increase awareness of the global nature of research. In this it has been very successful. These students interact strongly with our resident REU students, and there thus results a considerable synergy between the REU, iREU, and iREG programs.

### 3.3.4 RET Program

Five sites participate in an NSF-funded Research Experience for Teachers (RET) Program which began in March 2006. A second three-year NSF award was received in May 2009. Georgia Tech (lead), Harvard, Howard, Penn State, and UCSB host the teachers. In 2010, we had 22 participants: 9 females (41%), 13 males (59%) and 33% from underrepresented populations. This is consistent with the prior program which had 60 participants over 3 years: 33 females (55%), 27 males (45%) and 42% from underrepresented populations. Some sites leveraged the RET award (15 participants) with NNIN funds to support additional participants in 2010. We achieved our goal of having teachers from minority populations. We have also been highly successful in having teachers who teach at schools with high-minority populations - ~70% of the schools have a high percentage of underrepresented populations (race, ethnicity, and socioeconomic status).

Each RET participant completes a post- survey based on one developed by the RET Network. The survey was modified to reflect specific questions regarding nanoscale science and engineering (NSE). Results from some of our survey questions are in Table 8. These reflect some of the results that address the issues of whether the program provided a research experience, had an impact on teaching, and was an overall positive experience.

| Table 8. Examples of NNIN RET Post Survey Results 2010. | |
|---|---|
| Program was responsive to professional development needs | **3.6** |
| Program provided opportunities to engage in inquiry/research activities that I will adapt for classroom use | **3.8** |
| I collaborated in ongoing research with site staff | **3.0** |
| I operated instruments, equipment, & other technologies | **3.3** |
| Program increased interest in research & ways that STEM can be applied. | **3.7** |
| I gained greater understanding of the applications of STEM to everyday life. | **3.8** |
| I acquired greater understanding of fundamental concepts in STEM | **3.7** |
| I became familiar with new materials & equipment that I can use in my teaching. | **3.8** |
| I learned innovative ways to use standard materials and equipment in my field. | **3.5** |
| I increased my knowledge of current issues in STEM research | **3.5** |
| Mentor’s knowledge of roles & responsibilities of teachers in STEM | **3.7** |
| Mentor’s interest in helping you develop a plan to improve education in STEM | **3.8** |
| **Would you recommend the NNIN RET program to your colleagues?** | **4.0** |

*Likert scale 1-4 1= not at all; 2= small extent; 3= moderate extent; 4= great extent*

Separately, on a scale of 1-5, teachers rated the **NNIN RET program at 4.6/5.0** as a "professional development program.

The results indicate that teachers were actively engaged in research that they can adapt for their classrooms, a main goal of the program. The project mentors showed that they had an understanding of teacher roles and responsibilities and wanted to help the teachers in improving education. Teachers also indicated that they increased their knowledge of current issues in STEM research. Overall, the program received very high ratings.

During the school year, each site supports the teachers in their classroom to help introduce NSE into their courses.  The program culminates at the National Science Teachers Association (NSTA) annual meeting. All participants of the REU sites meet for a half-day session (NNIN REU Share-a-Thon ) where materials are shared and critiqued. Teachers interact with their fellow NNIN RETs which builds a sense of community.  Each participant develops an instructional unit for his/her classroom, which are then reviewed and field tested before placement on the NNIN education portal (http://www.education.nnin.org). In addition, the RETs "work" at the NNIN exhibit booth at NSTA and interact with attendees as experts in bringing nanoscale science and engineeriing into the classroom

### 3.3.5 iWSG

The international Winter Schools for Graduate Students (iWSG) are organized jointly by NNIN and institutions in third world countries with the goal of promoting international bridge building and understanding by bringing together students and faculty in an intense teaching and societal experience. Each year, approximately10 graduate students and 5 faculty participate in a rigorous course in an emerging and research-intensive interdisciplinary nanotechnology direction that is not part of US graduate curriculum. This lasts six days and includes laboratory sections. This is followed by travel to a rural part of the country (~4-5 days) where students spend time observing, experiencing and discussing the societal challenges and the part science and technology can play. A large group of students from the host country participate in the course part and a smaller group joins in the rural experience.

The third  iWSG took place at IISc-Bangalore, India during January 3-15 , 2011 with the societal experience in Dharmasthala. Thirteen graduate students from across US institutions participated in this event. The subject of the teaching was "Science and Technology of Nanofabrication". The rural experience focused on early education and rural needs. The participants visited such places ad the Rural Development and Self Employment and Training Institute, local schools, and an energy cooperative,among others. This year they also brought education demonstartions/hands-on activities to do with local school children.

*Figure 29; Scenes from the 3rd iWSG that was held at IISc, Bangalore, India and its post-teaching societal activities.*

Participating students were selected from a nationwide solicitation. Student participants for 2011 included:

- Julie Bert, Stanford University
- Blair Brettman, Massachusetts Institute of Technology
- David Carlton, University of California, Berkeley
- Matt Gibson, University of Michigan

- Joseph Grogan, Pennsylvania State University
- James Pikul, University of Illinois
- Michael Junkin, University of Arizona
- A.J. Kumar, Harvard University
- Vincent Lee, Columbia University
- Jonilyn Longenecker, Cornell University
- Sarah Lukes, Montana State University
- Kasey Phillips, Harvard University
- Thomas Woodson, Georgia Institute of Technology

Participating US faculty and personnel included

- Prof. Sandip Tiwari, Cornell University
- Prof. Steve Campbell, University of Minnesota
- Prof. Bart Vanzeghbroeck, University of Colorado
- Dr. Bojan Ilic, Cornell University
- Prof. Karl Böhringer. University of Washington
- Dr. Larry Goldberg, National Science Foundation

US participnt students completed an evaluation instrument for the event and the results are presented in Table 8. R Overall, the course received very good ratings including providing a broad perspective to the field and its challenges as well as allowing participants to interact across international boundaries and see the other world perspectives. This latter was an important goal of the program in that we are seeking to develop globally aware scientist through this experience. (an important focus of the program).

| Table 8. Evaluation results for iWSG 2010. | Response Scale 1-5 |
|---|---|
| **To what extend did the Winter School:** | |
| Give you a broad perspective of fabrication & its challenges | 4.5 |
| Introduce the context of fabrication and its current R&D context | 4.1 |
| Provide broad understanding of oxidation and chemical deposition processes | 4.2 |
| Provide introduction to vacuum equipment and physical deposition | 4.5 |
| Discuss and help you understand the variety of optical lithographic techniques | 4.4 |
| Discuss and help you understand electron beam and soft lithography | 4.3 |
| Provide and understanding of wet etching and dry etching techniques | 4.3 |
| Discuss inderpinnings of chemical precursors and related deposition | 3.1 |
| Discuss and introduce stress and defect evolution in films & crystals | 4.7 |
| Help you understand implantation and annealing | 4.8 |
| Discuss & helped you understand optical characterization techniques | 4.1 |
| Provide an understanding of how processes are integrated for MEMS | 3.3 |
| Provide an understanding of how MEMS devices are characterized | 3.3 |
| Provide an understanding of process integration for CMOS | 2.9 |
| Discuss and helped you understand other in-process characterization (AFM, SEM, etc.) | 4.2 |
| Present in an understandable way the context of technology in Indian environment | 3.8 |
| Help you see differences in perspective of how problems of living are viewed from Indian perspective | 4.2 |

Likert scale: 1= not at all; 2= not significantly; 3= somewhat; 4= significantly; 5= great extent

Participants in the field trip portion of the trip completed an essay on their thoughts and observations. These essays indicated that students were extremely positive about the workshop and the field trip. The visits to rural villages in India were “eye-opening” events for all participants and helped them to see how technology connects and potentially can help the poorest people in the world. Sample comments by the US participants are in the text boxes to the right. The comments reveal the various impacts that the rural experience had on the students.

The winter school is a comprehensive education program whose content is archived at the education portal of NNIN. See, e.g. http://www.nnin.org/nnin_iwsg_2010_bangalore.html for the latest course. Included in this education are quizzes to assess the learning. These also give an opportunity to compare the knowledge acquisition of the participants. Figure 30 shows distribution of scores from the iWSG3 of the US participants, and the non-local Indian participants through 17 quizzes.

Selected Comments from iWSG Participants.

*The field trip as a wonderful experience. {SKRDRP} is clearly a model for rural areas to develop themselves into self sustaining and progressive societies.*

*I was struck most by the fact that most of the programs involved local people providing help, support, and education to each other, rather than an outside group imposing help.*

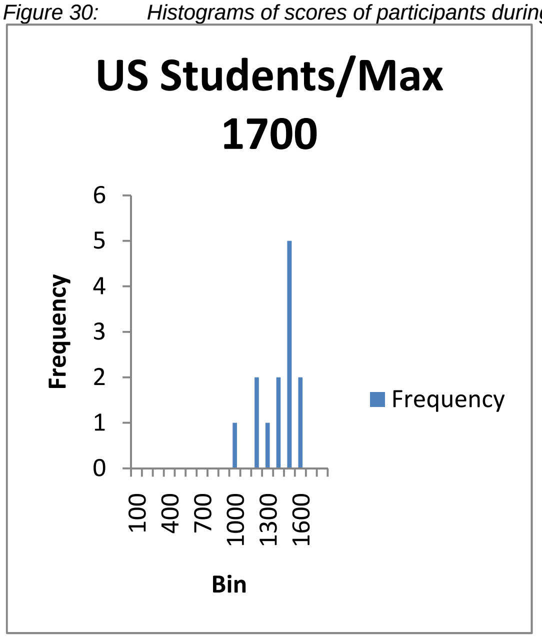
*My two favorite sites were the pico hydroelectric plant and SELCO. SELCO is a great model of using technology to solve problems in developing countries. They are developing appropriate (technology) that meets the local populations’ need. The pico hydroelectric plant was also an example of an appropriate technology. It was environmentally friendly and met the needs of the local community.*

*Among the things I particularly enjoyed was the visit to the hydroelectric village and the science experiments with the high school students.*

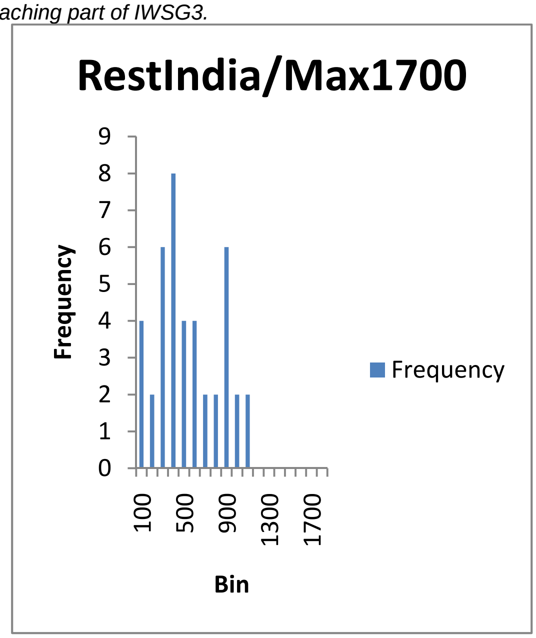
*One of the highlights of the trip for me was the diversity of our American group and the IISc group. People often cite the importance of diversity in science, but are unable to put it into practice. The key is accepting the difference and not viewing them as weaknesses. I was excited to spend time with such an intelligent and driven group of people that cared about their role in society and the world.*

*The field trip visit was a once in a lifetime way to see rural India. By working with SKRDRP we were able to get a feel for the broad range of methods used to improve the local community. One of the things that has struck me the most were the people. I was very impressed by their cooperation with other community members, such as in the coops and women’s group……… I was also impressed by the importance placed on education in the farming community of Dharmasthala. At the women’s group, many of the children were far better educated than their parents. The Ujire Yannad school had a unique approach by having students learn both practical faming skills and other standard subjects*

*Figure 30: Histograms of scores of participants during the teaching part of IWSG3.*




(a)




(b)

## 3.4 Other Education Programs

### 3.4.1 Teacher Workshops

NNIN (Georgia Tech) has developed and provided teacher workshops on nanoscale science and engineering (NSE). The intent of these activities is to give teachers the background and tools necessary to increase student awareness and interest in science and technology in general and NSE in particular. We believe it is very important to provide professional development training for teachers in order to move NSE into classrooms. Pre-survey of science teachers attending Georgia Tech workshops indicate that 25% knew nothing and 75% knew very little (had heard about it but did not know what it meant) about NSE.

Georgia Tech offers a variety of workshops ranging from two hours to week long that focus on how NSE can be included in standards-based science curriucla on including nanotechnology in science classrooms.  All of the instructional materials are tied to s and National Science Education Content Standards or state standards if the workshop is offered at a state meeting. This is done to ensure that teachers are using standards-based units. Workshops in 2010 were presented at the annual meetings of the Georgia Science Teachers Association, the South Carolina Science Council, the Wyoming Math and Science Teachers Conference, and national and regional NSTAs. Figure 31 shows the states and Georgia counties where the GT NNIN site has reached at least one teacher in a workshop (typically more than one per shaded area). These workshops have proved extremely popular, beyond the capacity of the GT site to provide. NNIN sites are now encouraged to either exhibit or present at their state science teachers' association meeting to inform teachers about NSE and its inclusion in the science curriculum.The office at Georgia Tech will be assisting with these regional events as appropriate to leverage the existing expertise of the network. The University of Texas (with assistance from the NNIN Education Office) exhibited at the Texas Science Teachers Assocation annual meeting in November which has over 7,000 attendees.

Stanford provides hands-on activities, lectures, and facility tours to teachers attending the weeklong Summer Institute for Middle School Teachers.

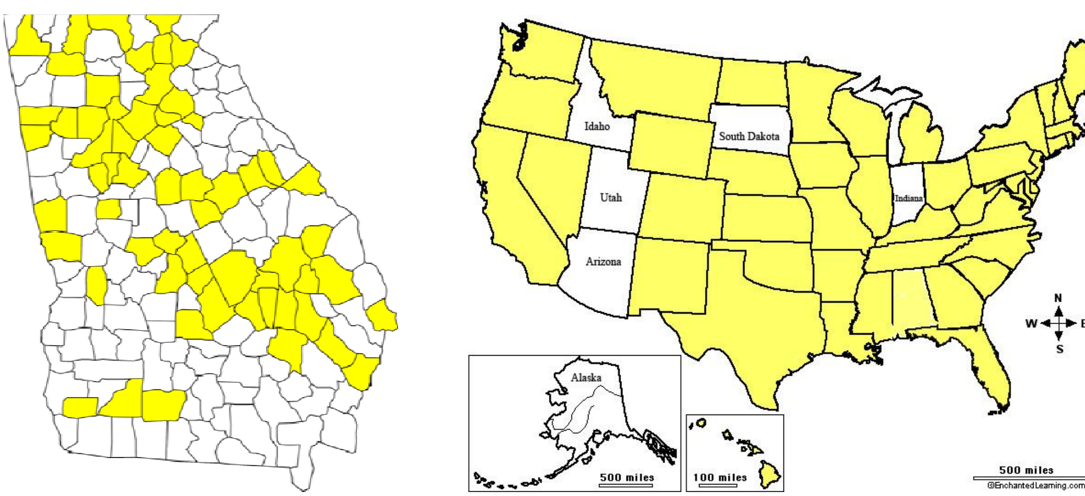



*Figure 31: Counties and states (shaded area) where the GT NNIN site has reached teachers in workshops.*

### 3.4.2 NanoTeach

In September 2008, NSF funded the Mid-Continent Research for Education and Learning's (McREL) *NanoTeach* project.  Stanford, Georgia Tech, and University of Colorado at Boulder (MRSEC) are the university partners for this professional development program.  Since its inception, the NNIN sites at

Stanford and Georgia Tech have been involved in the development of the two week professional development pilot workshop which occurred July 12-23, 2010. NanoTeach (http://www.mcrel.org/NanoTeach/index.asp) is using a combination of face-to-face and online professional development experiences for high school science teachers who teach physical science topics. The primary goal of NanoTeach is to prepare teachers to use an instructional design framework to integrate nanoscale science and technology content into their curriculum in significant ways. The Standord site developed remote access events for the summer pilot as well as assisting in the content portion of the workshop. Georgia Tech developed a PowerPoint on the *Big Ideas in Nanoscale Science and Engineering:A Guidebook for Secondary Teachers* (Stevens, et. al, 2009), developed posters on the Big Ideas, assisted in the analysis and selection of instructional materials, and recruited NNIN researchers to present webinars during the pilot. In the fall, we began the third year of this five year program.

### 3.4.3 Other K-12 outreach

Numerous outreach activities have occurred in 2010 including K-12 field trips to facilities, visits to schools, summer/weekend camps, workshops, and demonstrations. In order to provide these activities, the NNIN sites have developed hands-on activities, demonstrations, and presentations on NSE. We also adopt and adapt activities developed by other centers and programs such as University of Wisconsin-Madison MRSEC & NSEC, Nanosense (SRI), NISE Net, among others. The Georgia Tech site developed the *NNIN Outreach Demonstration Guide* which is a resource on how to adapt larger lessons developed by NNIN and other nanoeducation groups into demonstrations. This guide has been posted on the NNIN education portal - http://www.nnin.org/doc/NNIN_Outreach_Demo_Guide.pdf and was updated in 2010.

Hands-on summer, weekend, or after-school camps/programs to engage students in NSE are offered by UCSB, Georgia Tech, University of Washington, University of Minnesota, and University of Michigan. These camps/programs focus on middle and high school students and have a variety of formats (1day to one week) and content (chip camps, introduction to nano, biomedical, etc.). **Examples** of some of these programs include:

- UCSB “Chip Camps” provided hands-on nanofabrication to students from area high schools.
- Georgia Tech’s *Nanotechnology Explorations* camp for high school students
- University of Washington provides activities for visitors to the Pacific Science Center
- University of Michigan offers a day program for middle and high school students in introduce them to nanoscale science and technology
- Stanford provides support for the Summer Institute for Middle School Teachers by hands-on activities, demos and a tour of the cleanroom facilities.

In addition, most sites provide on-site activities for visiting school groups as well as the general public. These typically involve lectures, hands-on activities, demonstrations, lab tours, and cleanroom tours. Most include discussions on career and educational opportunities to encourage students to consider careers in STEM and in particular NSE. Sites are also involved in career days at schools, family science nights, science fairs, and community days. The University of Michigan and Georgia Tech judged local science fairs and provided awards for the best experiment in nanotechnology. Besides receiving a plaque for the achievement, the students in Michigan were special guests for a day at the LNF. Nearly all sites hosted NanoDays using materials supplied by NISE Net. At the September 2009 coordinators meeting it was agreed that all sites would seek materials from NISE Net to host a NanoDay event in 2010.

## 3.4.4 USA Science and Engineering Festival

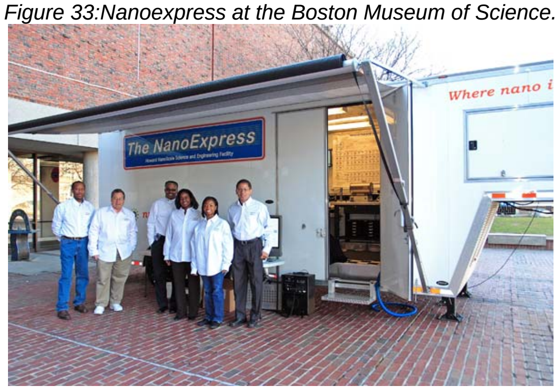
The NNIN was one of 550 participants at the first USA Science and Engineering Festival held the weekend of October 23-24. This was a massive but highly successful national outreach event. Several NNIN sites assisted in this effort: Cornell, Georgia Tech, University of Michigan, University of Minnesota, UCSB, and Washington University St. Louis. In addition, one of the 2010 REUs (Joseph Smalley) came from Penn State to assist us. We did demonstration and hands-on activities that included shape memory alloys, hydrophobic materials, thin films, nanoproducts, nanobumps (a prototype of an early detection device for diabetes), hand-held USB scopes and SEM picture matching, ferrofluids, quantum dots, and Nanooze. This was an extremely busy event (500,000 participants) and we estimate that we saw approximately 7,000 individuals during the two days. NNIN will be participating in this event again in the future.


*Figure 32: USASEF 2010.*

## 3.4.5 NanoExpress

Howard University launched the NanoExpress in summer 2006. This is a mobile laboratory which presents the world of nanotechnology to the general public from K-Gray. The NanoExpress(fig.33) is a mobile van with 208 square feet of lab space designed to facilitate hands-on experiments but also capable of doing nanotechnology research. Experimental areas include: Introduction to Passive Nanoparticles, Introduction to Self Assembly, Introduction to Micro and Nanofabrication, “Chips are for Kids”, Instruments for NanoScience, Shape Memory Alloys, and Soft Lithography. Undergraduate, graduate lab assistants, and RETs help supervise experiments. The NanoExpress has visited D.C. area schools, Boy Scouts and Girl Scouts, National Youth Medical Forum, George Washington University, and USA Science And Engineering Festival.

*Figure 33:Nanoexpress at the Boston Museum of Science.*




## 3.4.6 NNIN Education Portal

The NNIN education portal (http://www.education.nnin.org) serves as another avenue in reaching a variety of audiences by offering information for children and adults.

## 3.4.7 Nanooze

Cornell has developed a children’s science magazine related to physical sciences and particularly nanotechnology. *Nanooze* is a web based magazine (http://www.nanooze.org/), with kid-friendly text, topics, and games. It is designed for grades 5-8 but we have found that even high school students enjoy the magazine. *Nanooze* is available in English, Spanish, and Portuguese on the web. We now offer special topic issues of *Nanooze* in hard copy with the most recent issues focusing on nano-medicine and nano and food. A total of 8 issues are available. Teachers may request classroom packs of any or all of these issues. Through a variety of distribution mechanisms, including NNIN’s exhibit booth at NSTA, over 100,000 copies were distributed to upper elementary through high school students in 2010 (more than 600,000 copies have been printed). Additional details are available in the Cornell site report.

## 3.5 Technical Workshops--Laboratory Oriented

The NNIN is committed to workforce development training through a variety of activities which have been developed and implemented across the network. Training and development activities focus on undergraduate and graduate students, industry and government personnel, and faculty from other institutions. Information on these workshops is found on the NNIN website and upcoming events are advertised on the home page so that individuals can find quick links to the technical workshops. A variety of multimedia is also available on the website including talks, symposia, short courses, and equipment training - http://www.nnin.org/nnin_multimedia.html. Individual sites also offer online training materials which are downloadable. Many of these video demonstrations and lectures are downloaded by individuals worldwide for use in classrooms and training activities.

*Technology and Characterization at the Nanoscale* (TCN) is a workshop offered twice a year by Cornell. The content of the TCN is designed to encompass all nanotechnology techniques relevant to current research in the field. While traditional topics in nanotechnology - thin films, lithography, pattern transfer (etching), and characterization - provide the basic structure of the course, we include emerging technologies and new approaches in nanotechnology. Nano-imprint lithography, bottom-up nanofabrication, carbon nanotubes, soft lithography, and surface preparation for biology applications are among the topics addressed.

The University of Minnesota provided several workshops during the past year. The workshops included BioMems and Microfluidics short course, 6$^{th}$ Annual Nanotechnology conference, and Introduction to Thin Films. The University of Michigan presented Tip-based Lithography for Nano-engineers and Scientists and Coventor Software Tools for Bringing MEMS/NEMS Concepts for Reality. The University of Texas had two two-day workshops – one on Surface Measurement Systems and the other on Nano Imprint Technology - Step and Flash Nano-Imprint Lithography (S-FIL™).

Georgia Tech has developed *NanoFans* (**Nano** **F**ocusing on **A**dvanced **N**anoBio **S**ystems) a twice yearly forum to connect the medical/life sciences/biology and nanotechnology communities. The workshops reach out to researchers in the biomedical/life sciences areas to inform them about what nanotechnology can offer them in the advancement of their research. The May 2010 forum was on Nanotechnology and Cardiology and the November 2009 event focused on Nanotechnology and Drug Delivery. (http://www.mirc.gatech.edu/nanofans.php).

## 3.6 Symposia and Advanced Topics Workshops

NNIN has over recent years held a number of special focused advanced topic workshops or symposia which bring together significant contributors in fields covered by NNIN. In general, the purpose of these special workshops is to explore emerging areas in which NNIN may be able to make significant contributions. They aim to foster interactions with NNIN and interactions between the participants, and are one source of information to guide NNIN management in new initiatives. With the recent renewal, NNIN recommitted to these special symposia with a goal of 4 major events per year. Recent workshops are highlighted below.

### 3.6.1 Synergies in Nanoscale Manufacturing and Research

Cornell University hosted a two day workshop jointly sponsored by the NSF's National Nanomanufacturing Network which is centered at the University of Massachusetts Amherst. The event was held January 28-29, 2010 and was a by-invitation only working group intended to generate active discussion on the issues related to bringing emergent tools, processes, and materials into commercialization. The speakers, moderators, and attendees were selected from across the country and from industry, academia, and government labs to bring a broad range of expertise and experience to the discussion. The main themes dealt with issues such as infrastructure investment, standardization, development of methodology and quality monitoring methods, and scalability of emergent technologies.

Speaker topics ranges from roll-to-roll production of flexible electronics, mass methods of producing bit patterned magnetic media, ways to manufacture silicon with atomic precision to groundbreaking methods of making measurements of structural properties in complex materials. Additional reports were on several new means of highly specialized drug delivery, the possibility of mass production of carbon substrates for electronics, a new class of photochemicals compatible with organic materials, among others. The format included presentations followed by groups and breakout discussions centered on questions and topics stimulated by the speakers. The workshop report, including a summary of the general findings, can be accessed a http://www.nnin.org/doc/snmr10/SNMR_Summary_Document.pdf.

### 3.6.2 Interdisciplinary Challenges Beyond Moore's Law

In cooperation with NSF, NNIN organized over three days in August, 2010, a workshop on "Interdisciplinary Challenges beyond the Scaling Limits of Moore's Law." The workshop explreod overcoming of current barriers in further progress in scaling and computation by fostering interdisciplinary debate and dialog that integrated learning from engineering, physical and life sciences. The workshop brought together experts from academia, government, and industry in the fields of life sciences, chemistry, physics, mathematics, materials science, engineering, and computer science to discuss new approaches and approaches to overcome current barriers such as charge leakage effects and thermal limitations of additional scaling.

The workshop will further explored at the intersection of science and engineering to address the key questions ranging from macroscale to nanoscale materials, devices and systems. Some of the questions explored inlcuded the future of terascale devices, implementation strategy to minimize energy utilization, novel materials and devices, new approaches for reliability by adapting and self-healing and programming. A report and the summary of workshop are available at http://www.nnin.org/nnin_nsf_workshop_2010.html .

### 3.6.3 Symposium on Nanotechnology and Energy

The Colorado Nanofabrication Lab hosted this symposium October 25-26, 2010 that focused on the intersection between nanofabrication and energy. The objective was to bring local researchers and their student together with renowned experts and industry representatives. The key emphasis was on photovoltaics. Topics during the two day meeting included record efficiency solar cells. thin film cells, novel materials including nanoparticles and organics, nanofabrication techniques, material deposition, characterization and photovoltaics policy. There were 19 speakers/presentaion along with 13 poster presentations.

### 3.6.4 Organic/Inorganic Interfaces

Arizona State University organized a symposium in the area of Organic/Inorganic interfaces partly in support of its leadership role in the network in this thematic area, The symposium "Organic/Inorganic Interfaces and their Health Science Applications" took place on the ASU campus 13-14th January, 2011.The symposium consisted of three sessions addressing topics related to 1) Sensor Elements, 2) System Level Integration, and 3) Cellular Interfaces and Control, with over 100 participants from 16 universities along with 23 speakers. The program addressed critical issues in the integration of inorganic devices and structures with biological systems. The workshop highlighted the ASU node's expertise and should help build its user base in this critical area. More details about the symposium can be found at the following web site: http://thornton.faculty.asu.edu/Research/NNIN_Workshop/.

## 3.7 Diversity Related Efforts and Programs

A primary focus of NNIN E&O is inclusion of underrepresented populations and this theme runs throughout the education goals and objectives of the NNIN. While there are specific outreach activities that focus on underrepresented populations, inclusion is an underlying objective of all of our outreach programs. Discussed below are some of the specific programs that are occurring which highlight some of our inclusion activities.

Individual sites make every effort to ensure participation by underrepresented groups in the K-12 programs. With our data management system, gender and ethnicity is being tracked for all activities (when possible). Sites that are located in diverse areas of the country have the best opportunities for recruiting underrepresented participants to the events. However, all sites make an effort for reaching out to diverse populations. For example, the University of Michigan exhibits each year at the regional National Society of Black Engineers conference and UCSB works with students and teachers in high minority (Hispanic/Latinos) schools. Arizona State Universit has been in dicussions to bring outreach to Native American Schools.

### 3.7.1 Diversity in NNIN REU Program

Our REU program places a special emphasis on providing research opportunities for women and minorities. Specifically, the program requirements indicate, "Sites are encouraged to select applicants who are female, minority members, or from non-research institutions." The REU program has quantifiable benchmarks regarding participants which include 50% women participants, 20% from underrepresented minorities, 50% from schools with no Ph.D. program in science and engineering, and 50% from outside the 100 largest research universities. The results reported in the REU section of this report demonstrate that women typically have a higher participation rate in our program in comparison to the applicant pool and in 2010 we had 46% female participation in the REU program (54% in 2009) very close to our 50% benchmark. Minority students are participating at about the same rate as the applicant pool with 18% participating in 2010 from an applicant pool of 19%. This is very close to our benchmark of 20%. We cobntinue to fall short of our benchmark of having 50% of the interns come from schools with no Ph.D. program in science and engineering with 29% of our interns coming from these schools in 2010. We typically have two-thirds of our applicants coming from Ph.D. granting institutions which is then reflected in the participation percentage of around 67-70% each year.

### 3.7.2 Diversity in NNIN RET Program

The NNIN RET program recruits teachers who are themselves from underrepresented groups or teach at schools with a high percentage of underrepresented students or low socio-economic status. Since inception in 2006, there have been 101 RETs - 54 females (54%), 48 males (46%), and 42% from underrepresented populations. Our RET program has been very successful in including teachers who teach at schools with high-minority populations - >70% of RET schools have a high percentage of underrepresented populations.

### 3.7.3 Showcase for Students: An NNIN Diversity Program

NNIN has developed the *Showcase for Students* which is an all day workshop on nanotechnology with morning lectures and activities and demonstrations in the afternoon. This event features a series of talks in the morning about the career and education opportunities in NSE. The afternoon session consist of a variety of high-tech and low-tech demonstrations of nanotechnology instrumentation and concepts. NNIN has an array of portable nanotechnology instrumentation, including AFM, STM, SEM, and a variety of optical microscopes. These are set up for live demonstrations for the students to visit and interact with. In addition, staff from NNIN sites bring smaller items that can be used to demonstrate nanotechnology

*Figure 34: Showcase at SHPE meeting in Cincinnati.*

concepts. These include shape memory alloys, nanotechnology products, quantum dots, hydrophobic and hydrophilic materials, carbon nanotubes, and microfluidic devices. The focus is on undergraduate students who attend conferences sponsored by underrepresented professional science and engineering organizations. NNIN held one workshop in 2010 at the Society for Hispanic Professional Engineers in October 2010. We reached approximately 200 students at the event. The afternoon demonstration session is particularly well-received by attendees and they have indicated that they enjoy learning about nanotechnology but also interacting with NNIN researchers and staff who support the technical/demonstration session.

### 3.7.4 Laboratory Experience for Faculty Program

In fall 2007, NNIN introduced a new program, the NNIN Lab Experience for Faculty. The program focuses on supporting underrepresented faculty or faculty from minority serving institutions to perform research at one of our facilities. In some cases, the participants may become NNIN users in the future; in others, they will relate their experience to their students. Either way, NNIN has an impact on participation of underrepresented populations in nanotechnology. Nine awards of $12,000 each were made to Georgia Tech, Cornell (x2), and Stanford. Faculty spent 8-10 weeks in the summer of 2010 undertaking their own research project in nanoscale science. Table 10 summarizes the faculty and their projects.

**Table 10. NNIN 2010 LEF participants.**

| Faculty Participant | Home Institution | NNIN Site | Project |
|---|---|---|---|
| Prof. Tatiana Allen | University of Tennessee Chattanooga | Georgia Tech | Studying Nickel-molybdenum Thin Films |
| Prof. Amy Sullivan | Agnes Scott College | Georgia Tech | Photonic Device analysis, Design, Fabrication, and Testing |
| Prof. Adebayo Ariyibi | Tuskegee University | Georgia Tech | Optimization of QCM surface functionalization conditions for a study related to the detection of cancer biomarkers |
| Prof. Jennifer Lu | University of California Merced | Stanford | Fabrication of Nanohybrid Films for Energy Conversion and Harvesting |
| Prof. Andre Taylor | Yale University | University of Michigan | Light Trapping for High Efficiency Photovoltaics |
| Cheng Zhang | Norfolk State University | University of Washington | Self-assembly Electro_optic Thin Films for Silicon Nanophotonics |
| Kimani Stancil | Howard University | Cornell University | Nanorod Alignment and Polymer Influences |
| Andrey Chabanov | University of Texas, San Antonio | University of Texas | Demonstration of Extreme Optical Energy Focusing on a Nanoscale through Efficient Coupling to Traveling Surface Polaritons |

| | | | |
|---|---|---|---|
| Sylvia Thomas | University of South Florida | Howard University | Nanoporous SiC Implantable Cholesterol Level Detector |

## 3.8 Evaluation

NNIN has developed a variety of evaluation instruments for its major programs which include: REU, RET, iREU, LEF, past REUs, iWSG, teacher workshops (pre and post), camps (pre and post), and school visits (pre and post). Instruments have been shared among all of the sites which can adopt and adapt them for their particular programs.

In 2008, NNIN developed a logic model and evaluation plan with the assistance of an external consultant (Tom McKlin, The Findings Group). The model and plan were presented in the 2008 annual report. We use the plan to ensure that we are collecting the correct data to assess the impact and quality of our outreach endeavors. Data presented in this report represent some of our findings using our instruments and other data collection methods.

## 3.9 Program Summary

NNIN's education program Is widely recognized as a leader within the nanotechnology and academic research center community. NNIN has and will continue to offer a variety of education and outreach activities at the local and national level. Table 12 below summarizes the major network wide programs.

**Table 11. Summary of NNIN Network-wide Programs.**

| Program | Participants | Purpose | Status |
|---|---|---|---|
| **REU** | Undergraduates | Research experience for a diverse population of undergraduates; introduction to nanotechnology research & careers | Upcoming 15th summer in 2011 |
| **iREU** | Undergraduates – former NNIN REU participants | Develop globally aware scientists and engineers from the most successful REU participants | Upcoming 4th summer in 2011 |
| **iREG** | Graduate students from Japan (NIMS) | International outreach; reciprocity for iREU Japan; No cost to NNIN | Upcoming 4nth summer in 2011 |
| **RET** | Middle and high school science teachers | Introduce teachers to nanotechnology and experimental design; develop nanotechnology classroom activities | Refunded by NSF in May 2009; upcoming 6th year in summer 2011 |
| **LEF – Lab Experience for Faculty** | Underrepresented faculty and/or faculty from minority serving institutions | Increase diversity in NNIN user base and in STEM/ nanotechnology pipeline | Upcoming 4th summer in 2011 |
| **SFS – Nanotechnology Showcase for Students** | Undergraduates | Expose diverse population of undergraduates to education and career opportunities in nanotechnology | Plan to offer 1-2 times per year |
| **Nanooze** | Upper elementary and middle school students | Stimulate and maintain interest in STEM at a young age | Classroom packs distributed in 2010 on special topics. |
| **iWSG** | Graduate students | Develop globally aware scientists and engineers; Provide technical workshops in nano to US and foreign students; Encourage international collaboration | Third two week workshop held in B**angalore**, India in January 2011. |

## 4.0 NNIN Computation Program

The computation project of the National Nanotechnology Infrastructure Network (NNIN/C) focused, in 2011, on the following areas: (1) Continued service to member base in terms of access to (improved) hardware facilities and steadily expanding code base, (2) Expansion of full computation services to University of Michigan with emphasis on MEMS and NEMS, (3) Database Repository projects: virtual vault for interatomic potentials and virtual vault for pseudopotentials, (4) Workshops and specialized meetings, (5) Scientific collaborations focused on high performance computing with Defense Department (DTRA) and Department of Energy (Sandia, CINT), (6) Future of nanotechnology: NNIN/C participation in: Nanotechnology Research Directions for Societal Needs in 2020 – Retrospective and Outlook, organized by Mike Roco, NSF, and (7) Renovation of NNIN/C website to reflect the growth and changes in the program.

This report describes the workings of NNIN/C providing the metrics for codes and user numbers. It describes some highlights of recent publications and/or presentations resulting from NNIN/C support. It discusses the status of "virtual vault" database activities and collaborative programs between NNIN/C and other agencies. It describes recent workshops and finally it describes the major NSF symposium (Arlington, VA, March 2010) on the future of nanotechnology in which NNIN/C participated.

### 4.1 Codes at the Sites

Nanoscale science pertains to the regime where the number of atoms or molecules under study are too numerous and arranged in too complex a manner for a single-atom/molecule treatment, on the one hand, and the number and arrangement of atoms is neither regular (periodic) nor sufficiently large so as to make statistical (thermodynamic) treatments meaningful, on the other hand. Nevertheless, the foundations of nanoscale computation consist of **electronic structure codes**, which are initially appropriate for small atom number or periodic systems, and **molecular dynamics codes**, which are statistical insofar as they typically require ensembles of initial conditions and treat systems interacting with heat baths. Additionally, **photonics and phononics** codes address the primary bosonic degrees of freedom of nanoscale matter, **processing or fabrication** codes treat the physics of ion implantation (among other areas), and **multiscale or finite element** tools treat micro-fluidics, which while larger than the nanoscale often interfaces with nanoscale structures and are important in their own right.

Table 12 illustrates the matrix of computational codes available at the various NNIN/C sites. Some codes require that users register or purchase their own copy before using them on the cluster.

**Table 12 List of computational codes available at the various NNIN/C sites.**

| | Harvard | Cornell | Stanford | Michigan |
|---|---|---|---|---|
| ***Electronic Structure*** | | | | |
| Quantum Espresso | | X | X | |
| Abinit | | X | X | X |
| CPMD | | X | X | |
| WIEN2K | | X | X | |
| SETE | X | | | |
| LM Suite | | X | | |
| NWChem | | X | X | |
| Siesta | | X | | |
| PARSEC | | X | | |
| Akai KKR | | X | | |
| FDMNES | | X | | |
| QuantumWise | | X | X | |

| | | | | |
|---|---|---|---|---|
| Socorro | X | | | |
| VASP | X | X | X | X |
| CHAMP | | | X | |
| Gaussian | | X | X | |
| GAMESS | | | X | |
| Octopus | X | | X | |
| TurboMol | X | | | |
| Atomic Simulation Env. | | X | | |
| GPAW | | X | | |
| ELK | | X | | |
| SPR-KKR | | X | | |
| DFTB+ | | | X | |
| ATAT | | | X | |
| **Molecular Dynamics** | | | | |
| LAMMPS | | X | | X |
| DL_POLY | X | X | | X |
| Gromacs | | X | X | |
| MOSAICS | | | X | |
| Desmond | | | X | |
| CP2K | | | X | |
| SDTrimSP | X | | | |
| GULP | | X | | |
| NAMD | | | | X |
| MCCCS Towhee | | | | X |
| **Photonics & Phononics** | | | | |
| DDSCAT | | | | x |
| MIT Photonic Bands (MPB) | | X | | |
| MIT FDTD code (MEEP) | | X | | |
| FDTD (Lumerical Licenses) | X | | | |
| MULTEL | | X | | |
| **Multiscale** | | | | |
| Quasicontinuum | | | | X |
| OCTA | | | | X |
| LibMultiScale | | | | X |
| CADD | | | | X |
| ***Nanoscale Electrostatics*** | | | | |
| UT-MARLOWE | | X | | |
| UT_Quant | | X | | |
| ***Nanoscale Fabrication*** | | | | |
| Patacon | | X | | |
| ***Multiphysics & Finite Element Tools*** | | | | |
| FEATFLOW | | | | X |
| GetDP | | | | X |
| FEBio | | | | X |
| Elmer<br>InelliSuite<br>CFD-ACE+ | | X | | X<br>X<br>X |

## 4.2 Computation Users

The number of users of NNIN/C computer clusters who have performed computation in the current year are listed in the accompanying table.

| Table 13: Computation Users 2010 (11 months) | | |
|---|---|---|
| | Internal | External |
| Harvard | 28 | 11 |
| Cornell | 28 | 8 |
| Stanford | 19 | 11 |
| Michigan | 7 | 2 |

Additionally, NNIN/C does extensive consultation with computational scientists as well as experimentalists who do not use computational hardware and so are not included in the above count.

## 4.3 Research Highlights

The NNIN/C initiative focuses on providing doctorate level expertise and consultation, cutting-edge simulation tools, and computing resources to help researchers succeed. The effectiveness of this effort can be measured through the publications of NNIN/C users and the impact they have had in the scientific community. During 2010 and early 2011, 27 publications resulted from NNIN/C users in leading journals such as Nature Chemistry, Nano Letters, and Physical Review Letters. Since the NNIN/C program started in 2004, there have been 120 publications through the NNIN/C program that have been cited a total of 1340 times with an average of 11.167 citations/paper. The total collection of NNIN/C papers has a Hirsch or h index of 22 which indicates that 22 papers have 22 or more citations. (Citation data and statistics obtained from Thomson Reuters ISI Web of Knowledge).

A full list of NNIN/C publications is available at the NNIN website:

http://www.nnin.org/nnin_computation_publications.html

### 4.3.1 Förster Coupling in Nanoparticle Excitonic Circuits

*P. Rebentrost, M. Stopa and A. Aspuru-Guzik, Nano Letters **10**, 2849-2856 (2010).*

When a photon produces an electron-hole pair localized in a molecule, quantum dot or nanoparticle ``site," the excitation energy can transfer to a neighboring site via coupling of the electrons to the electromagnetic field; a process which is known as fluorescent resonant energy transfer (FRET). FRET, which also underlies energy transport between chlorophyll molecules in photosynthesis, is an essential process in various existing and envisioned nano-structured devices such as engineered excitonic circuits, artificial light-harvesting systems and quantum computation implementations. Exciton transport in semiconductor nanoparticles underlies recent experiments on electrically controlled nanostructures and proposals for new artificial light-harvesting systems.

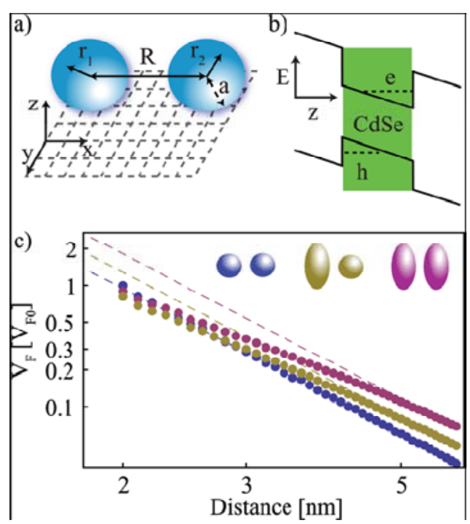



*Figure 35 : a) Two nanoparticles that spatially confine an electron-hole pair or exciton and exhibit Förster coupling. (b) Band structure of CdSe nanoparticle. (c) Förster coupling between particles as a function of distance for particles of various shapes*

In this study, the authors develop a new computational method for calculating the matrix element of the FRET transition rate which can be performed in an arbitrary geometry of dielectric and conducting materials. This flexibility is essential for evaluating the efficiency of different practical light-harvesting or emitting devices as well as for achieving a deeper understanding natural energy transfer in, for example, photosynthetic materials. (Fig.35)

### 4.3.2 Mechanism for Singlet Fission and Multi-Exciton Generation for Third Generation Solar Cells

*Paul Zimmerman, Zhiyong Zhang, and Charles Musgrave, Nature Chemistry **2**, 648–652 (2010).*

When a photon is absorbed, the energy in excess of the bandgap of the material usually is wasted as heat, thus limiting the maximum conversion efficiencies in a single junction solar cell to ca. 34%. One of the most intensive areas of research in photovoltaic is to explore mechanisms that can reduce the heat loss in the photovoltaic process. Singlet fission, and the closely related process, multiple exciton generation (MEG), describes the process in which, with the absorption of a single photon, two or more electron-hole pairs can be produced, thereby potentially doubling the output of a solar cell. (Fig. 36)

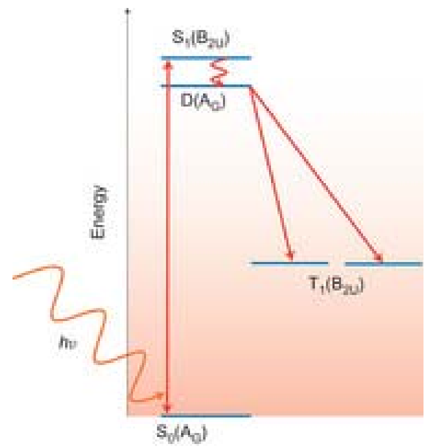



*Figure 36: Proposed mechanism of singlet fission in crystalline pentacene. Photoexcitation from $S_0$ to $S_1$ is followed by rapid conversion via a conical intersection to a multi-exciton singlet dark state D, which subsequently undergoes fission to create two triplets $T_1$ of $B_{2U}$ symmetry.*

Through the introduction and optimization of advanced simulation tools, we have revealed the underlying mechanism for singlet fission in pentacene, the prototype molecule for investigating singlet fission and many other photoelectric and electronic applications for organic materials. We have shown that photoexcitation from $S_0$ to $S_1$ is followed by rapid conversion via a conical intersection to a multi-exciton singlet dark state D, which subsequently undergoes fission to create two triplets $T_1$ of $B_{2U}$ symmetry. Further studies indicate that similar mechanisms are also applicable for singlet fission and MEG is different kind of materials, including graphene nanoribbon, carbon Nanotubes, and quantum dots of various kinds, thus opening the door for rational design of third generation photovoltaic material that can potentially double the conversion efficiency for third generation solar cells.

### 4.3.3 Band Gap and Electronic Structure of $Cr_{0.80}Al_{0.20}$ thin films

*Zoe Boekelheide, A. X. Gray, C. Papp, B. Balke, D. A. Stewart, S. Ueda, K. Kobayashi, F. Hellman, and C. S. Fadley, Physical Review Letters, **105**, 236404 (2010).*

Intermetallic compounds containing transition metals and sp elements often form a band gap at the Fermi energy due to hybridization. Based on these small band gaps, these materials have been exploited for applications in thermoelectrics and spintronics. Compounds based on a transition metal (A) and sp element (D) in the form $A_3D$ are usually ferro or ferri magnetic, with a magnetic moment well predicted by the Slater-Pauling counting scheme. $Cr_3Al$, however, is an antiferromagnetic and serves as an important exception to the Slater-Pauling rule. In addition, CrAl alloys in this concentration range are narrow-gap semiconductors and this behavior has not been explained by theory. The current work has used a combination of hard x-ray photoemission spectroscopy (HXPS) and density functional calculations of alloys based on a full potential Korringa-Kohn Rostoker multiple scattering approach within the coherent potential approximation. Photoemission measurements of a epitaxial $Cr_{0.80}Al_{0.20}$ thin film demonstrate a band gap at the Fermi energy with a minimum gap value of 95 ± 14 meV. Density functional calculations support the HXPS valence band analysis and show that the primary carriers in Cr, holes around the M k-point, are shifted almost entirely below the Fermi energy in $Cr_{0.80}Al_{0.20}$. The fact that the current calculations predict an incomplete band gap is not surprising given the well-known underestimation of band gaps by density functional approaches. (fig.37)

Density functional calculations for this work were done primarily by Zoe Boekelheide (graduate student at UC Berkeley) using NNIN/C computing resources at the Cornell Nanoscale Facility.  Zoe Boekelheide also won the 2011 Group on Magnetism and Magnetic Materials (GMAG) Disseration Award sponsored by the American Physical Society for her work on the effects of nanoscale structure on magnetic and transport properties of chromium and chromium-aluminum alloys.

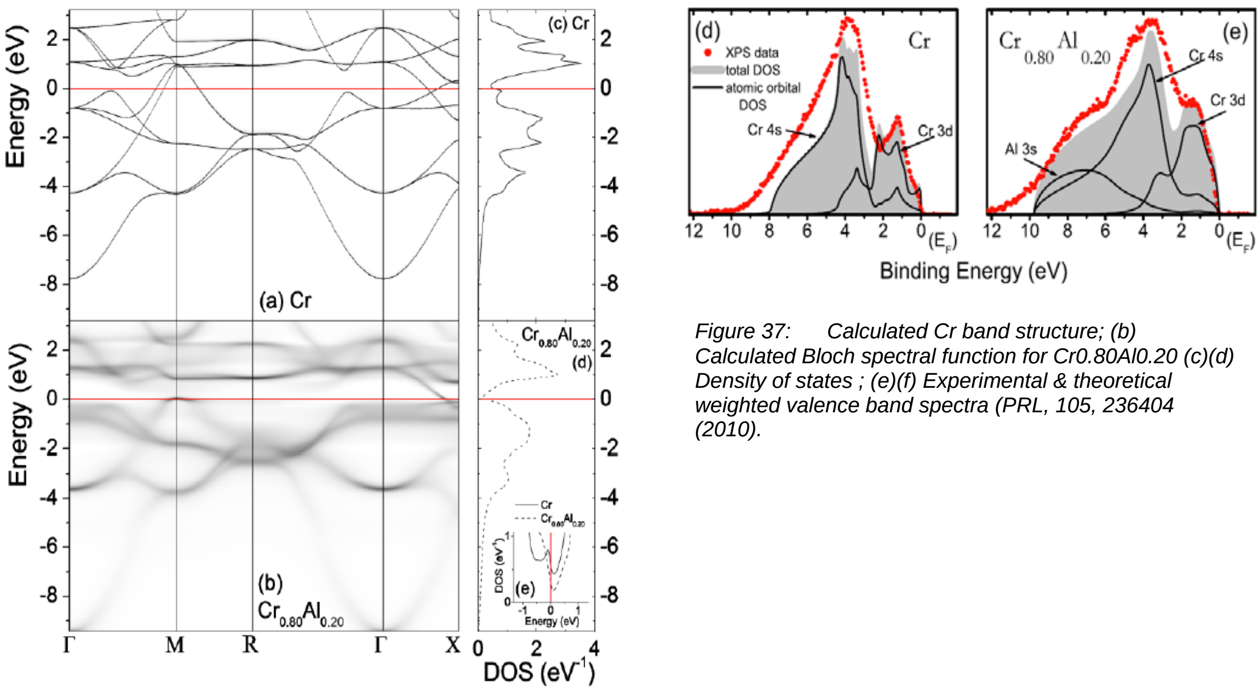



*Figure 37: Calculated Cr band structure; (b) Calculated Bloch spectral function for Cr0.80Al0.20 (c)(d) Density of states ; (e)(f) Experimental & theoretical weighted valence band spectra (PRL, 105, 236404 (2010).*

## 4.3.4 Multiscale Modelling of NEMS Dynamics

*Behrouz Shiari, University of Michigan*

The NNIN computation site at Michigan has been developing a concurrent multiscale simulations of dynamic processes found in nanosystems coupled to larger scale surroundings. The developed technique provides help to the researcher to study the behavior of NEMS, especially nanoresonators. The methodology of coupling of length scales employs an atomistic description of small but key regions of the system, consisting of millions of atoms, coupled concurrently to a finite element model of the periphery.(fig.38)

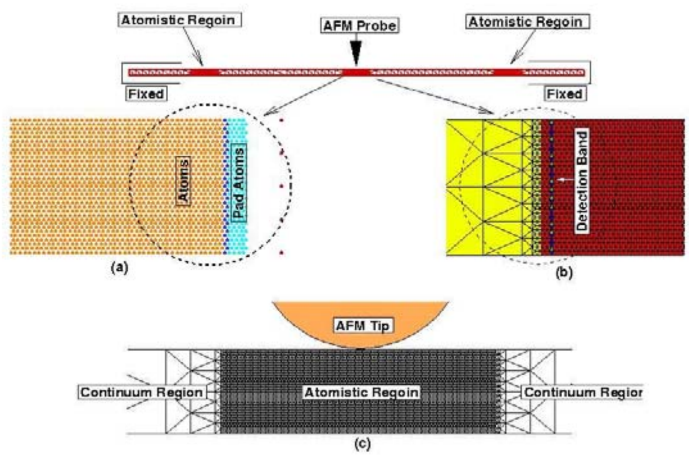



*Figure 38: Schematic illustration of the coupled atomistic/continuum/discrete dislocation solution procedure. a) The actual interface between the two regions is made up of the atom/nodes shown by dark blue filled circles, while cyan circles that lie inside the continuum region are used as a ''pad'' of atoms to couple the atoms to the continuum region. b) The blue elements are detection elements inside the atomistic region. c) Close-up of the atomistic/continuum interface.*

As shown in the figure, the method used in this research contains four main elements: a scheme to mechanically couple an atomistic region with a continuum region containing discrete dislocations, an algorithm to detect dislocations near the atomistic/continuum interface and pass dislocations from the atomistic region to the continuum region (or vice versa), an algorithm to impose and move atomistic dislocations as discrete dislocations in the continuum region and finally a thermostating algorithm to maintain constant temperature in a dissipating band located along the atomistic/continuum interface. The multiscale method can be used to optimize the size and geometry of nanosytems structural elements (e.g. nanobeam) for a mode of operation (static or resonant).

## 4.3.5 Thermodynamic Contributions to PDZ-Peptide Binding: A Theoretical and Experimental Case Study

*Vogt, Leslie; Karp, Ethan; Macbeath, Gavin; Aspuru-Guzik, Alan - Seminar, ACS, Boston, MA, August 22-26, 2010*

We performed molecular dynamics simulations of 26 related peptides bound to the protein TIP1 (shown) to determine the binding free energy for each peptide. The molecular mechanics/Poisson-Boltzmann surface area (MM/PBSA) method was applied to trajectory snapshots for enthalpic contributions and entropic contributions were determined from normal mode analysis on minimized structures. These values were compared to experimental data obtained via fluorescence polarization and isothermal titration calorimetry (ITC) to validate the method to derive microscopic insight into the contribution each residue plays in the overall binding affinity (fig. 39).

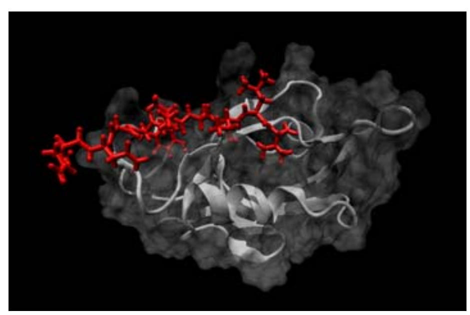


*Figure 39: Protein TIP1.*

## 4.3.6 Particle-induced Indentation of the Alveolar Epithelium Caused by Surface Tension Forces.

*Mijailovich S, Kojic M, Tsuda A. J. Appl. Physiol.* ***109****(4):1179-1194, 2010.*

Physical contact between an inhaled particle and alveolar epithelium at the moment of particle deposition must have substantial effects on subsequent cellular functions of neighboring cells, such as alveolar type-I, type-II pneumocytes, alveolar macrophage, as well as afferent sensory nerve cells, extending their dendrites toward the alveolar septal surface. The analysis reveals that the mechanics operating in the particle-tissue interaction phenomena can be explained on the basis of a balance between surface tension force and tissue resistance force. This particle-induced microdeformation could likely trigger adverse mechanotransduction and mechanosensing pathways, as well as potentially enhancing particle uptake by the cells. (fig. 40)

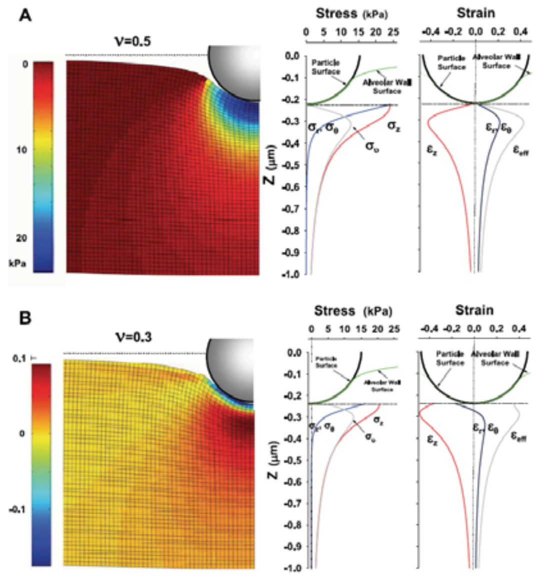
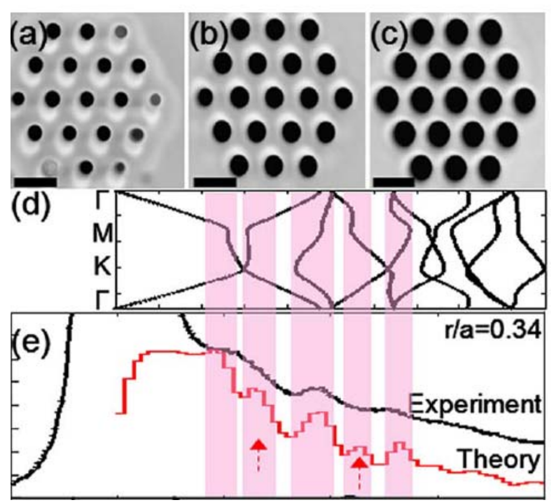



*Figure 40: Calculated stress and strain.*

## 4.3.7 Probing the Local Optical Density of States in Silicon Photonic Structures with Nanoscale Electron Spectroscopy

*J. J. Cha, Z. Yu, E. Smith, M. Couillard, S. Fan, and D. A. Muller, Physical Review B,* ***81****, 113102 (2010).*

*Figure 41 (a-c) Si photonic structures made of hollow cylinders with different ratios between the hole radius and distance between holes.; (d) Photonic TM band structure calculation of the structure in (c); (e) EEL spectrum for central hole compared to simulated photonic density of states. (from PRB,* ***81****, 113102 (2010)).*




Relativistic electrons moving through a crystal generate radiative losses (i.e. Cherenkov and transition radiation) that can serve as a virtual light source that couples to the local photonic density of states. Based on this principle, spatially resolved electron energy-loss spectroscopy (EELS) can be used to probe the photonic density of states in silicon photonic structures. This information is crucial in determine the presence of defects or to assess the nature of photon modes in small photonic devices. In this work, the radiative, photonic local density of states of a photonic crystal was mapped with nanometer resolution using EELS. Spectroscopic images were able to resolve distinct spatial distributions of photonic modes which agreed well with modes predicted by photonic band structure calculations. (Figure 41)

The photonic band structure calculations for this work were performed primarily by Eric Smith using the MIT Photonics Bands (MPB) on the NNIN/C cluster at the Cornell Nanoscale Facility. Eric Smith, an undergraduate at Columbia University, conducted the research for this paper as a CCMR REU fellow at the CNF during the summer of 2008.

## 4.3.8 Developing electrocatalysis for the next generation of batteries

*G. G. Rodriguez-Calero, M. A. Lowe, Y. Kiya, H. D. Abruna, Journal of Physical Chemistry C, **114**, 6169 (2010).*

Organosulfur compounds are a promising and cheap set of materials for cathodes in lithium-ion rechargeable batteries. However, they suffer from slow charge kinetics (charging, recharging). In this paper, the authors examine a group of conducting polymers which could serve as electro-catalysis that could accelerate the charge kinetics of organosulfur compounds and make them commercially viable. Density functional calculations of the thiophene based oligomers were done on the NNIN/C cluster at the CNF. The calculated highest occupied molecular orbital (HOMO) energy levels showed good agreement with experimentally measured oxidation potentials. The ordering of polymer oxidation potentials and relative energy difference between oxidations was successfully reproduced for short and long oligomers. The density functional calculations indicated that the electrocatalytic activity is influenced by both the electronic structure and the geometry of the monomer units. This knowledge could aid in future studies to design new electrocatalysis so that organosulfur compounds can be used in the next generation of rechargeable batteries.

## 4.3.9 Impact of Oxygen Vacancy Ordering on the Formation of a Conductive Filament in $TiO_2$ for Resistive Switching Memory

*S. Park, B. Magyari-Kope, and Y. Nishi, IEEE Electron Device Letters, 32, 197, 2011*

The electronic properties of rutile $TiO_2$ with an ordered arrangement of oxygen vacancies show a transition from a resistive to conductive oxide as a function of vacancy ordering. Vacancy ordering along two different directions (fig.42) [110] and [001],studied by the density functional theory, predicts that the geometries in which the vacancy-to-vacancy interaction is the strongest,within the nearest neighbor coordination, are thermodynamically favorable and of technological importance. The oxygen vacancies induce several occupied defect states of Ti 3*d* character, and according to our model, the vacancies are the mediators of the electron conduction, while the conductive filament is formed by Ti ions. We propose that the formation of these types of conductive filaments are intrinsically connected to the observed defect-assisted tunneling processes and oxide breakdown issues in $TiO_2$.

*Figure 42:Vacancy Ordering.*

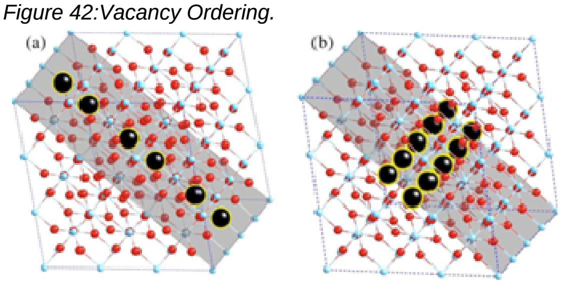
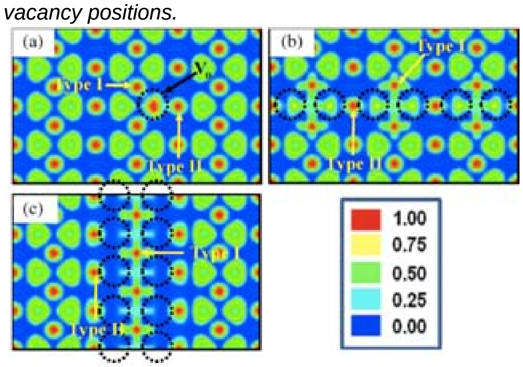
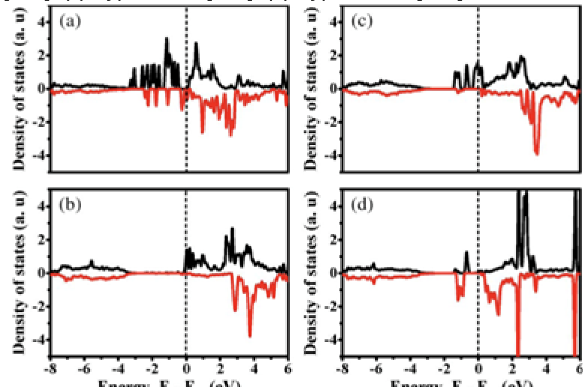



*Figure 43: Electron localization function of (a) isolated vacancy, (b) [110] chain with six vacancies, and (c) [001] chain with eight vacancies. Dotted circles denote oxygen vacancy positions.*




Along the [001] vacancy chain, the defect states are fairly discrete and distribute throughout the bandgap witha partial overlap between them, as shown in figure containing the partial density of states. As a consequence, metallic conduction through Ti ions can occur by defect-assisted tunneling, which may be the explanation of the "ON-state" conduction in $TiO_2$. In [001] vacancy chain structure the defect states originate from type-I Ti ions, and the electrons are transferred to type-I Ti ions. In contrast, [110] vacancy chain structure shows comparable amount of defect states in both types of Ti ions.(Fig.43,44)

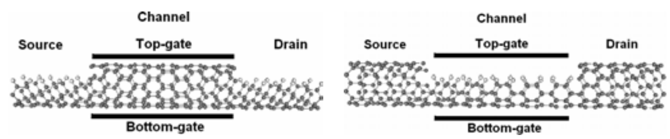
Figure 44: Density of states of the two types of Ti ions in the vacancy chain structure. (a) Type-I Ti in [001], (b) Type=II in [001], (c) Type-I Ti in [110], (d) Type-II Ti in [110].



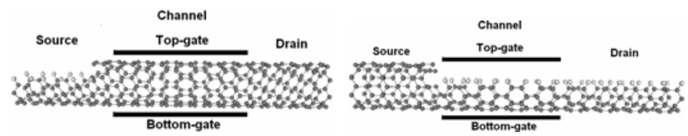
## 4.3.10 Multi-scale Simulations of Partially Unzipped CNT Hetero-junction Tunneling Field Effect Transistor

*L. Leem, A. Srivastava, S. Li, B. Magyari-Kope, G. Iannaccone, J. Harris, G. Fiori, Techn. Digest, IEDM 2010*

Band-to-band Tunneling Field Effect Transistors (TFETs) are emerging as a solution to break classical 60mV/dec sub-threshold slope limit of conventional MOSFETs. In this work, we present for the first time multi-scale simulation results of partially unzipped Carbon Nanotube heterojunction TFET(Fig. 45). Compared to the CNT and GNR homojunction TFETs, GNR/CNT heterojunction TFETs demonstrate superior sub-threshold region characteristics – $10^4\times$ smaller $I_{off}$, 61% smaller Subthreshold Swing (SS) which lies in the range of 22~26mV/dec and the I-V ambipolarity is completely eliminated. In this work, a multi-scale approach consisting of Density-Functional Theory (DFT), Extended Hückel Theory (EHT), Molecular Dynamics (MD) and atomistic Tight-Binding (TB) calculations were used to simulate Carbon nanostructure-based TFETs with type-II tunneling barriers that results from partially unzipping Carbon Nanotubes (CNTs). $I_{on}$ of GNR/CNT heterojunction TFETs strongly depends on the injecting states from the source region. GNR-CNT-GNR and GNR-CNT-CNT configurations show comparable $I_{on}$ as those of GNR homojunction TFETs. We conclude that the GNR/CNT heterojunctions demonstrated to be good candidates for low voltage logic applications and show better performance in terms of low subthreshold slope and strongly suppressed ambipolar behavior as compared to CNT and GNR TFETs.

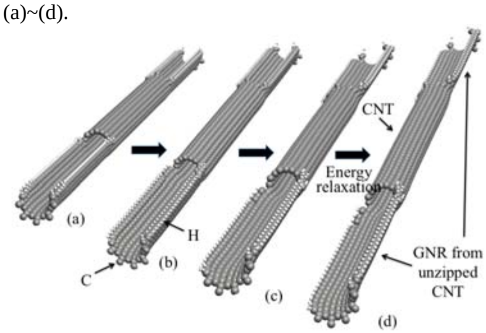



(a) GNR(*source*)-CNT(*channel*)-GNR(*drain*) (b) CNT-GNR-CNT

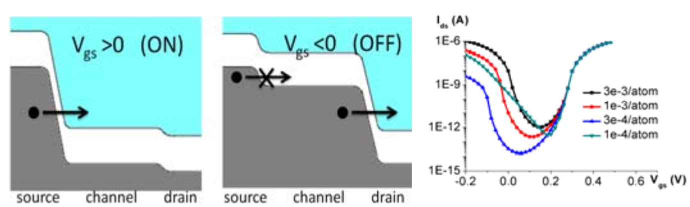



(c) GNR-CNT-CNT (d) CNT-GNR-GNR

**i)Partially unzipped Carbon Nanotube (CNT) Heterojunction Tunneling FET (TFET)** Cross-sectional schematics of simulated Graphene Nanoribbon (GNR)/CNT heterojunctions to study their effects on the Tunneling FET performance (a)~(d).




**ii) Energy-relaxed configurations of partially unzipped CNT obtained from Molecular Dynamics (MD) simulations.** Initial (a) and final energy stabilized configuration (d)




(a) (b)

**iii) Symmetric energy bands of Homojunction TFETs**. Energyband diagrams of a homojunction TFET when $V_{gs}$ >0 and $V_{gs}$ < 0, respectively (a). Tunneling happens for both $V_{gs}$ >0 and $V_{gs}$ <0, which leads to I-V ambipolarity in (b) of homojunction CNT TFET.

*Figure 45: CNT Heterojunctions.*

## 4.4 Progress on New Computation Initiatives

### 4.4.1 Virtual Vault for Interatomic Potentials

In September of 2009, the National Science foundation awarded a grant to the “Knowledge-Base for Interatomic Models,” (KIM). KIM is a program to test, validate and store interatomic model potentials for use in molecular dynamics calculations, which are at the heart of many biological and chemical simulation approaches. The principal investigators, Ellad Tadmoor, University of Minnesota, James Sethna, Cornell University and Ryan Elliott, University of Minnesota, plan to work with NNIN/C to make the database, which is a major output of their research, available to the nanoscience computing community. (Fig. 46)

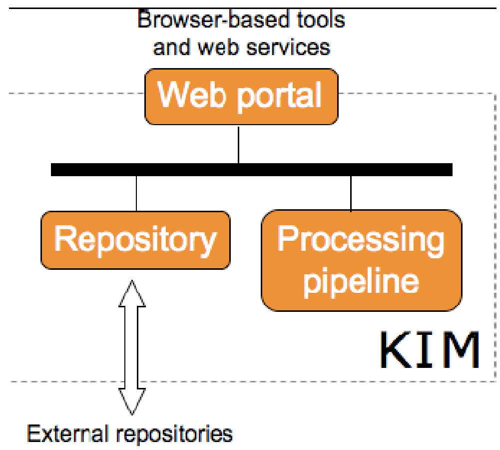



*Figure 46: Virtual Vault Schema.*

Atomistic simulations using empirical interatomic potentials are playing an increasingly important role in realistic scientific and industrial applications in many areas including advanced material design, drug design, renewable energy, and nanotechnology. The predictive capability of thes approaches hinges on the accuracy of the interatomic model used to describe atomic interactions. Modern potentials are optimized to reproduce experimental values and electronic structure estimates for the force and energies of representative atomic configurations deemed important for the problem of interest. However, no standardized approach exists yet for comparing the accuracy of interatomic models, or estimating the likely accuracy of a given prediction. In addition, a lack of standardization in the programming interface of interatomic potentials and the lack of a systematic infrastructure for archiving them makes it difficult to use potentials for new applications and to reproduce published results. *These limitations are preventing the field of atomistic modeling from realizing its true scientific and technological potential.*

The **Knowledgebase of Interatomic Models** (KIM) is a four-year NSF Cyber-Enabled Discovery and Innovation (CDI) program which seeks to address the limitations described above in two stages:

- Development of an online infrastructure consisting of a web portal, repository and processing pipeline.
- Development of a framework for evaluating the transferability and precision of interatomic models.

The KIM project has assembled a team of postdocs and students and is planning a major workshop in San Diego on February 26-27, 2011.

### 4.4.2 Virtual Vault for Pseudopotentials Development

The CNF hosts the development of the Virtual Vault for Pseudopotentials for the NNIN/C. While electron scattering from atoms can be describe using a full potential, this process is be computationally expensive and dramatically limits the number of atoms that can be considered. Pseudopotentials can efficiently capture the relevant scattering information and allow for large scale calculations. The NNIN database will provides the global scientific community with access and statistics on pseudopotentials used in a wide range of electronic structure codes. Since pseudopotentials are often described using different formats, it is also important to provide resources to convert between different codes.

CNF has developed a general clearinghouse for information related to pseudopotentials to serve as a cyberinfrastructure resource for the community. http://www.nnin.org/nnin_comp_psp_vault.html . This website includes links to over 12 different pseudopotential databases on the web, 10 pseudopotential generators, 4 pseudopotential generators, and links to key references on pseudopotentials.

Building on this initial step, the computation node at the CNF has developed a PHP-SQL database of pseudopotentials that can be accessed online. This database contains over 800 pseudopotential files drawn from several different pseudopotential codes including Quantum Espresso, Abinit, and Qbox. Users can interface this data through an online periodic table to find information related to a particular atom. Users can also search the database based on a given element and compare available pseudopotentials based on criteria such as exchange-correlation functional, pseudopotential class (i.e. ultra-soft, norm-conserving), parent electronic structure code, and more. In addition, members in the community have also begun to donate their own pseudopotentials to the database. This database provides the first centralized resource for pseudopotentials that spans multiple electronic codes.

Derek Stewart presented a talk "Developing a Virtual Vault for Pseudopotentials: A NNIN/C Initiative" at the 2010 Nanoinformatics meeting in Washington, DC.

### 4.4.3 GPU Initiative

The Graphical Processing Unit, highly parallel computing initiative of NNIN/C got underway in 2009 with the installation of the Orgoglio cluster. The cluster specifications are as follows:

- Single quad-core Xeon 'Harpertown' processors at 3 GHz
- 16 GB of EEC DDR2 800 RAM
- Two Tesla C1060 GPUs (each with 4GB of RAM)
- (total of 24 nodes/motherboards, 96 cores, 192 GB RAM, 48 S1070 cards).
- QLogic 24-Port 9024 DDR InfiniBand networking between the nodes.

The field of high performance computing has been transformed by the advent of GPU computing and the introduction of the CUDA programming language by Nvidia. On January 10-14, 2011, the Institute for Mathematics and it's Applications (IMA) at the University of Minnesota held a major workshop entitled High Performance Computing and Emerging Architectures. NNIN/C director Michael Stopa was an invited participant and presented a poster detailing high performance computing in NNIN/C.

## 4.5 Collaborative Projects

### 4.5.1 Defence Threat Reduction Agency Grant Award

In February of 2010 the Defense Threat Reduction Agency granted an award (Contract No HDTRA1-10 1-0046) for a proposal on Coherent Molecular Profiling Using Nano-Structured Environments submitted by Dr. Alan Aspuru-Guzik in collaboration with NNIN/C director Michael Stopa. The project calls for the development of analytical and numerical approaches to describe interaction of analyte molecules with excitations in nanostructured environments, as well as describing the influence of the nanostructured environment on the ground state properties of molecules. As an example the researchers explore several model systems for better understanding of the physical processes involved. The models were selected to benefit from our ongoing experimental collaborations.

a) Spectroscopy on a plasmonic surface. Within this subproject we analyze response of molecules adsorbed on a plasmonic structure. The ultimate goal is to differentiate physical processes responsible for modification of Raman spectra from analyte structures due to interaction with the substrate.

b) Quantum Mechanics in Complex Environments. Nano-structured devices are growing increasingly common in electronics and photonics and in chemical sensing, to name only a few areas. We have established real-space computational methods for calculating the electronic structure of molecules, quantum dots or nanoparticles when they are embedded in arbitrary dielectric or conducting materials.

c) Excitation dynamics in molecular structures embedded in optical cavities. We explore how an optical cavity modifies an electronic response from aggregated molecular structures. Specifically, we study coherent transfer of excitons in J-aggregated cyanine dyes in organic microcavity. The goal of this subproject is to obtain information about the energy transfer within the molecular complex by modifying radiative relaxation channels.

### 4.5.2 Center for Integrated Nanotechnologies, Sandia National Laboratory

*Project Title: Multiscale Calculation of the Strained, Multi-band Electronic Structure of Semiconductor Nanowires: Hetero-interfaces Investigators: Michael Stopa (Harvard University) in collaboration with N. Modine (CINT)*

The purpose of this work is to apply the computational tools developed in previous stages of this collaboration to calculate the effects of the inhomogeneous strain at hetero-interfaces on the electronic structure in an epitaxially grown quantum wire. Specifically, within a multi-band k·p model, we propose to calculate the variation of the band edges as well as the coupling between different angular momentum components of a band as a function of position. The structures we will consider begin with a wire with a simple interface between, for example, Si and Ge (or alloys thereof), but may also extend to more complex structures such as core-shell nanowires. The strain will be taken as input from the result of molecular dynamics calculations which give the equilibrium position of the atoms when, for instance, a compositional change along, say, the zdirection is made during the growth of the wire.

## 4.6 Workshops

NNIN/C held several workshops in 2010-2011.

### 4.6.1 The Joint NNIN/NCN Fall Workshop, "*Building a Collaborative Framework for Nanoscale Simulations", Nov. 14-16th, 2010, Cornell University*:

The Joint NNIN/NCN workshop brought together leading figures in the simulation community focused on simulating materials and nanostructures to address this issue and develop a set of *lingua franca* formats and libraries that allow easy translation of input and output files generated by different codes. Speakers discussed current efforts in the field such as the European Theoretical Spectroscopy Facility (ETSF), ESTEST, OpenBabel, NanoHub, and the Computational Materials Repository. We also addressed the development of international cyberinfrastructure resources that will provide trusted components required for atomistic calculations such as empirical potentials, pseudopotentials, basis sets, and atomic coordinates.

*Figure 47: NNIN Workshop Attendees at Cornell.*


Since this workshop focused on developing greater communication and collaboration in the nanoscale simulation community, the NNIN worked with the Network for Computational Nanotechnology to develop a joint event that would impact both user communities. The NCN contributed funds to help cover a portion of the workshop expenses and Professor Gerhard Klimeck (Associate Director for Technologies of the NCN) also spoke about Nanohub at the event.

A total of 43 participants took part in the workshop, including participants from 8 states (Michigan, New Mexico, Massachusetts, California, Pennsylvania, New York, Virginia, and Indiana), Puerto Rico, Belgium, and Denmark. Research disciplines of participants included Electrical Engineering, Physics, Chemistry, Ceramics Engineering, Civil Engineering, Mechanical Engineering, Materials Science, Computational Science, and Nanoscience.

### 4.6.2 IntelliSuite: MEMS/Microfluidic Design and Analysis Tool

The IntelliSuite workshop was held at Michigan Duderstadt Center training room equipped specifically for the purpose of computer training on Jan. 11, 2011. The training room was equipped with up-to-date hardware (22 workstations). The speaker and trainer was Dr. Joe Johnson of IntelliSense.

*Figure 48: MEMS/Microsluidic workshop at Michigan.*

The first section of workshop provided an overview of IntelliSuite Model Generation and Multiphysics - its capabilities, its new abilities and functionality enhancements, and its new, more efficient, user interface.

The second half of the workshop was a hands-on tutorial in IntelliSuite Multiphysics. Participants set up and solved three microfluidic problems designed to make participants quickly proficient in InelliSuite different modules - preparing the participants to use IntelliSuite on their own models.

### 4.6.3 Bringing MEMS/NEMS Concepts to Reality

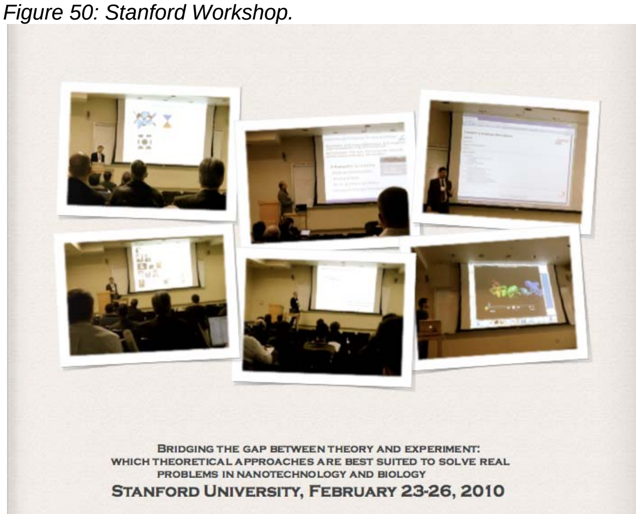
NNIN/C at Michigan held a tutorial workshop on methodology and tools for microsystem design and optimization on October 18, 2010. The event attracted engineers from around the region who are focused on micro/nanoscale design and modeling. The attendance was twenty-six people. The Coventor team presented lectures and hands-on sessions. The sessions were included live demonstrations of Coventor's products, including behavioral model creation and simulation with MEMS+®, simulations with the CoventorWare® suite of field solvers, and virtual fabrications of MEMS and semiconductor devices with SEMulator3D®.

*Figure 49: MEMS workshop at Michigan.*

### 4.6.4 Interdisciplinary NNIN Workshop: "Bridging the Gap Between Theory and Experiment: Which Theoretical Approaches are Best Suited to Solve Real Problems in Nanotechnology and Biology?"

Another major workshop for NNIN/C was the first computational workshop for NNIN organized on the west coast. The conference, held at Stanford Feb.23-26, 2010, attracted a total of 75 participants and invited speakers from academia and industry. This very successful conference stressed the importance of material simulations in several key areas, as the emerging applications of graphene, improving high-k oxides and metal gates for future transistors, impurity engineering in semiconductors, thermoelectric materials, fuel cells, catalysts and photonic materials. From biology the impact of implantable medical devices, the activity of the visual cortex, and the dynamics of membrane proteins were the subject of lively discussions.

*Figure 50: Stanford Workshop.*




The "bridge" between theory and experiment and nanotechnology and biology was the central theme of the workshop, which focused on the treatment of multiple spatial and time scales discussing the computational methods which are best suited for the diverse research areas as electronic materials and protein folding.

The workshop consisted of a total of four days, with two days of scientific presentations followed by hands-on training sessions. The trainings included electron transport calculations based on density functional theory and semiempirical methods; and biological simulations using molecular dynamics with CPU and GPU based implementations.

## 4.7 Nanotechnology Research Directions for Societal Needs in 2020

In March of 2010 the National Science Foundation sponsored a workshop dedicated to reviewing the progress in nanotechnology research over the last ten years and looking ahead to the challenges and desired outcomes of the next ten years. NNIN/C director Michael Stopa participated in the theory and modeling focus area of this workshop and the writing of the associated report.

The full report, released in September 2010, is available here: http://www.wtec.org/nano2/Nanotechnology_Research_Directions_to_2020/.

## 4.8 Webpage update

In 2010 a major effort was made to bring the NNIN computation portal webpages up-to-date with the activities of the network. The webpage construction is always ongoing but a considerable advance has been made. The results can be seen at http://www.nnin.org/nnin_compsim.html .

# 5.0 NNIN GeoSciences Initiative

## 5.1 Introduction:

Various reports produced by NSF-sponsored scientific committees and opinions expressed by researchers in the geo and environment sciences communities have identified sensors, sensing materials, and sensing systems as one of the major enablers in ocean, atmosphere, earth and space observatories. Over the past decade, significant advances have been made in nano and micro devices and sensing systems for emerging applications that include automotive, industrial, medical, and environment. One of the goals of the NNIN-Geo program is to bring together researchers from these two disconnected communities to provide enabling technological solutions to long-standing problems in geosciences.

To this end, NNIN has initiated a focused activity in the general area of geosciences (NNIN-Geo) under the leadership of two NNIN sites: University of Michigan and University of Washington.

The primary tasks are:

1. to reach out to the geosciences community and raise awareness, and disseminate information about the capabilities offered by the NNIN network of facilities and researchers;
2. to identify research needs and advances in the micro and nano fields, and develop clear and concise research collaborations between the two communities with the aim of producing short-term and long-term results for the geo community;
3. to disseminate research results from these collaborations to the broader geo community so that practical advantages of nanotechnologies and the capabilities of the NNIN for the geosciences can be more tangibly and explicitly understood;
4. to expand the user base and train users from the geo community as they begin to utilize the capabilities of NNIN.

## 5.2 Tasks and Accomplishments

Our plan is to accomplish these goals within a five year span; we have just completed the second year of this activity. Below, a summary of what has been accomplished will be provided.

### 5.2.1 Task 1: Outreach to Geo Community

The first step in reaching out to the geo community required the hiring of a domain expert with significant experience in geosciences. This position was funded for the University of Michigan and filled in September 2010 with the hiring of Dr. Helene Craigg as NNIN geosciences domain expert. Before her joining the University of Michigan, Dr. Craigg was a Research Associate Professor at the Center for the Study of Matter at Extreme Conditions at Florida International University. She brings expertise in physical properties of minerals and nanomaterials, and in high pressure and characterization techniques. She will coordinate all activities in the geo area, participate in various events to inform and attract geosciences users, develop and run workshops, help users in their nano-micro needs with a focus on sensors, and explore new areas where geoscientists can utilize the facilities of the NNIN.

Over the past year, NNIN-Geo conducted a number of outreach activities at several meetings and events. These efforts are summarized below.

A NNIN booth was set up at the American Geophysical Union Fall meeting (AGU 2010; December 13-17, 2010, San Francisco, CA) (Fig 51). Flyers dedicated to geosciences users (one for the whole network and one focused on the Michigan site) were created and distributed. Posters emphasizing nanotechnologies and sensors suitable for geosciences applications were displayed. About 40 new contacts were established with geoscientists of all disciplines. This meeting allowed us to better understand the needs of the geosciences community. Specifically:

*Figure 51: NNIN Booth at AGU conference.*


There is a strong demand for access to nanofabrication facilities for sample preparation and characterization expressed by the mineral physics community through the NSF Consortium for Material Properties Research in Earth Sciences (COMPRES)

The oceanography community is interested in nutrient sensors development and in low-power sensing in general. They also have a need for follow up on sensors testing in live conditions.

The drilling community is interested in micro Raman sensors to measure chemical and physical properties in boreholes.

The developing theoretical mineral physics community expressed an interest in the computational resources available at NNIN/C.

Finally, there is a need for educational resources aimed at geosciences students (see below).

NNIN will also have a booth at the Aquatic Sciences Meeting (ASLO 2011; February 13-18, 2011; San Juan, PR). New posters and printed materials are being prepared. During this meeting, we will hold a one and a half hour workshop on nanotechnology in geosciences entitled “Boost Your Research in Aquatic Sciences with the NSF National Nanotechnology Infrastructure Network (NNIN).” At the time of the writing of this report, the meeting was still forthcoming. We will continue to attend major meetings of the geo community to educate geosciences researchers about NNIN and its capabilities.

The new NNIN@Michigan website will include a section dedicated to geosciences activities. It will contain general information on geosciences capabilities for prospective users and examples of capabilities and projects we support. We expect that the website will be an effective source of information and promotion. An integrated beamline facility at the Advance Photon Source (The High Pressure Collaborative Access Team) already expressed interest in advertising NNIN to its users by posting our link on their web page.

Anne Rosenthl, scientific writer for SF Nature, will be contributing an article about nanotechnology in geosciences to a series of articles regarding her experience at the AGU2010 meeting.

The geosciences curriculum for undergraduate students does not currently include a significant amount of material related to nanotechnology. Prof David Mogk from the University of Montana and the NSF program “On the Cutting Edge: for the professional development for geosciences faculty” is interested in developing educational resources in collaboration with NNIN. As a first step, we are discussing a workshop on how to teach nanotechnology for geo undergraduate students at the Goldschmidt conference in 2012 (Montreal, Canada). Meanwhile, digital resources will be prepared for the “On the Cutting Edge” website.

Finally, a comprehensive brochure on nanotechnology as enabling tool for geosciences will be prepared for May 2011.

### 5.2.2. Tasks 2 & 3: Initiate Collaborative Projects and Disseminate Information:

In order to develop a geo community user base, we have been working at initiating projects involving researchers from both the geo and micro/nano communities. A first step was taken in February 2010 with a University of Michigan workshop entitled "Nano-enabled Sensing Microsystems for Geo Sciences." At the conclusion of the workshop, five white papers were written and three were later on converted to formal proposals. Two proposals have been funded by NSF and NOAA. A third was submitted as a collaborative proposal to NSF OTIC program but was not funded.

#### 5.2.2.1 Submitted Proposals

**Sensors for Multi-functional and Autonomous Analysis of Geofluids: A New Approach to the Design and Performance of Chemical Sensors in Extreme Environments**

*Investigators: Yogesh Gianchandani (U. of Michigan) and Bill Seyfried and Kang Ding (U. of Minnesota)*

The project focuses on hydrothermal system at mid-ocean ridges. Even though these systems have been studied for a long time, the lack of performing and reliable chemical sensors limits the quantitative studies. The proposal targets the improvement of chemical components measurement associated with hydrothermal vent fluids using high performance miniaturized sensor assembly and ultimately the development of on-board signal processing. The Michigan team has visited the Minnesota Geosciences team. They jointly have revised MEMS design concept based on Geosciences goal and properties of structural materials. The design phase is now done and Michigan started the fabrication phase with the customized YSZ disks.

EAGER Proposal, starting date: 8/1/10. Total Funding: $101,805, which is split roughly evenly. IDC has been waived at U. Minnesota, and reduced to 11% at U. Michigan.

**Raman-based Barcoding for the Identification of Toxic Marine Pathogens and Phytoplankton**

*Investigators: Vera L. Trainer and Mark S. Strom (West Coast Center for Oceans and Human Health), Mark L. Wells (U. of Maine), and Qiuming Yu (U. of Washington)*

Frequent phytoplankton blooms increase the risk of food contamination by algal-derived toxins. An efficient detection and quantification method of these toxins are essential to prevent human intoxication, which can be lethal. The goal of this proposal is to develop reagent-less, nanotechnology-enabled SERS based biosensing approaches for the detection of marine pathogens and HAB species. Proposal funded by NOAA Oceans and Human Health Initiative (OHHI 2010, starting date: 8/1/10). Work is under way

**A Microfabricated Protein-Based Array for Electrochemical Detection of Bioavailable Metals in Aquatic Environments**

*Investigators: Francois Baneyx (U. of Washington); Thomas Dichristina (GeorgiaTech); Karen Orcutt (U. of Southern Mississippi); Becky Peterson (U. of Michigan); Martial Taillefert (GeorgiaTech)*

The goal of this project is to design, build and field-test a revolutionary sensor for multiplex, real-time and on-demand quantification of bioavailable metals in aquatic environments. This transformative project will be conducted by an interdisciplinary team with synergistic expertise in molecular biology (Dichristina), protein and molecular engineering (Baneyx), nanosensor design (Orcutt), analytical electrochemistry (Taillefert) and microfabrication (Peterson). The sensor platform will harness the metal-selective transport properties of biological efflux pumps and the light-activated proton pumping power of bacteriorhodopsin to import and concentrate specific metal cations from the aquatic environment and into a microfabricated assay chamber. It will rely on built-in microelectrodes for high-sensitivity voltammetric quantification of metal ions. (OTIC 2010, $3M total request – not funded)

### 5.2.2.2 Pending Collaborations

**Microfluidic Chamber of Microbe Culture has been identified as a fourth project and is in its early stages of data gathering.**

*Inverstigators: Euisik Yoon (U. Michigan); Clara Chan (U. Delaware) Peter Hesketh (GeorgiaTech)*

Only an extremely small fraction of environmental microbes have been studied so far due to challenging growth conditions. Microfluidic devices appear to offer new opportunities for microbe cultures and study. Prof. Euisik Yoon shipped samples of his microfluidic chips to Prof. Clara Chan for initial testing of microbe culture and viability. Prof. Yoon was invited by Prof. Chan to give a talk at the Delaware Biotechnology Institute (DBI) seminar series in September and talked about his platform technologies with several researchers. We hope to further promote this collaboration and encourage the parties involved to explore funding opportunities.

### 5.2.2.3 Areas for Development

Through our interactions with the geo community at the AGU meetings, we also identified several possible areas of needs by the geo community. These are described below.

**Nanopillar deformation**

The deformation of nanopillars is a well-known technique used by material scientists to observe unusual deformation characteristics. Mineral physics researchers are starting to show interest in this method to study materials relevant to Earth or its study without confining pressure. If successful, this technique will open new doors for understanding deep Earth interior. Two separate projects are being discussed: one on ZnS (Patrick Cordier, U. of Lille) and another one on cBN (Jiuhua Chen, Florida International University)

**Sample preparation for diamond anvil cell *(DAC):***

Diamond Anvil Cells are high-pressure devices with small pressure chambers (typically 400µm diameter). To conduct a new type of deformation experiments, Pamela Burnely (U. Nevada Las Vegas) needs to develop a sample preparation technique suitable for DAC. Discussions are underway.

**Biomineralization:**

*Investigators: Udo Becker and Qiaona (Joanna) Hu (Department of Geological Sciences, U. of Michigan).*

The investigation of biomineralization is relatively new and mechanisms involved are the subject of intense research. In particular, it is not clear if biominerals grow by binding to functional groups oforganic molecules or solid organic templates. A group of biominerals of particular interest is calcium carbonates ($CaCO_3$) in the hard exoskeletons of marine organisms that can be used in extracting $CO_2$ from the atmosphere by creating a solid carbonate. Metal is evaporated on wafers as substrates for stable organic functional groups. Gold acts as an aligner for the carbon chains containing the functional groups and remain inert in further reactions. This work is part a PhD student project.

**Quantified ostracod surface morphology is a measure of ontogenetic change**

*Investigators: Janice Pappas and Daniel Miller (Museum of Paleontology, U. of Michigan)*

The surface morphology of ostracods can reveal important information about sex, ontogenetic stage and past salinity and climatic changes. Laser interferometry technique will be used for quantified surface metrology study. The result will provide a relationship between carapace surface roughness and ontogenetic parameters as well as a searchable database and digital library. The method is innovative of paleontological studies and will provide new data not accessible with traditional observation method.

The two researchers have started working on the project. They have tested the laser interferometer microscope at the Michigan NNIN site to collect data (see photo) and a proposal was submitted 01/16/11 to the NSF paleontology directorate, sedimentary geology and paleobiology program. Total funding asked: $296,678 for three years.

Finally, one of the outcomes of the February Workshop at the University of Michigan was a discussion between Professors Mark Wells (University of Maine), Khalil Najafi (University of Michigan), and François Baneyx (University of Washington) about the possibility of writing a NSF STC proposal on the theme of nano-enabled geo and ocean sciences. Further discussions will take place in the next few months to assess the viability of such a proposal and to identify possible partners. We envision that the proposal will come from the University of Maine under Mark Well's direction, with U. Michigan and U. Washington providing support as needed.

### 5.2.3 Task 4: Geosciences User Expansion at NNIN

While it is too early to expect a large number of geosciences users at NNIN sites, our goal is to expand the user base through the activities mentioned above. The charts show the fields of expertise and areas of interest of individuals who came to our booth at AGU2010. We believe that our geo activities during the past year have been very effective and expect that users will grow in number as the activities listed above bear fruit.  The following data shows the areas of particular interest to the Geosciences community in contact with NNIN.

*Figure 52: Interest of the geosciences community in nanotechnology by type of requests (percentage obtained from contacts established at the AGU 2010 and from new users at the Michigan site).*

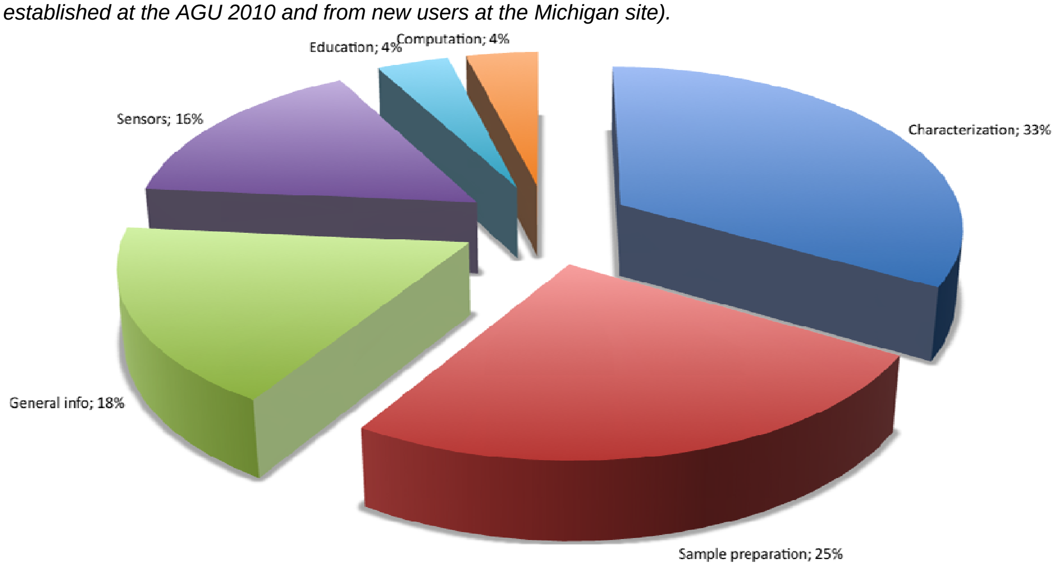
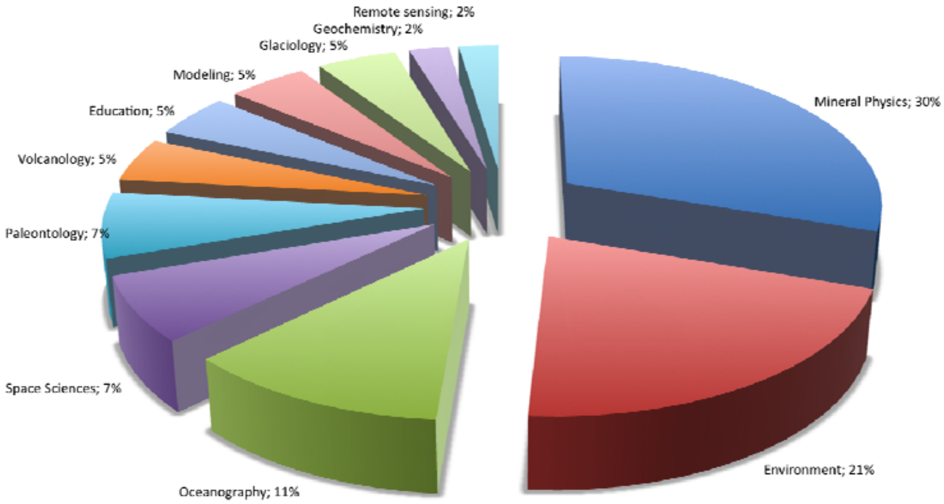


*Figure 53: Interest of the geosciences community in nanotechnology by geosciences specialty (percentage obtained from contacts established at the AGU 2010 and from new users at the Michigan site).*



# 6.0 Society and Ethical Implications of Nanotechnology

## 6.1 Vision and Goals

The Societal and Ethical Issues (SEI) component of NNIN seeks to increase national capacity for exploring the societal and ethical issues associated with nanotechnology. A particularly important part of this effort is to increase the awareness of SEI within the large NNIN user community. The NNIN SEI effort acts as a resource for education and information for our user community. As the largest single group of nanotechnology researchers in the world, NNIN has both a unique opportunity and a unique obligation to assure that its users have full awareness of the societal implications of their work and their associated ethical obligations.

To accomplish this goal, the SEI component has developed an infrastructure for conducting research and disseminating information about SEI. That infrastructure serves both the NNIN and the broader community interested in nanotechnology. Since its renewal, NNIN has placed particular emphasis on making the NNIN user base available as a research resource to social scientists for surveys and interviews.

## 6.2 SEI Activities

### 6.2.1. NNIN SEI REU Participation.

Three NNIN REU students worked on SEI related projects during the summer of 2010. Two were funded by the University of Colorado-Boulder and one at Cornell was funded by NNIN. All three attended the REU Convocation at the University of Minnesota and presented their work. The two students funded from the University of Colorado-Boulder NNIN site were from the Colorado School of Mines. They developed a framework for “Responsible Conduct in Research” that provides a series of questions that a undergraduate or graduate student could use to help guide research from the beginning of a project, during regular research meetings, and before submission for publication.

*Figure 54: Example of **Responsible Research in Action** Poster.*


The NNIN SEI REU intern at Cornell developed a series of SEI posters “Responsible Research in Action” suitable for posting in research labs. These posters are available online from the NNIN web site (http://sei.nnin.org/sei_posters.html) and are also made available in print on high quality poster stock and on static cling vinyl (for lab use).(Fig 55). The posters were developed by REU intern Chloe Lake, University of Buffalo, working under the direction of Dr. Katherine McComas and Norman Porticella.The messages for each poster were developed from discussions with the CNF users during the summer and expanded and refined by Ms. Lake through several focus groups of CNF users.

These posters are intended to be a small part of a NNIN SEI campaign to promote awareness within the NSE technical community of the broader impacts of advanced NSE research and everyone's responsibilities to the larger community.Providing resources to increase awareness of social and ethical issues related to nanotechnology is an important part of the NNIN training effort as noted in the discussion above regarding user training.

To date, we have sent copies of the posters to all the NNIN sites, as well as made copies available for downloading on the SEI web portal. We have also formatted the posters for use as screen savers. Several universities outside of NNIN have also requested and received copies. Copies are posted on the NNIN web site along with instructions for requesting copies.

*Figure 55: SEI awareness poster displays are now sprinkled generously around and in the NNIN facilities.*


### 6.2.2 NNIN SEI Seed Grant competition.

NNIN SEI research activity has been focused at the four sites funded by NNIN to do SEI research: Cornell, Georgia Tech, U. Washington, and Stanford. We would like to have foster broader participation in NNIN by the social science community at other NNIN sites. To stimulate these linkages, in 2010, we launched a Seed Grant competition, Eligibility is limited to faculty who are affiliated with one of the 14 NNIN universities. The competition offers one-time funding of up to $20,000. For the inaugural competition, seven proposals were received and two were awarded funding:

- **Nanotechnology's transition from discovery to commercialization in small and medium size enterprises: An exploration of evidence**, PI: Shapira (Georgia Tech) $19,712
- **Mental models of nanotechnology: A sunscreen case study**, PI: Bostrom (University of Washington) $19,976

  **Presentations resulting from funding of NNIN SEI Seed:**
  - Bostrom, A., Hudson, R., Scharks, T., & Gilliland, R. (2010). Characterizing mental models of emerging nanotechnologies: A nano sunscreen study. *Paper presented at the Society for Risk Analysis Annual Meeting, December 5-8, Salt Lake City, UT.*

### 6.2.3 NNIN SEI Travel Grants Program.

The intent of the travel grants is to bring in researchers outside of the network to conduct research on NNIN users and their technologies. Thus, priority is given to people not affiliated with an NNIN university. The program offers one-time funding of up to $15,000. We had no applicants for funding in 2010. However, the two projects that received funding in 2009 have reported the following impacts:

### 6.2.3.1 NNIN SEI travel grant, *Nanoscale Research Communities and Interdisciplinarity*, PI: Mody (Rice U.), McCray (UCSB), and Gray (UCSB) $14,997

**Publications:**

- Cyrus C.M. Mody, “Conferences and the Emergence of Nanoscience,” in *Social Life of Nanotechnologies*, ed. Barbara Herr Harthorn and John Mohr ([possibly] Oxford: Oxford University Press, submitted).
- Cyrus C.M. Mody, “Conversions: Sound and Sight, Military and Civilian,” in *Sound Studies Handbook: New Directions*, ed. Trevor Pinch and Karin Bijsterveld (Oxford: Oxford University Press, forthcoming).
- Cyrus C.M. Mody, “Integrated Circuits: Material, Social, Spatial,” *Volume* 24 (2010).
- Cyrus C.M. Mody, entries in *Encyclopedia of Nanoscience and Society*, ed. David H. Guston and J. Geoffrey Golson (London: Sage, 2010): “Chronology of Nanoscience”: xxxiii-xliii; “Center for Biological and Environmental Nanotechnology”: 76-78; “IBM”: 325-328; “Interdisciplinary Research Centers”: 348-350; “International Council on Nanotechnology”: 351-353; “Microscopy, Atomic Force”: 416-417; “Microscopy, Electron (Including TEM and SEM)”: 417-419; “Microscopy, Exotic”: 419-421; “Microscopy, Optical”: 421-422; “Microscopy, Scanning Probe”: 423-424; “Microscopy, Scanning Tunneling”: 424-425; and “National Institute of Standards and Technology (U.S.)”: 580-581.

**Presentations:**

- “Interdisciplinarity and Vietnam-Era Protest at Stanford” (Houston: Rice Center for Biological and Environmental Nanotechnology-Student Leadership Council semimonthly lunch talk series, October 28, 2010).
- Panel participant, “The Feynman Legacy,” (Darmstadt, Germany: Society for the Study of Nanoscience and Emerging Technologies meeting, September 30, 2010).
- “The Political Economy of the Knowledge Economy: Interdisciplinarity at Vietnam-Era Stanford” (Oxford, UK: Scientific Collaboration, Interdisciplinary Pedagogies and the “Knowledge Economy” invited workshop, September 9, 2010).
- “From Microscience to Nanotechnology, 1970-2000,” (Society for Social Studies of Science annual meeting, August 26, 2010).
- “Fifty Years of Nanotechnology,” (Palo Alto, CA: President’s Council of Advisers on Science and Technology NNI Review, panel on environmental, ethical, societal, and legal concerns, February 18, 2010).
- “Fifty Years of Nanotechnology” (Columbia, SC: Feynman Anniversary Symposium, February 13, 2010).
- “Conversions: Sound to Picture, Military to Civilian” (Maastricht: Sound Studies Handbook workshop, November 21, 2009).
- “Conversions: Sound to Picture, Military to Civilian” (Pittsburgh: annual meeting of the Society for the History of Technology, October 16, 2009).
- “Microscience/technology and Vietnam-Era Protest at Stanford” (Austin: Microelectronics Research Center talk, October 12, 2009).

**Funding:**

- The Rice-UCSB team leveraged the NNIN SEI travel grant to help it secure further funding. They, along with Mara Mills (NYU) and Hyungsub Choi (Chemical Heritage Foundation) received an ACLS Collaborative Research Fellowship for the current semester for a project, “Micro-Histories and Nano-Futures: The Co-Production of Miniaturization and Futurism,” which will allow them to weave evidence collected on the SEI travel grant into collaborative work with other scholars.
- Mody (Rice) has also received an NSF Scholars Award, “The Long Arm of Moore’s Law: New Institutions for Microelectronics Research, 1966-2004” (SES 1027160), which will entail looking at NNIN facilities. These two new grants work in concert with the ongoing Center for Nanotechnology in Society grant (SES 0531184) and a small amount of money from the Center for Biological and Environmental Nanotechnology (EEC 0647452), both of which have supported myself, Summer, and Patrick.

#### 6.2.3.2.NNIN SEI Travel Grant, Documenting the Integration of Social and Ethical Considerations into Nanoscale Research, PI: Valenzuela (ASU) and Fisher (ASU) $5,323

**Talks**

- Garay, M. & Fisher, E. (2010). "Documenting socio-technical integration at nanoscale research centers." *NSF site visit to CNS-ASU*. Tempe, AZ, May 06, 2010.
- Garay, M. & Fisher, E. (2010). "Assessing NSECs on the integration of societal concerns into nanotechnology R&D." *CNS-ASU All Hands Meeting*, Tempe, AZ, April 23-25, 2010.

### 6.2.4 NNIN SEI Brochure.

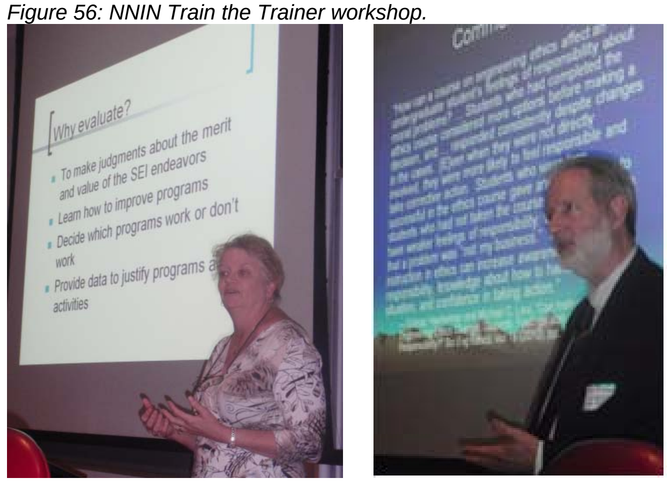
To increase the visibility of the SEI activities at NNIN, we produced a brochure for dissemination at conferences, meetings, and other appropriate venues.

### 6.2.5 Increased Visibility of SEI at NNIN Labs:

Each NNIN lab now includes a link to the SEI portal on their web site; a brief summary of SEI at NNIN; and a brief statement about SEI research at NNIN. Each site has also put up copies of the SEI Posters, Responsible Research in Action. This has increased the visibility of the NNIN SEI effort to NNIN users at each NNIN site.

### 6.2.6 SEI Orientation “Train the Trainer” Workshops for NNIN Labs:

*Figure 56: NNIN Train the Trainer workshop.*




NNIN has a user base of well over 5000 users each year and trains over 2000 new users each year. Following up the first one day workshop (hosted at CNF on January 22, 2010), we conducted another workshop on “Implementation and Impact of the Societal and Ethical Issues (SEI) Training at NNIN Laboratories,” at Knight Conference Center, hosted by the Nano Research Facility at Washington University-St. Louis, MO, on October 15, 2010. Thirteen participants from 13 NNIN sites (one site was absent) participated in this workshop. The purpose of the workshop was to follow up with all the NNIN sites regarding the status of the SEI orientation in their respective sites. In addition the workshop showcased other scholarly activities related to SEI throughout the network. At the beginning, Dr. Katherine A. McComas, the NNIN-SEI Coordinator, provided a brief overview of SEI activities at the NNIN and also about the structure of the workshop. Next, each site representative shared a 5 minute overview of their SEI orientation, key changes since January 2010 workshop at Cornell, and any plans for new developments in their respective sites. Additionally, there were presentations from other NNIN sites given by researchers working in several aspects of nanotechnology. Dr. Ira Bennett from Arizona State University spoke on outreach with the Arizona Science Center, Dr. Katherine McComas from Cornell University on SEI Posters, Dr. Carl Mitcham from Colorado School of Mines on Matching Goals of Ethics Education with Evaluation, Dr. Nancy Healy from Georgia Tech on Learning from the NNIN Education Experience, and Dr. Ethan Allen from University of Washington on SEI Dialogues. Towards the end of the day there was a lively discussion on ways to measure impact of SEI orientation and other SEI activities on the scientific community.

At the end of the workshop, 8 participants out of 13 provided their opinions about the workshop in an evaluation form. Among the 8 participants, 1 participant rated the workshop as excellent, 6 of them rated it as very good and, and 1 of them rated it as fair. Most of them liked the content of the presentations and materials provided to them; 1 of them rated the content as excellent, 7 of them rated the content as very good. Most of them thought that the workshop covered most of the materials that they expected. All of them thought that the materials provided in the workshop were helpful and considered using them in their own work. Interestingly, all 8 participants, who provided the workshop evaluation form, recommended this kind of workshop once in a year, in the future too. However, most of the participants wanted to discuss the strategies to network and to share resources among the sites in the future workshops.

### 6.2.7 Additional, Ongoing Activities:

- Promoted the visibility of NNIN as a site for SEI research on nanotechnology via web sites, list serves, conferences, publications.
- Maintained open and frequent communication between SEI contacts at NNIN sites to facilitate SEI research, address any challenges, and discover any opportunities for network collaboration.
- Maintained the SEI website as a key destination for current research and conference alerts.
- Exposed graduate students, tomorrow's leaders, to societal and ethical questions related to Third World contexts through multi-day field experience during the international Winter Graduate School.
- Presented research at academic and professional conferences.

### 6.2.8 SEI Publications and Presentations from NNIN SEI Princpals

- Publications


1. McGinn, R. (2010). What's Different, Ethically, About Nanotechnology?: Foundational Questions and Answers. NanoEthics, 4, 115-128.
2. Patra, D., E. Haribabu, and Katherine A. McComas. 2010. "Perceptions of Nano Ethics among Practitioners in a Developing Country: A Case of India", *NanoEthics*, 4, 67–75.
3. Patra, D. 2010. "Journal of Nanoparticle Research", in David Guston (Ed.), *Encyclopedia of Nanoscience and Society*, Thousand Oaks, CA: Sage Publications, p. 379-380.
4. Patra, D. 2010. "Small Times", in David Guston (Ed.), *Encyclopedia of Nanoscience and Society*, Thousand Oaks, CA: Sage Publications, p. 720-721.
5. Patra, D. 2010. "Titanium Dioxide (TiO2)", in David Guston (Ed.), *Encyclopedia of Nanoscience and Society*, Thousand Oaks, CA: Sage Publications, pp-759-760.

6. Thursby, J., & Thursby, M. (in press). University-industry linkages in nanotechnology and biotechnology: Evidence on collaborative patterns for new methods of inventing. *Journal of Technology Transfer.*

- Conference Presentations

1. McComas, K.A. “Researcher Views about Funding Sources and Conflicts of Interest in Nanotechnology”, Society for Risk Analysis Annual Meeting, Salt Lake City, Utah, December 5-8, 2010.
2. McComas, K.A. “Fairness and nano risk perceptions”. Risk Perception Specialist Workshop, Center for Nanotechnology and Society, University of Santa Barbara, Santa Barbara, CA., January, 2010.

- Teaching Materials

1. Patra, D. 2010. NNIN SEI Orientation User Manual 1.2, CNF, Ithaca, NY (CD version).

# 7.0 Site reports

## 7.1 Arizona State University Site Report

### 7.1.1 Site Overview

Arizona State University joined the NNIN in March of 2009 as one of three new schools added to the Network. The facility is operated as the ASU NanoFab by the Center for Solid State Electronics Research, and maintains ~20,000 sq. ft. of laboratory and office space, including a 4,000 sq. ft, Class-100 cleanroom. As well as maintaining a general purpose semiconductor and MEMS processing capability, the technical focus of the ASU NanoFab within the NNIN is the interface between organic and inorganic materials. The NanoFab has a full time staff of seven process and equipment engineers and two NNIN domain experts, Wayne Paulson (MEMS and thin film processing) and Punarvasu Joshi (BioMEMS and organic/inorganic interfaces).

### 7.1.2 NNIN Symposium

To increases awareness of the ASU role as the technical lead for organic/inorganic interfaces and to foster collaboration with neighboring schools, an NNIN Symposium was held on the ASU campus during 13-14th January, 2011. The theme of the symposium was “Organic/Inorganic Interfaces and their Health Science Applications”. The symposium comprised three sessions addressing topics related to 1) Sensor Elements, 2) System Level Integration, and 3) Cellular Interfaces and Control. Approximately 100 participants registered for the symposium to hear 23 speakers, including 15 from external universities, present on subjects that ranged from pore-based DNA sequencing and graphene chemical sensors, to fully integrated environmental monitors for personal health care, and CMOS based sensing of cultured cells. A lively student poster competition took place on the Thursday evening with the external speakers judging the posters to pick the top three finalists. More details about the symposium can be found at the following web site: http://thornton.faculty.asu.edu/Research/NNIN_Workshop/.

*Figure 57: NNIN Symposium at ASU*

## 7.1.3 Project Highlights

The number of external users at ASU continues to grow, with 17 researchers from 10 universities and 14 staff from 12 small companies making use of the facility during the period March 2010 to January 2011. A summary of a few of the external projects is presented below.

**Cell/Nano-Environment Interactions:** *Junkin and Wong, University of Arizona;* The purpose of this project is to study cellular interfaces with nano-scale stimuli similar to those occurring in the body. The patterns created by the ASU NanoFab served as 3D master surfaces for creating PDMS molds used to chemically pattern surfaces via shielded plasma exposure. The chemical patterns have enabled insight to cellular decision making and interactions with nano-scale stimuli for understanding processes such as cell migration and axon growth. The millimeters long nano-scale lines were critical to these investigations as the nano-sized lines had to be patterned over large areas and conventional photolithography could not produce dimensions at relevant biological scales.

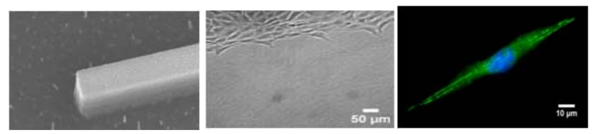


*Figure 58: Cell/Nano-environment interactions*

**Bose-Einstein Condensation of Positronium:** *Bayless, First Point Scientific Inc.*; FPSI is developing target structures that will be irradiated with a mono-energetic positron beam and will facilitate the formation of positronium and its condensation into the Bose-Einstein state. Proof-of-principle targets have been successfully fabricated at the ASU NanoFab using oxidized poly-silicon and $XeF_2$ etching. These structures are now under test in the FPSI positron beam facility in California.

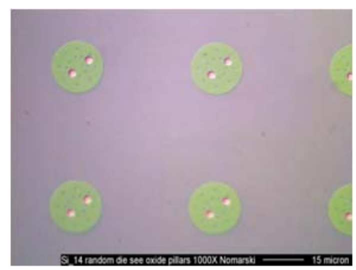


*Figure 59: Targets for BE condensation*

**Microchip Ionizer:** *Pau, University of Arizona;* The purpose of the Microchip Ionizer Project is to create an efficient, low power, low form factor ion source for mass spectrometry and ion pump applications. The device is fabricated using an SOI wafer and consists of cathode and anode electrodes separated by a sub-micron gap. Application of voltage, either AC or DC, between the electrodes generates a high electric field that ionizes gas molecules passing through the electrode apertures. The first generation test structures are currently under electrical evaluation.

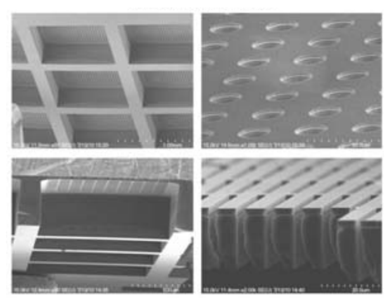


*Figure 60: Microchip Ionizer*

**Flexible and Stretchable Sensors:** *Yu, Jiang and Cheng, ASU and Purdue;* Flexible and stretchable electronics and sensors have been attracting significant attention due to their unique characteristics and wide applications. This project demonstrates manufacturing technologies including: 1) thin film transfer of fully flexible and stretchable temperature sensors on an elastomeric substrate; and 2) laser dynamic forming of thin film devices on a 3D surface.(fig. 61)

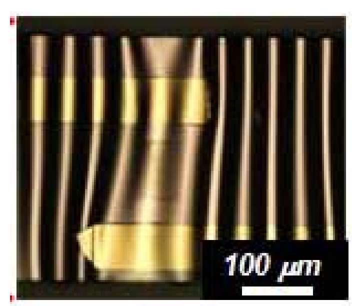



*Figure 61: Flexible Sensor*

### 7.1.4 Education & Outreach

During the last 12 months the ASU node has continued to work closely with the NSF supported Center for Nanotechnology in Society (http://cns.asu.edu/) implementing a variety of educational and outreach activities on the ASU campus and across the wider Phoenix community. A series of training sessions were held throughout the year to train ASU graduate students in best practice techniques for presenting their research topics to the public. Each session consisted of an initial meeting during which the NanoDays 'kit' was introduced and participants took part in a role playing exercise in which they took turns presenting the various activities to another participant who took the role of a 4th grade student. During the second session participants were given the opportunity to describe results from their own research project as if they were presenting to the lay public. In this way more than a dozen students were trained and given the opportunity to present at the Arizona Science Center on Friday and Saturday mornings during the busy March-May period when Arizona schools have completed the AIMS testing and are looking for exciting field trips to take their students. We estimate that more than one thousand middle school students took part in the activities presented at the NNIN-CNS tables set up in the main lobby of the AZ Science Center. ASU graduate students also presented at the Tempe Festival of Arts, an event that attracted more than 200,000 visitors during March 26-28, coinciding with the national Nanodays festival coordinated by the NISE Network.

*Figure 62: ASU Education Outreach*

At the request of two local schools the ASU node has begun to develop a classroom lesson suitable for 4th Grade students. The current listing of NNIN classroom materials does not include many lessons suitable for middle school students. The lesson being developed addresses two of the 4th Grade Arizona Science Standards for *Concept 2: Science and Technology in Society*. In particular we shall introduce the concept of nanosilver as part of a lesson that addresses the curriculum requirement to "describe benefits and risks related to the use of technology". The lesson plan will introduce students to the helpful role that nanosilver can take as a natural biocide while drawing attention to the risks associated with leaching of the nanoparticles from consumer products. The lessons will first be piloted at Fountain Hills Charter School (FHCS), a small Montessori school with a student enrollment of 148. The town of Fountain Hills is the nearest population center to the Fort McDowell Yavapai Nation and three Native American students from the tribe are enrolled in the charter school. The pilot lessons will be taught at FHCS in February and then again later in the spring at Navajo Elementary School, a Title 1 school with a STEM focus.


*Figure 63: ASU Outreach Activity*

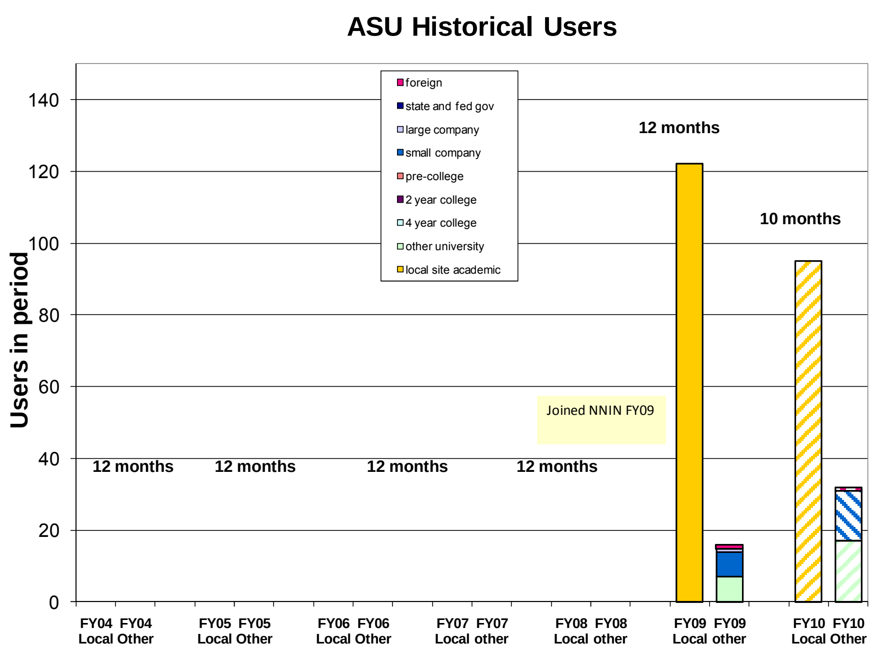
### 7.1.5 SEI Activities

All of our new users now receive an introduction to SEI topics during their health & safety training. The SEI discussion is lead by Dr. Ira Bennett, a post-doctoral scholar in the Center for Nanotechnology in Society. Dr. Bennett is supported by Brenda Trinidad, a Ph.D. student in CNS with partial support from the NNIN. The SEI materials are introduced using 'traffic bumps' as an example of a widely used speed enforcement tool that is simple to implement but can have a significant impact on local residents and drivers who may have diverse opinions. This example generates discussion within the group about the pros and cons of regulatory powers as applied to nanotechnology and how the work of the researchers in the group may impact society. We have adopted this format for about 6 months and find that it works well to engage the participants.

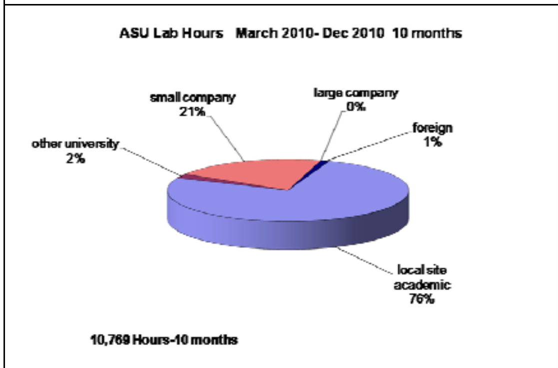
Dr. Bennett represented ASU at the October SEI meeting held at Washington University, St. Louis. An outcome of this meeting has been that the next NNIN SEI meeting will be held in November 2011 at ASU as part of the Congress on SEI Education for Scientists and Engineers. The Congress will be held in conjunction with the 3rd Annual Meeting of the Society for the Study of Nanoscience and Emerging Technologies (S.NET). By combining the NNIN SEI meeting with the Congress and S.NET meetings it will be possible to bring together a broad cross-section of the SEI community under one roof for several days to discuss educational programs and models, and to compare different activities taking place across the nation.

## 7.1.6 ASU-Selected Site Statistics

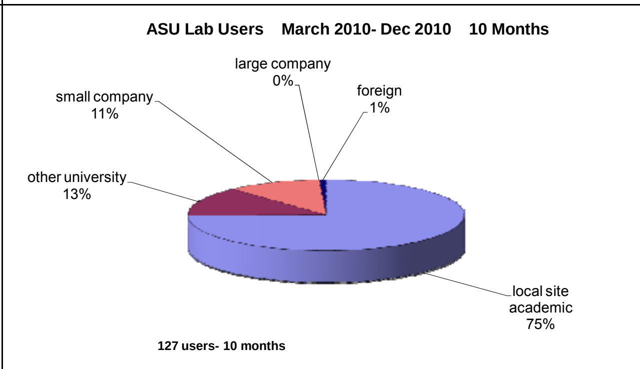
a) Historical Annual Users



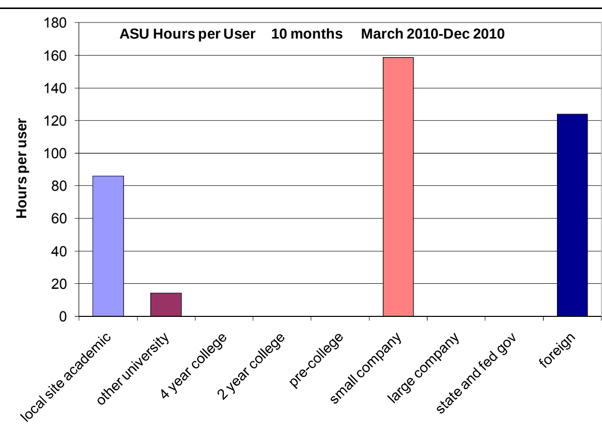

b) Lab Hours by Institution Type




C User Distribution by Institution Type




d) Average Hours per User ( in 10 months)




e) New Users

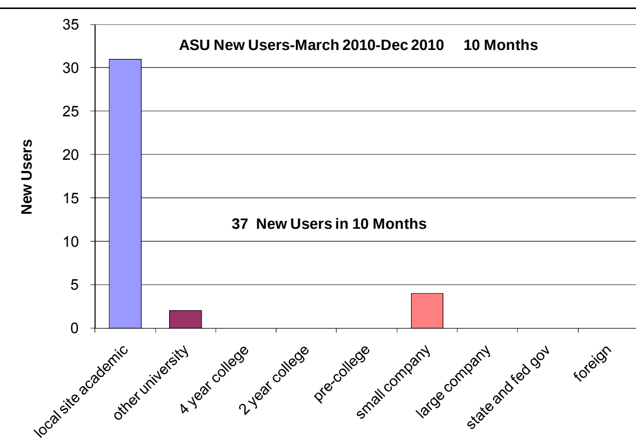



*Figure 64: ASU Site Statisics*

### 7.1.7 ASU User Institutions

| Table14: ASU User Institutions | | |
|---|---|---|
| **Academic** | **Small Company** | **International** |
| Auburn University | Ambature | University of Padova |
| Louisiana State University | Cactus Custom Analog Design Inc | |
| Northern Arizona University | EntroPlus | |
| Purdue University | First Point Scientific | |
| Truman State University | GaNotec | |
| University of Arizona | KISLED Inc | |
| University of Colorado | Laser Components DG Inc | |
| University of Delaware | NabSYS | |
| Univ of Mass at Amherst | NthDegree Technologies | |
| University of Washington | Rose Street Labs | |
| | Sonata Biosciences | |
| | Tempronics | |

## 7.2 Cornell University NNIN Site Report

### 7.2.1 Overview

CNF serves as an open resource to scientists and engineers from a broad range of nanotechnology areas, with emphasis on providing complex integration capabilities as well as support of the SEI initiative, Computation and other specific thrust areas within NNIN. CNF has operated as a dedicated user facility since 1977. In addition to technical management and administrative staff, it currently has a technical staff of 21 who maintain the equipment and baseline processes, while assisting users at all levels - particularly focusing on the needs of our large external user community. CNF maintains a full spectrum of processing and characterization equipment, with emphasis on electron beam lithography at the smallest dimensions, and a wide array of deposition and etching resources necessary to handle the needs of a wide spectrum of materials. CNF continues to be an interdisciplinary facility with activities fairly evenly spread across physical sciences, engineering, and life sciences. Both the replacement of old tools and the addition of new capabilities keep CNF at the technology forefront.

### 7.2.2 Users and User Base

CNF served over 670 users in 2010, one of the largest user bases in NNIN, with a large fraction of outside users. Our users clocked over 70,000 hours of lab usage this year. Within the outside user base, CNF has a particularly strong outside academic user presence, from large universities and small colleges around the country. There were 54 such academic institutions along with 34 companies, 4 international institutions and 3 government labs. Users came from 28 states and 4 foreign countries. CNF has a refined process for integration of new users in the laboratory with an emphasis on best safety practices. New users are accepted into the CNF each Monday. Basic orientation is accomplished within two intense training days to allow rapid initiation of projects.

### 7.2.3 Technical Highlights

Research reports are provided annually for many projects and are published as the CNF Research Accomplishments and online at **http://www.cnf.cornell.edu/cnf5_research.html** . Here we highlight some of the most significant examples of research enabled by CNF in the past year.

- In **Nature Physics**, the Gasparini group at the University of Buffalo published a study of quantum-mechanical coupling and the proximity effect manifested in the in the superfluid transition in $^4$He dots. By using wafer-bonding techniques to fabricate millions of micron-scale helium reservoirs connected by a nm-scale 2-dimensional channel, they were able to measure for the first time how superfluidity in the reservoirs affects the specific heat and superfluid density of helium in the 2-dimensional channel. This experiment illustrated important differences between superfluidity in helium and superconductivity in metals.
- In the **American Journal of Cell Physiology**, the Herzog group from the University of Calgary published measurements on the force generated by single muscle myofibrils that challenge part of the standard model for how muscles work. This standard model is that muscles pull on account of the relative sliding between two contractile filaments, actin and myosin. However, the new results show that when muscle filaments are stretched so much to eliminate the overlap between the actin and myosin, there is still an active force that can be traced to a structural muscle protein, titan. These new results are important in understanding how muscles can avoid injury during stretching.
- In **Applied Physics Letters**, the Hone and Kim groups from Columbia University have demonstrated a technique to actuate and detect vibrations in graphene resonators at radio frequencies, more than two orders of magnitude faster than previous electrical readout techniques. They observed a signal-to-background ratio of over 20 dB for a doubly clamped

graphene sample with resonant frequency ~ 34 MHz and quality factor ~ 10,000 at 77 K. This new technique paves the way for the use of graphene in high frequency devices such as filters and oscillators.

- In **Optics Express**, the Preble group at the Rochester Institute of Technology showed that hydrogenated amorphous silicon is a promising material for on-chip nonlinear optics applications. By measuring the propagation of ultra-short pulses, the group found that the nonlinear coefficient in hydrogenated amorphous silicon is 5 times that of crystalline silicon at telecom wavelengths (1550 nm), while amorphous silicon maintains the same ability of crystalline silicon to confine light within very narrow waveguides.
- In **Physical Review Letters**, the Austin group at Princeton reported studies of the collective motion of self-propelled bacteria within fluidic microchannels containing microstructured ratchets. The bacteria demonstrated an density-dependent self-organization that allowed them to migrate against the funnel-shaped barriers by creating and maintaining a chemoattractant gradient. This self-organized motion may be related mathematicaly to the collective dynamics observed during cell crowding and for three-dimensional flights of birds.
- In **Applied Physics Letters**, the Kent group at New York University studied the effects of thermal fluctuations on the spin-transfer switching characteristics of magnetic memory devices, in order to understand the factors governing switching reliability and thermal stability of next-generation magnetic memory. The experiment covered a very broad range of time scales from less than a nanosecond to more than a second. Two physical regimes were clearly distinguished: a long pulse duration regime, in which magnetic reversal occurs by spin-transfer assisted thermal activation over an energy barrier, and a short-time large pulse amplitude regime, in which the switching probability is determined by the spin-angular momentum in the current pulse.
- In **ACS Nano**, the Gaitan group from National Institute of Standards and Technology demonstrated that microfluidic mixers can achieve improved control of the formation of liposomes -- lipid-coated fluid vesicles with diameters of 10's of nanometers. The vesicle size is strongly affected by the microfluidic device geometry in conjunction with hydrodynamic flow focusing, providing a coarse method to control the size distribution, while the total flow rate allows fine-tuning. The on-chip synthesis of nanoscale lipid vesicles is of interest for making artificial drug carriers.
- In **Nature**, the Lipson group from Cornell published a milestone for controlling the optical properties of photonic structure by using optical forces to manipulate the structure. They demonstrated a static mechanical deformation of up to 20 nanometres in a silicon nitride optical resonator, using just three milliwatts of continuous optical power. Because of the sensitivity of the optical response to this deformation, the optically induced displacement introduced resonance shifts spanning 80 times the intrinsic resonance linewidth. This research is a first step toward new micro-optomechanical systems with novel functionalities.
- In **Science**, the Cohen group from Cornell demonstrated that the process of epitaxial layer-by-layer growth commonly used at the level of single atoms can also be used at the level of micrometer-scale colloidal particles to assemble photonic band gap structures and other metamaterials. They showed quantitatively that colloidal epitaxy obeys the same same two-dimensional island nucleation and growth laws that govern atomic epitaxy. However, they found that in colloidal epitaxy, step-edge and corner barriers that are responsible for film morphology have a diffusive origin. This diffusive mechanism suggests new routes toward controlling film morphology during epitaxy.

- In **Science**, the Ralph group from Cornell showed that single-molecule transistors made with molecules having an intrinsic spin can serve as excellent model systems for studying the fundamental quantum mechanics of correlated electrons. By connecting metal electrodes to an individual transition-metal coordination complex with spin 1 $\hbar$, they achieved for the first time a realization of the "underscreened Kondo effect," a quantum-mechanical state predicted over thirty years ago but never studied experimentally. By stretching the molecule to deform its symmetry, they were also able to break the energy degeneracy of the molecular spin states and observe the development of magnetic anisotropy in an individual molecule.

### 7.2.4 Focus Areas/Assigned Responsibilities

As one of the largest nodes in NNIN, CNF has been assigned special leadership responsibilities in the network for: Electronics, Optics, and MEMs; for Computation; for SEI activities; and for Education, as well as broad responsibility to support all NNIN technical areas. CNF actively supports users and provides specialized and generalized resources as discussed below.

#### Leadership areas:

- **Electronics, Optics, MEMS:** CNF has extensive facilities and processes to support the traditional areas of Electronics, Optics, and MEMS. CNF has the most advanced e-beam lithography facilities in the network and is positioned to maintain that leadership for several years with future upgrades and system acquisitions. These, along with other advanced photolithography capabilities, support fabrication of advanced electronics, optics, and MEMS structures and a growing number of life sciences projects. CNF also has a broad silicon CVD/oxidation capability with up to 20 process tubes. We continue to acquire leading edge tools such as a Graphene/ Carbon Nanotube Furnace from FirstNano. Supplemental ARRA funding to NNIN has permitted the addition of a Suss mask and bond aligner, a high speed Heidelberg Laser writer for mask making, a Veeco Dimension Icon atomic force microscope, and other upgrades. Users from the Cornell Center for Nanoscale Systems (CNS), a separate parallel NSF funded research center, help provide a critical mass of research and technology in advanced device structures. We also expanded our fluidics capabilities for the life sciences with the acquisition of a VersaLaser cutting tool and a short course offering on PDMS casting (co-instructed with the Nanobiotechnology Center staff). CNF staff are particularly skilled in complete process integration issues involving deposition, etching, and lithography.

- **Computation:** CNF is one of four NNIN nodes with major nanotechnology computation capabilities. CNF has invested in computational resources and a nanotechnology computation technical liaison (Dr. Derek Stewart) to support and expand facilities for users. Details of the expanded hardware, software, and outreach for the CNF computational program are described in a separate section below.

- **Social and Ethical Issues in Nanotechnology:** CNF is a major site for NNIN SEI activity. Both the NNIN SEI Coordinator for the network and research associate are based at Cornell and paid from Cornell site funds. Detailed SEI activities for the year are discussed below.

- **Education:** CNF has extensive education activities, primarily directed to the university level and above but with significant outreach among younger students as well. These are covered in the Education section below.

#### Other Assigned Areas:

- **Life Sciences:** CNF actively supports projects involving biological applications of nanotechnology. To provide discipline specific support for life sciences users, CNF has a technical liaison (Dr. Elizabeth Rhoades). The Cornell Nanobiotechnology Center (NBTC), a parallel NSF funded center, helps provide a critical mass of nanobiology users who contribute to the technology base available to users. Current CNF projects include considerable work in bio-sensors and microfluidics. CNF maintains a number of processes which significantly or exclusively support nanobiotechnology (molecular vapor coating, parylene deposition, embossing, PMDS casting, and microcontact printing). CNF has implemented an extensive process and sample compatibility study with input from NBTC staff. A lab demonstration on soft materials was added to our TCN course this year and a quarterly short course on PDMS stamping was developed and taught with the NBTC staff.

- **Materials and Materials Analysis**: CNF supports a broad range of materials and materials related research both in-house and through facilitated access to electron microscopy facilities within the Cornell Center for Materials Research (CCMR). STEM, TEM and FIB facilities can be accessed by our users via CCMR. CNF has excellent SEM facilities in the form of two Zeiss Gemini series digital field emission microscopes. To assist users in true nanoscale probing of materials and device structures, CNF has a Zyvex nanomanipulator system, allowing probing within a SEM with 1 nm motion resolution. CNF's Dimatix materials ink jet printer supports a novel fabrication process with organic and inorganic materials "inks", on rigid and flexible substrates. Along with the Reynolds Tech cluster tool for deposition of organic conductive coatings, we have made significant strides in establishing an organic electronics capability. The Oxford ALD continues to serve materials research with highly conformal metal nitrides, hafnia and, aluminum oxide and silicon dioxide film deposition with monolayer control. Our Woolam spectroscopic ellipsometer, Wyco interferometer, and Filmetrics thin film mapper all support film characterization for both organic and inorganic materials.
- **Remote Processing:** Remote usage serves as a way to engage future users, achieve higher tool utilization, and enhance the NNIN network value to users. Remote processing is generally limited to single steps or short process sequences that have a high probability of success. In this reporting period, over 75 remote jobs were completed. While mask making, lithography, and thin films are the most common remote requests, more complex structures are being accomplished. We also make use of inter-site capabilities. For example, shipping a user's wafers to U. Michigan or UCSB for etching or to Stanford, Georgia Tech, and Harvard when a CNF system is down for repairs. We have gotten excellent cooperation from the other NNIN sites when users require this backup support.

### 7.2.5 Equipment and Facilities

CNF operates in a suite of labs in Duffield Hall, a state of the art research building on Cornell's Engineering College part of campus. CNF user facilities include a 16,000 sq. ft. clean room, but also include wet and dry non-cleanroom labs for additional chemistry and biology support facilities. There is also a characterization lab, a CAD room, and an ion implantation laboratory. In addition, CNF has nanoscale computation facilities (hardware, software, and support) that specialize in assisting users in interfacing with the various modeling programs. CNF maintains a broad set of processing and characterization tools with emphasis on patterning at the smallest dimensions. Our two 100keV ebeam lithography tools are the cornerstone of our materials patterning capabilities; they are supported by contact lithography (3), steppers (3), mask makers (2), 16 dry etch tools of various types, and extensive thin film deposition and inspection capabilities. In total, over 90 major processing tools are available.

- In 2010, CNF was active in upgrading and adding process equipment and computing resources. The first phase of our upgrade path for our electron beam lithography tools was completed with the installation of a JEOL JBX 6300FS. It has been up and running for about eight months and we have already trained 110 users on this system! We are also pleased to announce that CNF will be the site of the first, next generation tool from JEOL, the JBX 9500 FSZ. This will be first major advance in EBL in a decade and will likely set the standard for the next decade.

- The NNIN ARRA funding for capital resulted in delivery of a new Veeco Dimension Icon AFM, a Heidelburg Instruments DWL 2000 mask making system, a Karl Suss MA/BA6 contact aligner, a Filmetrics thick film measurement system, and an upgraded interface for the Eaton Nova Ion Implanter. All of these are now up and running and serving users.
- The *FirstNano* carbon nanotube/graphene furnace is up and running. Several local research groups with expertise in catalytic growth of CNTs and graphene are pitching in to help establish baseline growth conditions.
- Through a joint development agreement with SUSS Microtec, CNF has received a hardware addition for the SUSS MA6 aligner that performs substrate conformable imprint lithography (SCIL). This is the first installation on this side of the Atlantic. This is part of a larger contract that will also bring a SUSS Gamma advanced coating system that will include an Altaspray coating system for applying photoresist over extreme topography. We expect delivery in April '11.
- As a complement to our current wet etch/critical point drying method of MEMS release, we will be receiving a Primaxx μEtch dry HF vapor etch system. This is a new product sized for the research community that is based on proven technology in larger systems. CNF will be the first site to receive this tool.

### 7.2.6 Site Usage and Promotion Activities

CNF distributes a set of eight professionally designed color brochures covering each of the primary technical areas. These brochures are widely distributed as a marketing tool to potential users both in NYS and around the country. We also distribute a professionally produced tri-fold brochure as a "light" alternative for wide mailings and trade show distribution. CNF staff manned the NNIN Booth at AVS, MRS, EIPBN, and APS.

CNF annually publishes its annual CNF Research Accomplishments consisting of research reports from many of its users. One hundred and thirty three reports were featured in the 2009-2010 edition, which is available on request from CNF or via the CNF web site at http://www.cnf.cornell.edu/cnf_2010ra.html . "The Nanometer", the CNF glossy newsletter was also published and distributed to 1400 users, former users, corporate supporters, and visitors. Recent issues of the NanoMeter are available at http://www.cnf.cornell.edu/cnf5_nanometer.html

The visibility of CNF is enhanced by Cornell's use of Duffield Hall as a venue for campus events. Numerous visits by company executives and government leaders to campus have been accompanied by visit and tour requests. In 2010 alone, CNF hosted over 1180 visitors in 35 corporate visits and over 139 academic, educational and government visits and events. This is over and above our users and external outreach activities.

### 7.2.7 Education Contributions

CNF supports a broad range of educational activities, primarily at the undergraduate, graduate, and professional levels.

- **Research Experience for Undergraduates:** Research Experience for Undergraduates: CNF plays a leadership role and participates actively in the NNIN REU program. In summer 2010, CNF hosted ten students including four women. CNF staff provide most of the administrative support for the entire network REU program including advertising, processing of over 850 applications, initial interaction with participants, and preparation and printing of the REU research accomplishments for the 14 sites. CNF also underwrites the laboratory charges for all the cleanroom and tool charges incurred by the Cornell faculty-hosted REU participants.

- **Laboratory Experience for Faculty**: As part of the NNIN Laboratory Experience for Faculty Program, CNF hosted a faculty members during the summer of 2010; Prof. Kimani Stancil from the Department of Physics and Astronomy at Howard University worked with Prof. Richard Robinson in Material Science and Engineering at Cornell. Prof. Stancil's project involved nanoparticle synthesis, encapsulation by polymer gels either in solid matrix and in solution, and assembly through patterning. He synthesized nanoparticles with different ligand coatings, created ordered assemblies of the rods and particles and looked for swelling and nano-solute-surfactant adsorptive behavior. In addition to the technical success, the summer served the important goal of bringing a underrepresented faculty into the CNF and NNIN user program.

- **Nanooze:** As part of its national educational outreach CNF has committed to producing Nanooze, a children's science magazine relating to physical sciences and particularly nanotechnology. Nanooze (http://www.nanooze.org/) is a both web-based and printed magazine, with kid-friendly text, topics, and navigation. Nanooze is predominantly the work of Prof. Carl Batt and his students, with support from CNF. Nanooze is available in English, Spanish and Portuguese. This year two new issues were completed and distributed highlighting Nanomedicine and Nanotech Applications in Space Science. The issues also feature Q&A with Biochemist Heather Clark and Astronaut Michael Barratt. Circulation has grown to nearly 100,000 copies per issue as requests from classroom teachers continue to grow.


*Figure 65: Two most recent issues of Nanooze*

- **TCN – Technology and Characterization at the Nanoscale:** TCN is CNF's introductory course to Nanotechnology. The course is open to the public and aims to educate students, industrial personnel, technology managers and entrepreneurs with an interest in Nanotechnology. CNF offers the TCN semiannually during the summer and winter recess, so that interested students from Cornell and other universities can easily participate. Combined, about seventy-five students and scientists participate in the two courses offered per year, representing Biomedical Engineering, Optics, Physics and Applied Physics, Material Science, Chemical Engineering, Environmental Health and Safety, and Electrical Engineering. On average, about one third of the participants are Cornell graduate students, one third are graduate students from universities other than Cornell, and one third are undergraduate students, teachers, and industrial participants. The content of the TCN is designed to encompass a wide range of nanotechnology techniques relevant to current research in the field. While traditional topics in nanotechnology - thin films, lithography, pattern transfer (etching), and characterization - provide the basic structure of the course, we include emerging

*Figure 66: Cornell TCN Course*

technologies and new approaches in nanotechnology. Nano-imprint lithography, bottom-up nanofabrication, carbon nanotubes, soft lithography, and surface preparation for biology applications are among the topics addressed. The printed notes for the TCN course have been developed over 17 years and are a highly valued resource. The course includes lectures and laboratory demonstrations as well as hands-on photolithography sessions. The evaluation forms for the TCN conducted afterward showed that 90% of the participants rated both the lectures and lab course good to excellent. 100% would recommend the course to others. The TCN course will next be offered in June 2011. In addition to preparation time, this course occupies most of the CNF staff for the three-day duration of the course.

- **NanoMedicine Workshop:** A Cornell intercampus workshop entitled, “Molecular Targeting for Imaging and Intervention” was held on March 26-27, 2010 in Ithaca, NY. It was organized and sponsored by the CNF, the Office of Intercampus Initiatives and the Weill-Cornell Medical College Department of Radiology. Faculty from two Cornell campuses, the Weill-Cornell Medical College and the Ithaca campus, met to exchange their research capabilities and needs. The goal was to initiate new research collaborations in the design and implementation of agents for cancer detection and therapeutics and imaging technologies for cancer and cell biology. Faculty with expertise in oncology, engineering, chemistry, cell biology, animal modeling, nanofabrication and materials science attended. Thirty-one people attended the event, 25 presentations were given, including capabilities that nanoscale research and fabrication could contribute to new collaborations.
- **Microfluidics Mini-Course:** A new hands on lab course in microfluidics was offered twice in 2010 as a joint effort between the CNF and the Nanobiotechnology Center (NBTC). The 3-day course covered the fabrication, assembly and uses of microfluidic devices. It was taught by Beth Rhoades, the Life Sciences Liaison of the CNF, and Penny Burke and Teresa Porri of the NBTC. Cornell researchers who have made microfluidic devices at the NBTC and CNF made short presentations and showed their research devices to the attendees. Attendees came from the Cornell community initially to “get the kinks out” but enrollment is now being expanded to external registrants will be offered multiple times per year.
- **CNF at Weill Medical College in NYC:** We continued our outreach to the life sciences community in NYC this year. Two of our staff members periodically travel to Weill Cornell Medical College and use the office located at the Institute for Computational Biomedicine, Room Y13-02, 1305 York Ave. From there they promote the use of nano- and micro- fabrication techniques for clinical and basic life sciences research. CNF staff is available for consultation and translating design ideas into working devices.
- **Advances in DUV Stepper Lithography:** In September of 2010, CNF and vendor partner, ASML, held a Lithography Workshop focused on the PAS5500 Deep Ultraviolet (DUV) Wafer Stepper platform tools. CNF was chosen as the location for this event in part due to our recent acquisition of a PAS5500/300C 248nm DUV wafer stepper as part of a collaborative effort with ASML in the Eastern US. The workshop was a one-day event and was primarily attended by users, staff and industrial customers. The workshop brought together current and potential customers of PAS5500 tools for discussions of current field performance, specific processing results, and enhancements to the systems developed recently. System enhancements/upgrades included Smartstart, for overlay improvement with thin-film disk drive head processing, Alignment Analyser and Overlay Analyser, software for improving layer-to-layer registration, and 3DAlign, a system for performing front-to-back wafer alignment. Results from the application of these systems were presented, and other potential applications were discussed. The installation and performance of CNF’s PAS5500 stepper were also presented.

- **Computational Workshop:** A Joint NNIN/NCN Fall Workshop, “Building a Collaborative Framework for Nanoscale Simulations”, was held Nov. 14-16th, 2010, at Cornell University. ( http://www.cnf.cornell.edu/cnf_fallworkshop2010.html ) The field of nanoscale simulation relies on intensive atomistic simulations that often generate copious amounts of data so there is a growing need to develop a common collaborative framework to provide meaningful comparisons between calculations and also to provide a set of robust technical components and results that can be used the next generation of researchers. The Joint NNIN/NCN workshop brought together leading figures in the simulation community focused on simulating materials and nanostructures to address this issue and develop a set of lingua franca formats and libraries that allow easy translation of input and output files generated by different codes. Speakers discussed current efforts in the field such as the European Theoretical Spectroscopy Facility (ETSF), ESTEST, OpenBabel, NanoHub, and the Computational Materials Repository. We also addressed the development of international cyberinfrastructure resources that will provide trusted components required for atomistic calculations such as empirical potentials, pseudopotentials, basis sets, and atomic coordinates. The workshop spanned three days, with the first day devoted to hands-on tutorial sessions for participants on different simulation approaches (ASE, etc.). The remaining two days consisted of 13 lectures from an international collection of speakers and a roundtable discussion to identify future areas for greater collaboration in nanoscale simulations. We worked with the Network for Computational Nanotechnology (NCN) to develop this event. A total of 43 participants took part in the workshop, including participants from 8 states (Michigan, New Mexico, Massachusetts, California, Pennsylvania, New York, Virginia, and Indiana), Puerto Rico, Belgium, and Denmark. Research disciplines of participants included Electrical Engineering, Physics, Chemistry, Ceramics Engineering, Civil Engineering, Mechanical Engineering, Materials Science, Computational Science, and Nanoscience. Participants were surveyed on their experience at the end of the workshop and were overall very enthusiastic about the event. Comments included “This was one of the best workshops I have ever attended.” …“Thanks for organizing this; I thought the meeting was very useful and saw a lot of useful communication coming out of this. I would be happy to be involved in similar meetings in the future.” …“Through this workshop, I have seen a lot of opportunities of establishing collaborative computational platforms, and benefited a lot from others' broader vision of how to contribute to the community.” Based on discussions at the workshop, the Cornell NNIN/C will serve as a beta test site for the ESTEST storage and validation system for electronic structure calculations developed by Prof. Francois Gygi (University of California, Davis). This platform provides research groups with an easy web-based way to share and store data from calculations.


*Figure 67: Cornell Computation Workshop Attendees*

- **SEI Workshop:** Following up the first one-day workshop (hosted at CNF on January 22, 2010), we co-hosted another workshop on “Implementation and Impact of the Societal and Ethical Issues (SEI) Training at NNIN Laboratories,” at Knight Conference Center, Washington University-St. Louis, St. Louis, Missouri, on October 15, 2010. Thirteen NNIN sites participated in this workshop. The purpose of the workshop was to follow up with all the NNIN sites regarding the status of the SEI orientation in their respective sites. In addition the workshop showcased other scholarly activities related to SEI throughout the network. Katherine A. McComas, the

NNIN-SEI Coordinator, provided a brief overview of SEI activities at the NNIN and each site representative shared a brief overview of their SEI orientation, key changes since the January 2010 workshop at Cornell, and any plans for new developments in their respective sites. Additionally, there were presentations from other NNIN sites given by researchers working in several aspects of nanotechnology. Ira Bennett from Arizona State University spoke on outreach with the Arizona Science Center, Katherine McComas from Cornell University on SEI Posters, Carl Mitcham from Colorado School of Mines on Matching Goals of Ethics Education with Evaluation, Nancy Healy from Georgia Tech on Learning from the NNIN Education Experience, and Ethan Allen from University of Washington on SEI Dialogues. There was lively discussion on ways to measure impact of SEI orientation and other SEI activities on the scientific community.

- **Junior FIRST LEGO® League:** The CNF sponsored a Junior FIRST LEGO League (Jr.FLL) Expo for 50 kids ages 6 - 9 from 9 teams. The teams came in from a wide area covering Rochester to Ithaca, NY. The theme of this year's expo was Body Forward, dealing with Biomedical Engineering. Beginning in the fall, the teams had to pick a body system and study what can go wrong with it, and model a device in LEGO®s to assist or studying that system. Teams from around the area presented their LEGO model and poster and received an award for their work. Staff from CNF organized the event and served as project reviewers. This event was also partially underwritten by a grant from the Shell Oil Company.

*Figure 68: FIRST Junior Lego League Event*

## 7.2.8 Computation Contributions (CNF/C)

During 2010, the computational branch of the Cornell Nanoscale Facility continued to help foster nanoscale research and education through direct consultation and access to a wide array of simulation tools on the CNF cluster.

- **Publications 2010**: Work on the CNF cluster resulted in 13 research articles in 2010 and one publication in early 2011, bringing the total number of publications to 46 since the cluster came online in February 2005. The 2010 papers include articles published in *Nano Letters, Physical Review Letters, Journal of Chemical Physics, Phys Rev B,* and *ChemPhysChem*. The full collection of papers has h-index of 11 and has currently been cited 455 times. Recent research topics include thermal transport in graphene, exciton dissociation in nanocrystals, conducting polymers, structural searches for new crystal structures, electronic structure of semiconducting chromium aluminum alloys, and new oxide materials for magnetic tunnel junctions.

- **New Computational Users for 2010**: In addition to usage by several veteran CNF cluster users, 21 new users obtained accounts in 2010. The new computation users included researchers from UC Berkeley, SUNY Albany, Alfred University, and UT Austin. In 2010, the CNF site had 36 active users, 28 Cornell users and 8 external users.

- **User Awards** Zoe Boekelheide (University of California, Berkeley) won the American Physical Society, Group on Magnetism and Magnetic Materials (GMAG) Dissertation Award for 2011. Her work focuses on the effects of nanoscale structure on the magnetic and transport properties of chromium and chromium-aluminum alloys. She has performed numerous simulations of CrAl alloys on the CNF cluster that resulted in a recent *Physical Review Letters* article.

- **Educational Outreach**: During the 2010 Fall semester, Derek Stewart worked with Prof. Richard Henning (MSE, Cornell) on computational materials science course (MSE5720) that used the CNF cluster. 24 students participated in this course and students used the CNF cluster during class tutorials and also for their term projects. Dr. Derek Stewart also gave a guest lecture on high performance computing for material science applications. Some of these students are now using the CNF cluster in their own research.
- **Synergistic Activities:** A Joint NNIN/NCN Fall Workshop, "*Building a Collaborative Framework for Nanoscale Simulations*", was held Nov. 14-16th, 2010, at Cornell University
    - o (see description above).
- **Virtual Vault for Pseudopotentials Development** : The CNF hosts the development of the Virtual Vault for Pseudopotentials for the NNIN/C. While electron scattering from atoms can be described using a full potential, this process is be computationally expensive and dramatically limits the number of atoms that can be considered. Pseudopotentials can efficiently capture the relevant scattering information and allow for larger scale calculations. The NNIN database will provide the global scientific community with access and statistics on pseudopotentials used in a wide range of electronic structure codes. Since pseudopotentials are often described using different formats, it is also important to provide resources to convert between different codes. The CNF has developed a general clearinghouse for information related to pseudopotentials as a resource for the community. (See http://www.nnin.org/nnin_comp_psp_vault.html .) The clearinghouse consists of a PHP-SQL database of pseudopotentials that can be accessed online, containing over 800 pseudopotential files drawn from different pseudopotential codes including Quantum Espresso, Abinit, and Qbox. Users can interface this data through an online periodic table to find information related to a particular atom. Users can also search the database based on a given element and compare available pseudopotentials based on criteria such as exchange-correlation functional, pseudopotential class (i.e. ultra-soft, norm-conserving), parent electronic structure code, and more. In addition, members in the community have also begun to donate their own pseudopotentials to the database. *This database provides the first centralized resource for pseudopotentials that spans multiple electronic codes.* Derek Stewart presented a talk "Developing a Virtual Vault for Pseudopotentials: A NNIN/C Initiative" at the 2010 Nanoinformatics meeting in Washington, DC.
- **Cluster Simulation Options**: Four new software packages were added to the CNF computational resources available for users in 2010. Currently, CNF users have access to over 30 different computational packages for topics including nanophotonics, fluidics, molecular dynamics, and electronic transport in nanostructures. In addition, the computational branch at the CNF continues to provide the only public access point for the UT Quant code which is used to calculate C-V characteristics for MOS structures. In 2010, this code was requested from researchers at institutions in the United States, Mexico, and India.
- **New Hardware Added to the Cluster**: The Cornell Nanoscale Facility is committed to maintaining a modern computational facility for nanoscale simulations. In June 2010, the Cornell Nanoscale Facility purchased 20 additional dual processor quad-core Intel Xeon (2.4 GHZ E5620) nodes (24GB RAM/ node) as well as a new master node and new router for the cluster. These new nodes allow users to tackle intensive parallel calculations of nanoscale structures with large numbers of atoms. The expanded storage space on the main node is also crucial for research calculations that generate output files several gigabytes in size. This addition brings the overall capacity of the CNF cluster to 152 processors or 288 computing cores and helps insure that the NNIN/C resources remain relevant for scientific research.

- **New software added in 2010**
  - **Atomic Simulation Environment**: Python package that provides a python simulation environment with modules for building atomic structures, molecular dynamics, structure optimization, analysis, and more
  - **GPAW:** density functional python code based on the projector-augmented wave approach
  - **ELK**: full potential linear augmented plane wave code
  - **SPR-KKR:** pin polarized relativistic Korringa Kohn Rostoker code, users must register with code developers first
  - **Software updated to Newer Versions:** Abinit, Quantum Espresso, Gromacs, Siesta, OpenMX

### 7.2.9 Social and Ethical Issues in Nanotechnology

Social and Ethical Issues (SEI) activities form an integral part of NNIN training at its 14 sites where we aim to develop social and ethical consciousness both within user community and the broader nanotechnology community. Katherine A. McComas and Debasmita Patra at Cornell University are responsible for coordination of the SEI component of NNIN. Prof. McComas joined the NNIN team as the SEI coordinator in October, 2008 and Dr. Patra joined in December, 2008 as a postdoctoral associate. Below we provide a brief overview of several SEI activities that have been carried out at CNF.

- **SEI Orientation at CNF:** In an effort to implement an interactive way of engaging scientists and engineers to think about SEI issues, Debasmita Patra at CNF developed a new presentation as part the new user safety training and orientation. These materials are used to stimulate discussion seeking out the opinions of the users. This interactive session replaced a video made in 2007 by Prof. Kysar et al. The new presentation has been iterated and improved based on feedback from the users obtained during the classroom interactions and through feedback forms. The sessions are well received by the scientific community, as evident from the kind of feedback attendees provide after each session. This effort of SEI training began at CNF in December 2008 and by December 2010 more than 480 users had participated. Since limited time is available, the sessions provide only an introduction to SEI. In Jan 2010 a workshop was held to “train the trainers” at all the other NNIN sites in the use of the SEI orientation materials.
- **NNIN SEI Workshop:** Following up the first workshop (hosted at CNF on January 22, 2010), we co-hosted another workshop on “Implementation and Impact of the Societal and Ethical Issues (SEI) Training at NNIN Laboratories”, Washington University, St. Louis, Missouri, with Nano Research Facility (NRF), Washington University-St. Louis, on October 15, 2010. (see above).
- **Public Service Posters:** Working with Dr. McComas, summer intern Chloe Lake developed an array of SEI related posters that bring common SEI themes to the attention of lab users. The themes and art work were tested on focus groups and final versions were professionally produced. These have been posted throughout CNF and are now available at all NNIN sites.
- **Coordination Activities:** In order to facilitate SEI research, we compiled a user database comprising information about users at all 14 NNIN sites. This dataset has already been used for several SEI research projects. An SEI Advisory Board has also been established which will help in reviewing and selecting the research proposals both from within and outside the network for SEI research at the NNIN sites. To attract SEI researchers into the unique NNIN environment, travel grants have been awarded to several researchers.

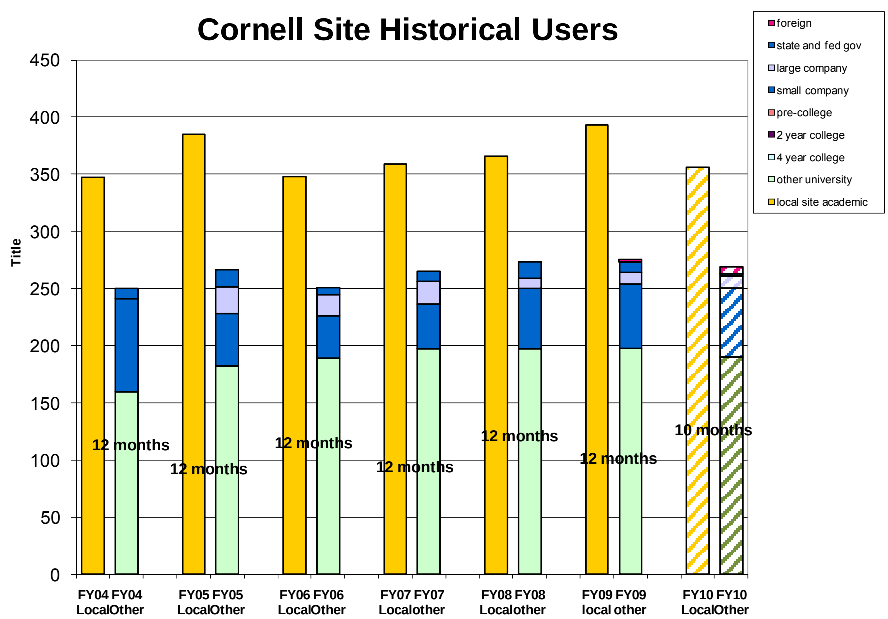
- **SEI Research Impact:** The SEI team has 9 papers published or under review and one in preparation based on a user population survey. Additionally there have been three conference presentations, a poster paper and they have produced a revised SEI orientation manual.
- **SEI- NNIN Website (www.sei.nnin.org)** The SEI portal provides relevant information on several issues related to society and ethics. This web portal underwent a major modification under the leadership of Dr. Patra in 2009-2010. This new version displays several new additions of categories such as, 'What is SEI?', 'What is Nanotech?', 'History of Nano', 'What is SEI in Nanotech?', 'SEI Training at NNIN'. New resources such as Articles, Books, Links, Multimedia, Presentations, Reports, and Workshops were added to the website. New pages such as Issues, Events, and Spotlight were added to the web portal, and pages on Environmental, Ethics, Green Nano, Interdisciplinary, Nanotoxicology, Nano-Bio-Info-Cogno (NBIC), Regulation, Risk, and Technoscience were added, as well. In 2010, the number of resources increased to 515 with additional information on 49 events.

### 7.2.10 Staffing

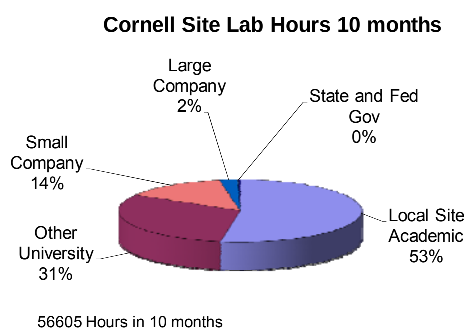
CNF has a staff of 29 technical and administrative professionals, all dedicated to CNF/NNIN user functions. All staff members are supported entirely by CNF core funding and user facility funds. In July of 2010 we welcomed Prof. Daniel Ralph (Physics) as the new Director of CNF. We also added Noah Clay as an experienced process integration engineer this year to respond to needs and requests from CNF users.

## 7.2.11 Selected Cornell Site Statistics

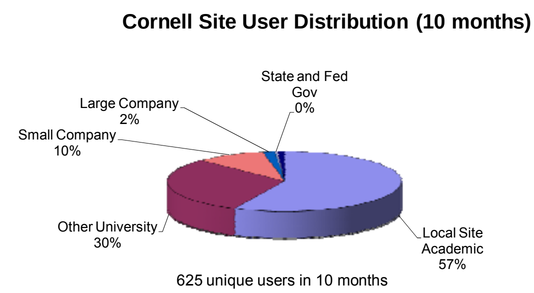
a) Historical Annual Users



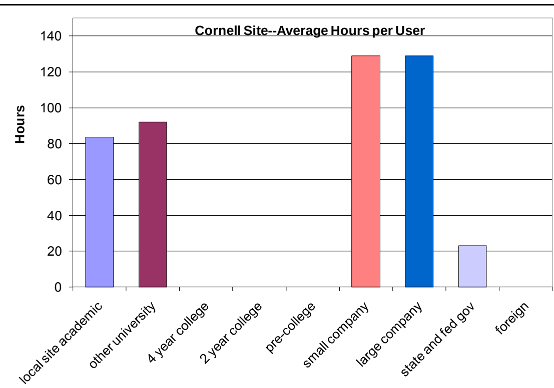

b) Lab Hours by Institution Type




C User Distribution by Institution Type




d) Average Hours per User ( in 10 months)




e) New Users

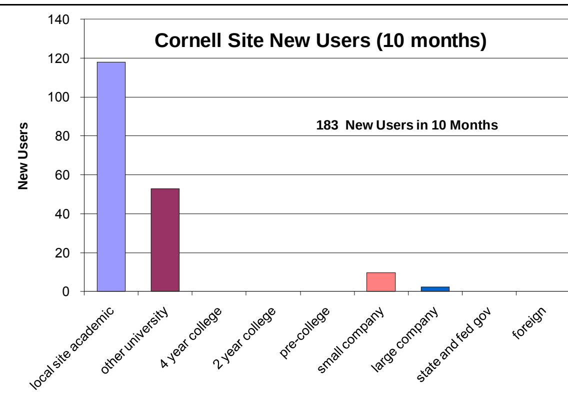



*Figure 69: CNF Site Statistics*

## 7.2.12 Cornell User Institutions

| US Universities | Small Companies | Large Companies |
|---|---|---|
| Arizona State University | Advanced Diamond Tech. | ASML |
| Boston University | Agave BioSystems | ATK-GASL |
| Brigham Young University | Agiltron Inc. | Corning, Inc. |
| Case Western Reserve U. | API Defense, Inc. | GE Global Research |
| City University of New York | Applied Pulsed Power, Inc. | Xerox Corporation |
| Clarkson University | Bandgap Engineering | |
| Clemson University | BinOptics Corp | |
| Colgate University | BioArray Solutions Ltd | |
| Columbia University | Brown & Associates | |
| Harvard University | Calient Optical Components | |
| Ithaca College | Custom Nanotech, LLC | |
| Lehigh University | EIC Biomedical | **State and Federal** |
| MIT | EigenPhase Technologies | Brookhaven National Laboratory |
| New Jersey Ins. of Tech. | Faraday Technology, Inc. | |
| New York University | Gamechangers, LLC | |
| North Carolina State Univ. | iFyber, LLC | **International** |
| Northeastern University | Illuminaria, LLC | McGill University |
| Northwestern University | Kionix, Inc. | Peking University |
| Old Dominion University | MCB Clean Room Solutions | University of Waterloo |
| Oregon State University | MicroGen Systems, LLC | |
| Princeton University | NABsys, Inc. | |
| Rensselaer Polytechnic Inst. | Nanodynamics 88 | |
| Rochester Inst. of Tech. | Orthogonal Inc. | |
| Stony Brook University | Pacific Biosciences | |
| SUNY Albany | PC Mirage LLC | |
| SUNY Binghamton | Phoebus Optoelectronics, LLC | |
| Syracuse University | QEL Inc | |
| Texas A&M University | RAC Nanotech LLC | |
| Pennsylvania State Univ. | RTS Inc | |
| UC Santa Barbara | Transonic Systems | |
| University at Buffalo | Widetronix Semiconductor Inc | |
| Univ. of California, Berkeley | | |
| Univ. of Colorado at Boulder | **US Universities** | |
| Univ. of Connecticut | University of South Carolina | |
| Univ. of Kentucky | University of Washington | |
| University of Maine | University of Wisconsin | |
| University of Maryland | Utah State University | |
| University of Pennsylvania | Vanderbilt University | |
| University of Pittsburgh | Yale University | |
| University of Rochester | | |
| *Continued-* | | |

## 7.3 Georgia Tech Site Report

### 7.3.1 Research Highlights

**Nanolithography**: The Nanolithography Facility continues to successfully operate with a JEOL JBX-9300FS Electron Beam System.Both academic and industrial users have successfully engaged at Georgia Tech to achieve their research goals.A research project was started and completed with Cambrios Technologies of Sunnyvale, CA.Cambrios has an advanced technology for making transparent conductors based on nanostructures.The project successfully fabricated devices to explore the relationship between electro-optical properties and nanostructure material and geometry.Another project, which is still ongoing, is in biomedical research with Kimberly Clark corporation.For more than a century, Kimberly Clark has been transforming insights and technologies into innovative products and services that improve the lives of nearly a quarter of the world's population.48 unique users have used the Georgia Tech Nanolithography Center in 2010.

**Graphene and Carbon Nanotube Research**:The NRC continues to support transformative research into post-CMOS technologies including graphene and CNTs. Commonly used tools by graphene-researchers include the graphene growth furnace (from CVD-FirstNano), JEOL 9300FS e-beam lithography, Veeco AFM, Zeiss Ultra 60 SEM, and Thermo Raman imaging. A number of innovative results were reported last year including size-dependent mobility of graphene nanowires, single-step complemenatary doping of graphene, and bandgap measurements inepitaxial graphene ribbons grown on vicinal faces of SiC. Many of the graphene-researchers at GT organized and attended a graphene workshop in Amelia Island (Florida) in Sept. 2010; the list of attendees included researchers and graduate students from across the country working on various aspects of epitaxial graphene.

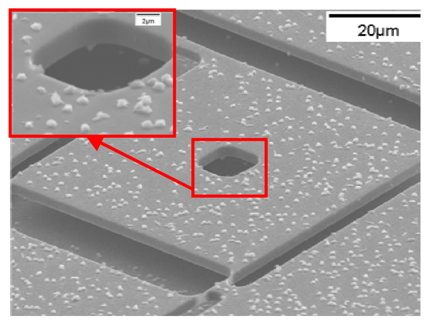



*Figure 70: Micromechanical Oscillator*

**Self-Sustained Micromechanical Oscillators and Nanobalances, Siavash Pourkamali (University of Denver)**Interactions between thermal actuation and the piezoresistive effect in certain micromechanical resonant structures can lead to an internal positive feedback mechanism producing self-sustained oscillation without the need for supporting electronic circuitry. Single crystalline silicon extensional mode dual plate resonators with frequencies in the few MHz range have been fabricated to demonstrate this concept. Such devices provide the technological basis for sensitive nanobalances for sensor applications, and detection of individual particles with submicron diameters has been demonstrated.

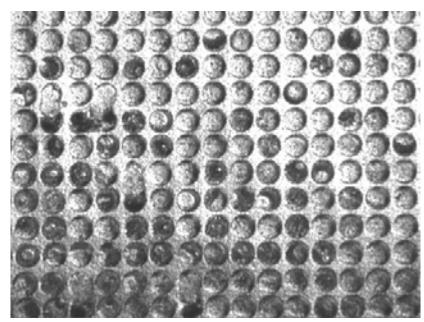


*Figure 71: Transdermal Patches*

**Inkjet Printing of Transdermal Patches, Ajay Banga (Mercer University)** Preparation of transdermal patches coated with drug formulations was achieved using inkjet printing in both burst mode and on-the-fly printing.The drug/formulation exists in the dry state on the backing membrane.This method can be adapted for proteins and vaccines, and is designed to be used in conjunction with microneedle (characterized using SEM) poration of the skin.

**Development of Stroke Sensors, Galina A. Izykenova (CIS Biotech Inc.)**CIS Biotech is researching the use of quartz crystal microbalance (QCM) technologies to study interactions between a peptide antigen and polyclonal antibodies, in an experimental format suitable for diagnostic assays. In the chosen model, a synthetic NR2 peptide, the fragment of NMDA neuroreceptors (a stroke associated antigen) was immobilized by an optimized chemical protocol applicable to QCM sensors. A preliminary study of the peptide immobilization was performed to optimize the signal-to-noise ratio using mixed self-assembled monolayers in a gold surface. The antibody detection limit was determined to be 0.02nM in diluted human serum. This value is in agreement with the reported rank distribution of NR2 antibodies in non-stroke patient sera. Label-free and real-time technologies such as QCM could be precious tools in future diagnostic assays.

### 7.3.2 Expansion and Growth of the Georgia NRC Facilities, Equipment and Capabilities

Marcus Organic (Bio) Cleanroom was designed to accommodate the growing number of users who work at the interface between nanotechnology and life sciences, and has now been outfitted with 10 major tools and additional supporting equipment to facilitate this usage.New instrumentation added in the past year includes nanoparticle characterization (Malvern Zetasizer Nano ZS) and surface plasmon resonance (Biacore T200) as described elsewhere.In addition, a separate and customized orientation program for Organic Cleanroom users was begun in May, 2010 and has already authorized nearly 300 users for this specialized facility (25% external).Approximately 35% of these individuals are users exclusively of this NRC facility implying that this unique laboratory and its associated tools have filled a critical need for a previously untapped user base.

Tool installation for the organic and inorganic cleanroom space is approximately 75% complete.New capabilities include etch, CVD & metrology.Tools in queue and to be installed in the next few months in the inorganic cleanroom include thermal processing, ICP etch, PECVD, RIE, lithography, and electron beam evaporation.One new electrical engineer will be added to assist with tool installation and user support.

Recent acquisitions for our new life-science oriented cleanroom include a recently arrived GE Healthcare Biacore T200 Surface Plasmon Resonance (SPR) tool which will allow characterization of protein-surface binding interaction measurements, on- and off-rate kinetics, and quantification / analysis of interactions of very low molecular weight compounds (no minimum MW for small organic compounds).Typical injection volumes range from 2 to 350ul and analysis per-cycle time runs generally between 2 to 15 minutes.There are 4 flow cells with auto-switching between up to 4 buffers.Sample concentration need only be a minimum of 10pM.Common applications include drug discovery and immunogenicity testing.

A Malvern Zetasizer Nano was obtained which is used for particle size and distribution measurement (0.3nm – 10um) using non-invasive back scattering technique. This tool also allows for the determination of aggregation and optimum crystallization conditions for proteins in 2µm sample volume by measuring a sample's *Zeta-potential.*Samples can be suspended in aqueous or organic solvents and controlled between 0 – 90C using a Peltier temperature controller.Applications include: pharmaceuticals, food industry (condiments), nanoparticles, protein crystal screening, protein melting point, etc.

The recent acquisition of a Microtech LW405A Laser-Writer will allow in-house photomask production of both flat and curved surfaces, (>75mm radius of curvature) made possible due to auto-focusing optics.The write field ranges from 5mm x 5mm up to 6in x 6in with a maximum substrate thickness of 3mm.Three head sizes are available (0.8um, 2um, 8um) and automatically chosen for a balance between resolution and write duration.The GaN laser source has grey-level capability with 256 levels per pixel.Software settings and strong laser source allow patterning of low-sensitivity SU8 coated substrates.The optics in conjunction with the smart software allows the use of alignment marks for building up subsequent patterns.The 3 write modes available include *beam scan, stage scan,* and *vector* providing a balance of speed and resolution depending on desired pattern.The XY stage has a resolution of 10nm and will allow patterning to the substrate edge.Manual mode allows for laser engraving, manual trimming, and even profilometry (100nm vertical resolution) using interferometry.In addition, special available masks by the manufacturer do not require photoresist or any pre- or post- processing (black masks turn clear when exposed).

The latest acquisition for the materials characterization area is an IonTOF 5 Time-of-Flight Secondary Ion Mass Spectroscopy (ToF-SIMS). Atomic weights from 1 up to >10,000 amu (i.e., $H_2$ up to large molecules) can be detected with a mass resolution, dm/m, up to 10,000.Analysis depths range from the surface (tens of angstroms) in static SIMS mode, down to depths of several microns.The system can detect trace elements down to concentrations of a few parts per million of a monolayer, making it the only standard technique capable of dopant-level surface and depth profile characterization.It can produce chemical maps and 3-D chemical reconstructions with single-nanometer depth resolution and 0.1-micron lateral resolution using Bi, Cs, and O beams.The 5-axes sample navigator and fast-entry load-lock improve handling of a sample and chamber vacuum.Commonly analyzed materials include: semiconductors, polymers, paint, coatings, glass, paper, metals, ceramics, biomaterials, pharmaceuticals, organic tissues, etc.

### 7.3.2 Diversity Activities:

GT has participated in the NNIN Laboratory Experience for Faculty program, which encourages faculty from underrepresented minority institutions to use the facility at no cost for a period of time.Professor Amy Sullivan from Agnes Scott College, Professor Tatiana Allen from University of Tennessee Chattanooga, and Professor Adedayo Ariyibi from Tuskegee University, were able to use the NNIN resources under the LEF program in 2010.All of the LEF participants continue to use the GT facility.

### 7.3.3 Special Focus/Leadership: Education:

The NNIN's Education and Outreach Office is housed at Georgia Tech.The staff consist of the NNIN education coordinator who oversees network, national and local efforts, full-time assistant education coordinator whose primary focus is GT initiatives and a full-time education assistant.

Georgia Tech's education program is a very active outreach program with more than 60 events directly reaching over 4,200 individuals. Our focus encompasses a variety of K-12 student programs, including summer camps; on and off-site school programs; teacher professional development workshops; and presentations at local and regional science teacher meetings.

**Bio-Outreach:**NRC technical liaisons attended, exhibited, and/or presented at numerous bio-related events in 2010.Events included invited presentations at University of Georgia, Fort Valley State University, University of South Florida, Clemson University, Mercer University.

We also offer professional workshops and have developed a program titled *NanoFans* – **Nano F**ocusing on **A**dvanced **N**anoBio **S**ystems. The goal of the forum is to connect the medical/life sciences/biology and nanotechnology communities. *NanoFans* seeks to reach out to researchers in the biomedical/life sciences areas to inform them about what nanotechnology can offer them in the advancement of their research. The series offered two events: May 27, 2010 – Nanotechnology Application in Cardiology and November 18, 2010 – Nanotechnology in Drug Delivery. Approximately 240 participated in the events.

**Nano@Tech** is a joint NRC education/outreach and research program.The featured speakers for the twice-a-month seminars come from all of the disciplines involved in nanotechnology research (including the social sciences), and the seminars represent an excellent opportunity for cross-pollination and collaboration forming.Attendees include faculty, graduate and undergraduate students from Georgia Tech and other local campuses, and professionals from the corresponding scientific community.Nano@Tech members (more than 500 on the mailing list) also support the NNIN Education and Outreach Office at Georgia Tech by providing volunteers for K-12 outreach activities.Since January 2008, 47 seminars have been held in this program and the attendance has steadily doubled over that time period.Most of these seminars have been captured on video and archived on the SMARTech website (http://smartech.gatech.edu/handle/1853/14205) where they have been viewed or downloaded as many as 2000 times. Finally, this past year began a new component of Nano@Tech with the inclusion of student mini-seminars each semester.

Georgia Tech is the lead on an NSF awarded RET program which includes Harvard, Howard, Penn State, and UCSB.During summer 2010, four teachers undertook research during their six-week experience at Georgia Tech and have designed classroom instructional units for use in high school science classes.These materials are posted on the NRC website and are linked to Georgia Performance Standards thus making them a useful resource for Georgia science teachers (http://www.mirc.gatech.edu/education/instructional_units.php).The teachers also present their experience at the Georgia Science Teachers Association annual meeting.

Georgia Tech also supported six REU interns during summer 2010. The three males and three females worked with GT faculty and staff on a variety of research topics.As with past years, our participants rated our program at the NRC very highly. Three of these students will participate in the NNIN International REU in summer 2011.Georgia Tech also hosted two Japanese graduate students during the summer as part of the NNIN's international Research Program for Graduate Students. The students came to us through NanoNet (Japan) and the National Institute of Materials Science in Tsukuba, Japan. They spent a total of 10 weeks doing research with faculty and graduate students. We also hosted three faculty participating in NNIN's Lab Experience for Faculty (LEF) program which encourages nanoscale research by women and minorities.Our participants came from Agnes Scott College, University of Tennessee at Chattanooga, and Tuskegee University. We also had two high school interns work at the NRC as part of the Technical Association of Georgia.These two students worked with cleanroom staff on implementation of new equipment.

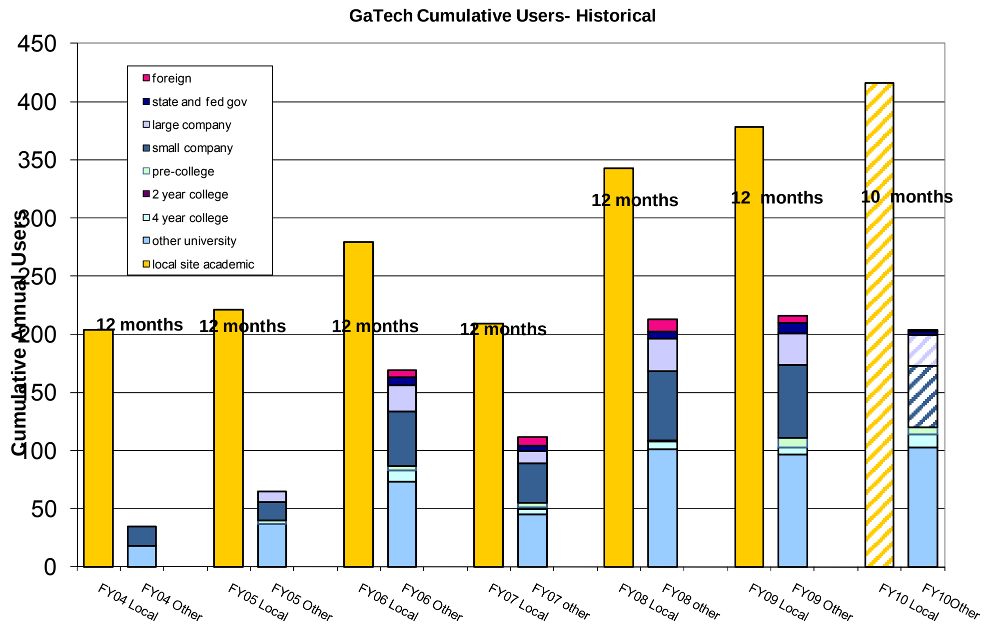
In October, 2008 GT joined MCREL and NNIN Stanford's site on a new NSF-funded project titled *NanoTeach.* This 5 year, professional development program will develop a combination of face-to-face and online professional development experiences for high school science teachers who teach physical science topics. During 2010, Georgia Tech has taken the lead in developing day one activities, providing content support for the team, developed nine posters on the Big Ideas in Nanoscale Science and Engineering, developed a PowerPoint on the Big Ideas, delivered the PowerPoint at the pilot workshop, and assisted with activities at the pilot workshop.

Georgia Tech was very active in providing teacher professional development workshops on how to include standards-based nanotechnology lessons into the science curriculum.We delivered workshops at national, regional, and local events for middle and high school teachers. We have developed a teacher workbook for high school teachers connecting the lessons to the "Big Ideas."

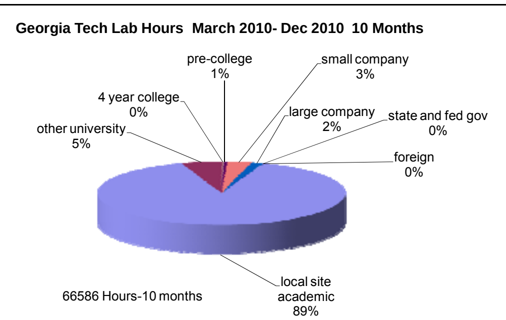
*---End of Georgia Tech text report---*

## 7.3.4 Georgia Tech Selected Site Statistics

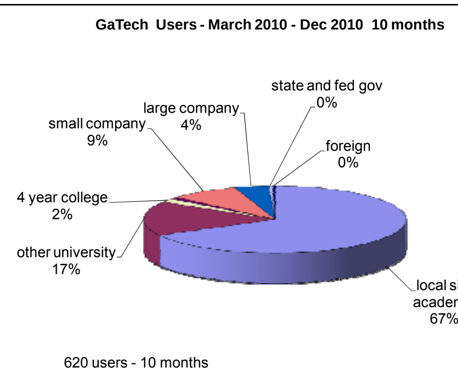
a)Historical Annual Users



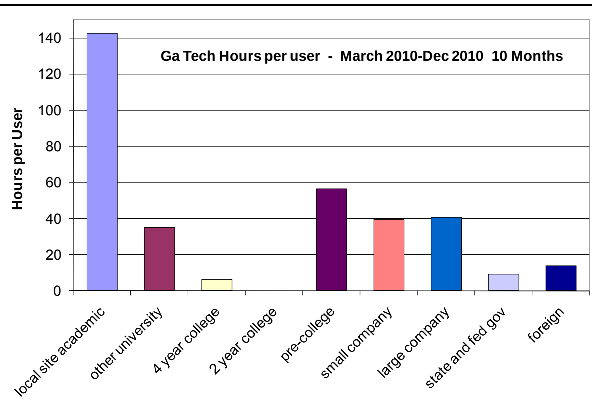

b) Lab Hours by Institution (10 months)




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

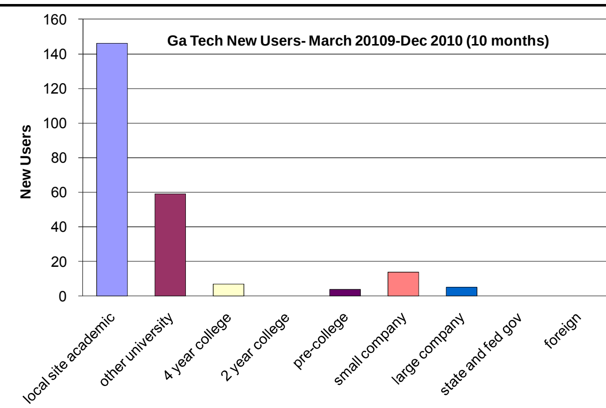



*Figure 72 Georgia Tech Selected Site Statistics*

## 7.3.5 Georgia Tech User Institutions

| Table xxxx | | |
|---|---|---|
| **US Academic** | **Small Companies** | **Large Companies** |
| Agnes Scott College | Accellent | CIS Biotech |
| Georgia Perimeter College | Advanced Power Solutions | Cox Communications |
| Morehouse College | Astrowatt | Houghton Metal Finishing |
| Spelman College | Atlanta Medical Center | Kimberly-Clark |
| Wooster College | Auriga Microwave | KLA Tencor |
| University of Michigan | AVX Corporation | Milliken |
| Albany State University | Axion Biosystems | Sandisk |
| Arizona State Univ | BioForce | Sensor Electronic Tech |
| Clark Atlanta University | Cambrios Technology | St. Joseph's Translational Research Institute |
| Clemson University | Cardiomems | Theragenics |
| Covenant College | Cherry Systems | |
| Dartmouth Univ. | EnGeniusMicro | |
| Drexel University | Excellatron | International |
| Emory Univ. | Genel Systems | Unv of Perguia (Italy) |
| Georgia State Univ. | H2 Scan | Waterloo University |
| Kennesaw State Univ. | Helios | Nagoya University |
| Louisiana State Univ | HRL Laboratories | |
| Mercer University | Integrated Device Tech. | State and Federal |
| New Mexico State University | InviPharm | CDC |
| Norfolk State University | JP Innovations | |
| Oklahoma State - Tulsa | Lehigh Technologies | |
| Rensselaer Polytech | Memtronics | |
| Rose-Hulman Inst. Of Tech. | Molecular Imprints | |
| SUNY Binghamton | NanoGrip | |
| Tuskegee Univ | NGIMAT | |
| Univ. Michigan | Open Cell | |
| Univ. of Alabama Tuscaloosa | Qualtre | |
| Univ. of Central Florida | Touchdown | |
| Univ. of Missouri Rolla | UES | |
| Univ. of New Mexico | VT Silicon | |
| Univ. of South Carolina | Zurvahn, LLC | |
| Univ. of Tenn.-Chattanooga | | |
| Univ. of Texas - Austin | | |
| Univ. of Texas - Dallas | | |
| Univ. of Tulsa | | |
| Univ. Texas at Arlington | | |
| University of Denver | | |
| University of Georgia | | |
| University of Missouri | | |
| Univ. of North Carolina at Charlotte | | |
| University of South Florida | | |
| Vanderbilt | | |

## 7.4 Harvard University Site Report

### 7.4.1 Facility Overview

Year 7 (2010-2011) was another significant year of growth in users and capabilities for the Harvard University site. Highlights include a record number of users overall, record number of industrial users, and all-time highest percentage of external users.During this review period several new instruments were added to our laboratories, and an additional technical staff member has been added to the CNS.A new class 10,000 soft-materials fabrication facility was commissioned and is now serving a vibrant microfluidics community.Many of these improvements were shared with the other NNIN sites during an all-site meeting with the NNIN Advisory Board hosted on the Harvard Campus in April 2010.

Harvard continued as the headquarters for the NNIN computation technical area (NNIN/C) led by Dr. Michael Stopa.A summary of NNIN/C is given elsewhere, but highlights for computation at the Harvard site include upgraded hardware facilities and A steadily expanding code base.As an example, our GPU process hardware was commissioned and is now running simulation software.In February of 2010 the Defense Threat Reduction Agency granted an award for a proposal on Coherent Molecular Profiling Using Nano-Structured Environments submitted by Harvard's Alan Aspuru-Guzik in collaboration with NNIN/C director Michael Stopa. The project calls for the development of analytical and numerical approaches to describe the interaction of analyte molecules with excitations in nanostructured environments, as well as describing the influence of the nanostructured environment on the ground state properties of molecules.

Regarding site management, in July 2010 Frans Spaepen, the John C. and Helen F. Franklin Professor of Applied Physics, completed his year as interim CNS Director. Replacing him is a long-time CNS user, Thomas D. Cabot Professor of Chemistry Roy Gordon.His research interests include spectroscopy, phase transitions, the kinetics of crystal growth, and vapor deposition processes.His contributions to process technology are widely used commercially for making thin films in solar cells, energy-conserving window coatings, display devices, and semiconductor electronics.

### 7.4.2 Research Highlights

The Harvard site continues to support a very broad range of research activities, spanning nano-materials, low-dimensional physics, medical diagnostics, renewable energy, and optics.Graphene continued as a significant theme and several new projects were initiated in the area of diamond films.

Bio-inspired activities increased during the past year, fueled primarily by the researchers of the Boston-based Wyss Institute for Biologically Inspired Engineering.Work conducted by this team included topics such as "Bio-Inspired Approaches to Crystal Design", "Bio-Inspired, Reconfigurable, 'Spiny' Surfaces: En Route for Adaptive Materials", and "Dynamic, Bio-Inspired Nanofur."

Progress in the area of laser development continued as CNS researchers announced a breakthrough disc laser design which uses an elliptical cavity, and demonstrated for the first time highly collimated unidirectional microlasers.By shaping the microlaser as an ellipse with a wavelength-size notch carved out from its edge, Federico Capasso's team found that the cycling whispering gallery modes scatter efficiently off the notch and emerge as nearly parallel beams from the microlaser.The prototypes are quantum cascade lasers emitting an optical power of 5 milliwatts at a wavelength of 10 micrometers. The microlaser performance is insensitive to the details of the notch, making this device design very robust. This advance has a wide range of new applications in photonics such as sensing and communications.

A project in InN nanorods showcased our expanded capabilities in nanomanipulation.InN has interesting optical properties, however it is difficult to study in nanorod form because these rods are typically synthesized in great density.With rods closely packed together it is difficult to extract and study a single one.The InN nanorods in this project are about 250 nm in diameter and 1.5 micrometers long. CNS staff

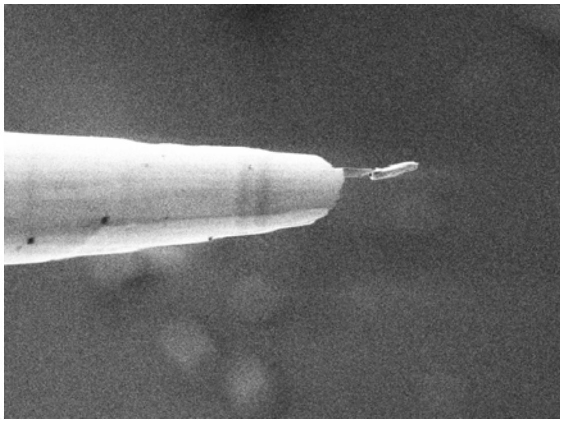


Figure 73; Nanorod on FIB-enclosed nanopositioning tip.

member Nicholas Antoniou demonstrated a new process for nanorod extraction using our Autoprobe 300 nanoprobe embedded within our FIB (Fig. 73).Using this process he was able to extract individual rods from the “forest” of other rods.Following extraction, the rods were sectioned thecharacterized by AFM.Key to his ability to capture these small rods was a sharpening process for the nanotip.By rotating the tip in situ Nicholas was able to sharpen a tip to about 10 nm and then use Van der Waals forces to pick up a single rod.

Nanopore research continues as a strong topic at CNS and the Meller group from BU is one of the more active in this area.Having previously demonstrated their ability to fabricate nanopores in freestanding silicon nitride (SiN) membrane using a focused electron beam, the team is now moving on to demonstrating applications including the use these pores for novel optical DNA sequencing.Pore sizes in the diameter range 4-5 nm are used because they guarantee unfolded DNA entry and slower transport than larger pores. This membrane is assembled between two miniature fluid chambers and hydrated. When a positive bias is applied across the SiN membrane, negatively charged DNA molecules are captured and linearly threaded through the nanopore.Once unzipped by squeezing through the pore, the nucleotides can be optically identified.This process can be readily scaled to multi-pore readout.

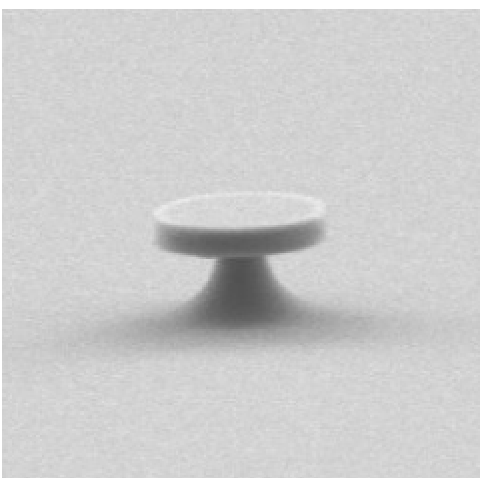


Figure 74: Brown University microdisc resonator.

In another project related to disc resonators, the Xu group from Brown studied silicon microdisks studied fabricated to be smaller than the free-space wavelength of light being stored in the cavity in all spatial dimensions and are much smaller in the axial dimension (Fig. 74). Following fabrication in the CNS cleanroom, these structures were probed with tapered fiber spectroscopy.

Patterned substrates have emerged as a frequently recurring experimental platform.Patterning is typically achieved using PDMS or PMMA on common substrates such as glass.Current projects employing these engineered surfaces include mechanical studies of confined cells (Parker et al), improved silicon solar cells (Mazur), wetting and evaporative properties of liquids, and studies of biofilms and biofouling.Research teams active in patterned substrates include several from Harvard, neighboring hospitals, BU, and MIT particularly the mechanical engineering department.An interesting industrial client active in this area is California-based Teledyne Technologies which is a leading provider of sophisticated electronic components, instrumentation, and communications and control products. Teledyne is exploring patterned substrates as a remote user of the CNS cleanroom and Soft Lithography Foundry. To date, four CNS staff members worked remotely on the design and fabrication of the Teledyne.

Progress by our other industrial clients also continued during the past year.Massachusetts-based Pixtronix continues to develop their MEMS based display technology and presented an update on their results at a SPIE meeting this year titled: “Digital Micro-Shutter Display Technology: a MEMS Display for Low Power Mobile Multimedia” Several other start-ups continued to use CNS laboratories to develop technologies for renewable energy applications, notably LumenZ and Draper Labs spin-out MTPV.Other technical areas pursued by our industrial clients were IR imaging arrays (QMagiq LLC), energy storage (Lilliputian), conformal CMOS (MC10), MEMS (Analog Devices), displays (eInk – supplier for the Kindle) and biotechnology (Semprus Biosciences). New large companies using the facilities during this period include Lockheed, Paratek Microwave, and a newly opened Pfizer research technology center (RTC).

### 7.4.3 Facility and Operations Highlights

The capabilities of the CNS facility were expanded through the establishment of a new Soft Materials Cleanroom (SMCR) specifically dedicated for microfluidic and soft-lithographic processing.The SMCR opened in May 2010. This class 10,000 cleanroom was purposefully designed and equipped for those users who fabricate devices using “soft” materials such as silicone elastomers, plastics, and gels - materials that are not typically allowed in standard cleanrooms. The SMCR is adjacent to the main CNS cleanroom and hosts all the tools, equipment and chemicals needed to do SU-8 photolithography and soft lithography. It serves as the “one-stop-shop” to CNS’ microfludics and lab-on-a-chip community.SMCR’s tools and capabilities include an AB-M mask alignment/exposure system, three wet benches (one spin-coating and the other two for solvent and acid/base processing), Nikon SMZ100 stereoscopic microscope, hotplate tower, curing oven, Thinky centrifugal mixer/degasser, Anatech oxygen plasma barrel etcher, vacuum and silanization chambers.

CNS infrastructure was also improved when an updated instrument interlock and management system was deployed during this past year.The new “CNS Laboratory Equipment Access Network” (CLEAN) access management system provides improved scheduling and usage-reporting capabilities, including enforcing scheduling policies, flagging no-show events, and generating electronic invoices.CLEAN can manage access to laboratory instruments either using electrical or software interlocks depending on instrument operation.The web-based system is explicitly architected from open-source scripting languages and databases (PHP and MySQL), and the interlocking circuitry is developed from off-the-shelf Ethernet controlled modules and commercially available electrical devices.This system was presented at the UGIM2010 meeting at Purdue University in July.

### 7.4.4 Equipment Highlights

During this review period several new instruments were added to the CNS portfolio, three through ARRA funding.The first ARRA-funded instrument was a Seki Technotron **diamond CVD system** which supports our rapidly increasing number of diamond-related research projects (Fig. 75).The AX5010 deposits diamond films and micro or nanocrystalline material on substrate areas up to 1” in diameter.This new deposition system is fully commissioned and high quality films have already been demonstrated.

*Figure 75: New diamond CVD system at Harvard site.*

The second ARRA-funded acquisition - our new OAI LS 30 **UV exposure system** - was recently commissioned in our Soft Lithography Foundry.This new system has a 350 W near-UV light source which provides a highly collimated and uniform beam of 6" diameter and divergence half-angle of less than 2.6 degrees. Its intensity and exposure time is operator-adjustable over a wide range. This system is very suitable for doing single-layer photolithography at relatively low-resolution for fabricating microfluidic devices, and for researchers wanting to fabricate structures with feature sizes on the order of tens or hundreds of micrometers.In addition, this system is able to expose photocurable polymers which are widely used in soft lithography techniques such as replica molding (REM).

The third ARRA-funded instrument acquired this year was an additional **sputter system**.This three-target system supports both DC and RF sputtering and provides much-needed additional capacity (supplementing our existing 6-target load-locked system) as well as greater flexibility with regard to target changes.

Beyond the ARRA-acquired instruments, several new instruments were added to the CNS portfolio through donation or direct university purchase and are listed below:

*Figure 76: Ice crystal formed on FIB cryostage.*

- **Cryo Stage**Beyond the previously mentioned nanoprobe, our focused-ion beam (FIB) systems has been expanded with the recent addition of a new Leica cryostage system (Fig.. 76).This Leica EM VCT100 Vacuum cryo stage system allows ion patterning and imaging of soft materials solidified by cooling.This system has a cryo transfer system allowing samples to be transferred in high vacuum conditions between the FIB and a BalTec preparation instrument. The specimen temperature range is from -150 C to 50 C. Applications include manipulation of soft materials such as polymers and fragile biological specimens.

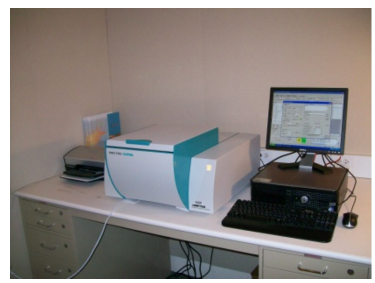


*Figure 77: XRF system.*

- **XRF Spectrometer**A Spectro XEPOS Benchtop XRF was commissioned and is now used for the elemental analysis of solid, liquid or powder samples at atmospheric pressure (Fig. 77).
- **NanoIndentor** CNS commissioned a new MFP NanoIndentor on one of our existing Asylum AFMs.This nanoindentor addresses the following growing research requirements: a) indentation measurement including hardness, elastic behavior and stress for “traditional material” such as metals, ceramics, semiconductors and polymers;b) study ofmechanical behavior of soft and biological material, where low force loading is required (<~1uN); c) controllable scratching /patterning applications.
- **Constant Temperature Bath** This system was added to the Nanoparticle Facility to provide a stable environment for viscosity measurements of diluents of nanoparticle suspensions.
- **Confocal Microscope** This year CNS received another equipment donation from Intel, a Zeiss 310 CLSM confocal microscope. New hire Dr. Arthur McClelland will be commissioning the system in early 2011.

### 7.4.5 Staff Highlights

In the past year CNS has expanded our technical team and hired a replacement optical microscopist, metrology engineer, and sample preparation scientist.In the cleanroom team, Dr. Jiangdong Deng was promoted to the position of Nanofabrication Manager with oversight responsibility for the CNS cleanroom. Assuming some of Jiangdong’s previous responsibilities, Jason Tresback joins us as our new Senior Metrology Engineer and will be the technical lead for both cleanroom metrology and our AFM systems.He has master’s degrees in Materials Science from both U. Connecticut and the Ohio State University. He most recently has been employed in the LED industry and he brings over five years of lithography, deposition, etching and metrology experience to CNS, where he was an active user since 2008.

Dr. Arthur McClelland joins us at our new optical micoscopist, and will oversee our confocal microscopy and laser illumination facility.He has extensive hand-on experience with lasers, optical setups, spectral analysis systems, and non-linear optical techniques.Dr. McClelland has a Ph.D. in Applied Physics from the University of Michigan.

Carolyn Marks joins us as a replacement Sample Preparation scientist, and Adam Graham has joined us as a senior technician.

### 7.4.6 Education and Outreach

Beyond training and technically supporting our very large population of NNIN users, CNS staff members continued to support both broad educational activities and public outreach during the past year.Representative events are listed below.

*Figure 78: Visiting middle school students view laboratory demonstration.*

CNS staff member Olivia MacPherson participated in an NNIN outreach event at last year's Society of Hispanic Professional Engineers (SPHE) meeting in Cincinnati, OH.In January, CNS hosted a group of 40-50 Cambridge public school 7th graders.These students visited as part of a local Project TEACH to learn about experimentation in our cleanroom.In October, another group of middle school students from Maryland were on site for demonstrations and discussions. As in years past, this June CNS staff conducted orientations and presentations for the 60 visiting undergraduate REUs who were on campus.These students were largely beyond the five supported directly by the NNIN program and included those supported by our campus NSEC and MRSEC. Subsequent to this orientation, many of these students conducted research activities in the CNS laboratories as part of their REU projects.

During summer months, nanofabrication staff members presented a public and free series of 10 instructional sessions (Nanofabrication Summer School) on cleanroom/microelectronic/nanoelectronic processes, including photolithography, RIE, CVD, e-beam lithography, mask design, metrology, packaging process and cleanroom facility.

Several formal courses for non-Harvard students were instructed by CNS staff members were conducted in CNS laboratories and coordinated by the Harvard Extension School.These courses are typically held in the evenings as continuing education for the local community and do not require an application.During summer 2010, CNS Materials Facilities manager Dr. Fettah Kosar taught a 7-week-long summer course titled "Introduction to Fabrication of Microfluidic and Lab-on-a-Chip Devices", which was fully enrolled at 15 students. The course covered the field of miniaturization of pharmaceutical, biological, chemical, and biomedical assays. It served as an introduction to the facilities, tools and techniques used for the fabrication of microfluidic and lab-on-a-chip devices and reviewed some of the latest advances in this field.During the 2010 Fall semester, CNS managers Dr. Jiangdong Deng and Dr. David Bell taught a course "Nanofabrication and Nanoanalysis' also through the Harvard's Extension School. This laboratory course explores the concepts of nanotechnology through classic nanofabrication and nano-analysis. Through fabricating real devices in the cleanroom students learned the complete sequence in the nanofabrication process from CAD design to fabricated structure.Included in this process flow were photolithography, thin-film deposition, etching, and basic metrology and characterization. Several analysis techniques are applied to the devices and structures which were fabricated in class.Other continuing education classes conducted this year in a similar manner were "Introduction to the Fabrication of Microfluidic and Lab-on-a-Chip Devices", and "Nanoscale Optics with Applications in Biotechnology."

Dr. Fettah Kosar also went off-campus to the University of Notre Dame in order to teach microfabrication, soft lithography and microfluidics techniques to a group of students during a 2-day course. This course had classroom and laboratory components. It was received very well and will be repeated in an expanded manner next year.Dr. Fettah Kosar supported the very popular Harvard General Education science course, “Science and Cooking: From Haute Cuisine to the Science of Soft Matter” in the Fall of 2010, by helping students image their creationsfor their projects using the X-ray MicroCT system located at CNS.

Again this year CNS conducted a very significant program of more than 40 free and public events and seminars.These events are regularly attended not only by NNIN users but also by non-NNIN-affiliated individuals who are able to attend in part because of Harvard’s central location in a very dense environment of educational and technical institutions. Early in 2010 we presented“Particle Characterization Workshop: How Light Scattering Techniques Influence Particle Design and Engineering". This one-day event included two seminar presentations by visiting researchers: "Engineering Semiconductor Quantum Dots for Molecular and Cellular Imaging"; and "Particle Characterization by Light Scattering Methods").In April of 2010, CNS co-hosted a public meeting on focused ion beam techniques particularly FIB 3D Nanotomography. In May the CNS Materials Group hosted an open seminar titled “CellSurgeon and TissueSurgeon: Utilization of Femtosecond Lasers to Manipulate Cells and Tissues in 3D” and given by a guest speaker from Germany, Lothar Grammeman from Rowiak GmbH. 50 attendees were present at this seminar.

In November, 2010 CNS organized and hosted nanotechnology event attended by about 100 guests. At this ““Advances in Nanotechnology Instrumentation” event nine guest speakers presented the state‑of‑the‑art technologies and instrumentation facilitating nanotechnology research. The topics included Multifrequency Atomic Force Microscopy, Nanoparticle Characterization, Infrared and Raman Microscopy, Atom Probe Tomography, Focused Ion Beam, Surface Analysis Techniques and Raman Spectroscopy, and X‑Ray Nano‑Computed Tomography.In September CNS hosted a workshop in Nanoindentation with ~100 participants including several from out-of-state.In the first day of the workshop, 10 scientists from NIST, Harvard, MIT, Brown University, and Asylum Research gave talks on the latest advances and research being done in nanomechanics—from cell mechanics to semiconductor characterization. The second day of the workshop included a half day of equipment demonstrations and imaging techniques on CNS AFM systems. This event was videotaped and available for streaming from our public website.

Other topics during the year included “Droplet-based Microfluidics” (>90 attendees), “Spins and Charges in low Dimension.”, “Silicon Energy”, and Cryogenic sample preparation.In the autumn of 2010 two public training sessions on basic vacuum technologies were presented. The first of these was an “Introduction to Vacuum Systems”, attended primarily by more than 60 graduate students from on and off campus and industrial engineers.The second was on “Practical Physical Vapor Deposition” was attended by ~40 researchers.In June, CNS co-hosted the 7$^{th}$ Annual Coherent Raman Microscopy Workshop covering Coherent anti-Stokes Raman scattering (CARS) and Stimulated Raman Scattering (SRS) microscopy allow noninvasive 3D imaging of living cells and tissue based on the vibrational contrast intrinsic to molecular species.This workshop included staff-led laboratory demonstrations in the CNS confocal facility.

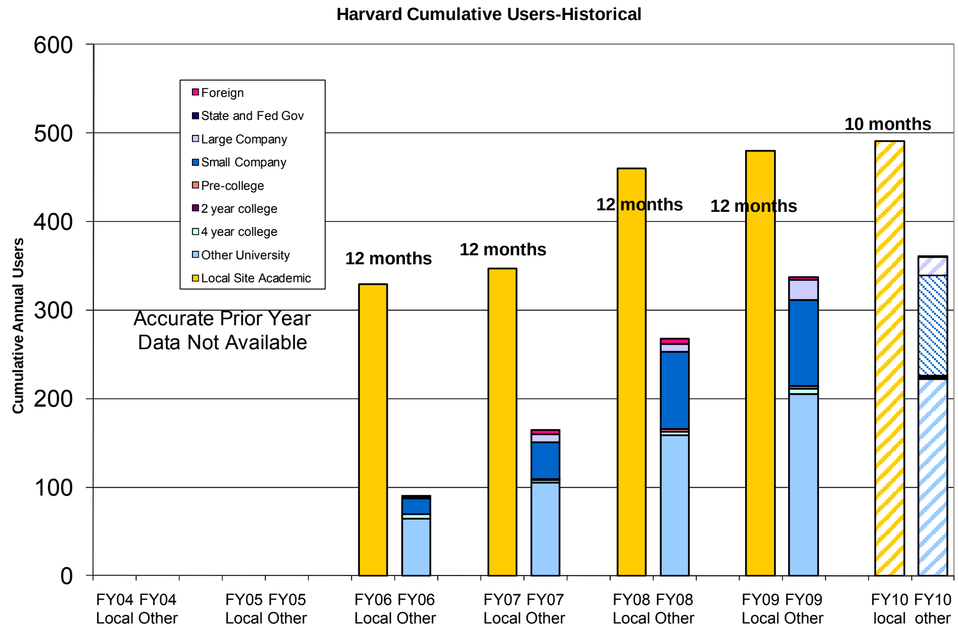
### 7.4.7 Society and Ethics

John Sweeney, CNS Health and Safety Officer, and SEI trainer attended the Cornell SEI follow-up workshop in October 2010 with other NNIN consortium members.The focus of this workshop was on "Implementation and Impact."Based on discussion from this meeting and the SEI coordinating meeting the previous January, John has reformatted and improved SEI training that all CNS enrollees are required to complete.

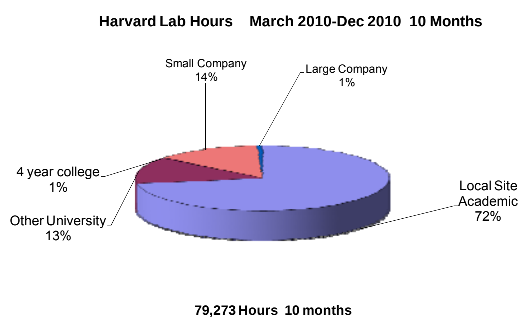
--End of Harvard Text Report---

## 7.4.8 Selected Harvard Site Statisitcs

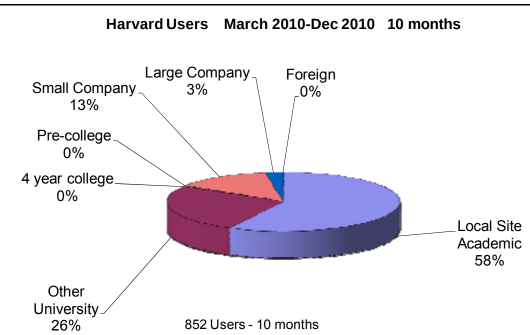
a)Historical Annual Users



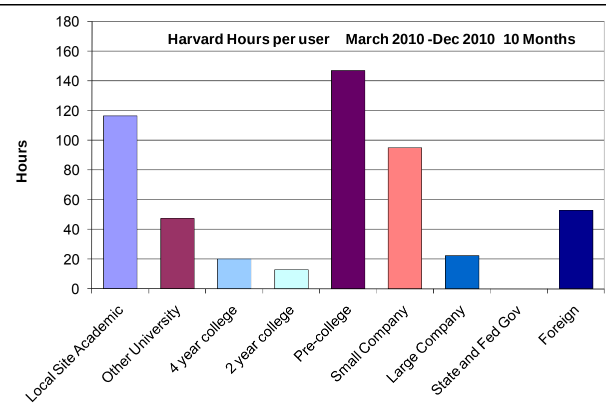

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

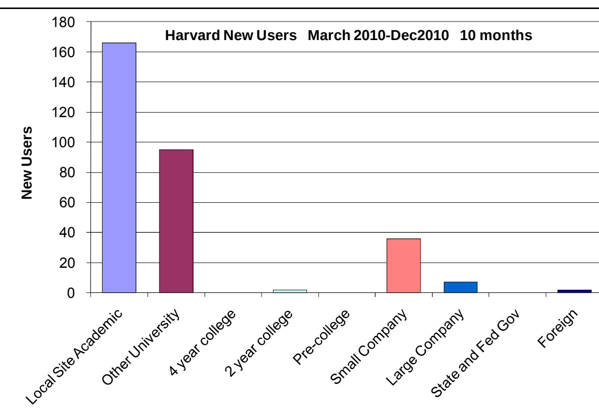



*Figure 79 Selected Harvard Site Statistics*

## 7.4.9 Harvard Site User Institutions

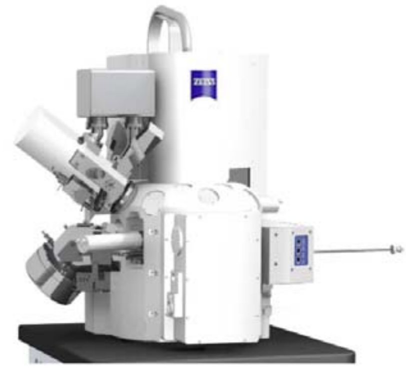
| **Harvard Center for Nanoscale Systems** | | |
|---|---|---|
| **Outside US. Academic** | **Small Companies** | **Large Companies** |
| Arizona State University | 1366 Technologies | Analog Devices, Inc. |
| Boston College | Agiltron | Dow Chemical Company |
| Boston University | Applied NanoFemto Technologies | EMD Chemicals, Inc. |
| Brown University | Arradiance, Inc. | Lockheed Martin |
| Bunker Hill Comm. College | Arsenal Medical | Morpho Detection |
| Cornell University | Bandgap Engineering | Technic, Inc. |
| CUNY /CCNY | Boston Micromachines | Teledyne Scientific |
| Florida International U. | Boston MicroSystems | Varian Semiconductor Eq. |
| MIT | Brunswick Laboratories | |
| Mount Ida College | Chemicro Engineering | |
| Northeastern University | Custom Nanotech, LLC. | **International** |
| Seton Hall University | Davol, Inc. | Saint-Gobain R&D |
| Stanford University | DNA Medicine Institute | University of Toronto |
| Truman State University | E Ink Corporation | |
| Tufts University | FastCAP Systems Corporation | |
| Tulane University | Giner Electrochemical . | |
| UCLA | GVD Corporation | |
| U C-, Santa Cruz | HabSel, Inc. | |
| University of Connecticut | Hybrid Silica Technol. | |
| University of Delaware | Hyperion Catalysis Int. | |
| University of Florida | LightSpin Technologies, | |
| U. Massachusetts, Amherst | Lightwave Power, Inc. | |
| U. Mass., Dartmouth | Lilliputian Systems, Inc. | |
| U. Massachusetts, Lowell | Living Proof, Inc. | |
| U. Medical School | Lumarray, Inc. | |
| University of New Mexico | LumenZ, Inc. | |
| University of Puerto Rico | MC10, Inc. | |
| University of Rochester | Mears Technologies, Inc. | |
| University of Texas, Austin | Microscale, Inc. | |
| University of Virginia | MTPV, LLC. | |
| Worcester Polytechnic | NABsys, Inc. | |
| Wright State University | Nano-Terra, LLC. | |
| | Nantero, Inc. | |
| | New England Analytical | |
| | Optron Systems, Inc. | |
| | Paratek Microwave, Inc. | |
| | Photonic Glass Corporation | |
| | Pixtronix | |
| | Qmagiq, LLC. | |
| | Quanterix Corporation | |
| | Radiation Monitoring Devices, Inc. | |
| | Sand 9, Inc. | |
| | Semprus Biosciences | |
| | Sionyx, Inc. | |
| | Solid State Scientific Corporation | |
| | TIAX, LLC. | |
| | Trelleborg Offshore Boston, Inc. | |

*Figure 80: Harvard User Institutions*

## 7.5 Howard University Site

### 7.5.1 Overview

*Figure 81 Auriga Dual Beam FIB*



The National Nanotechnology Infrastructure Network (NNIN) has changed the model for user based research facilities in the US. The Howard Nanoscale Science and Engineering Facility (HNF) has been the vehicle Howard has used to increased activity in this area and has lead to a third year of the Howard University Program for the Expansion of Research and Education in Nanotechnology (HUPEREN). This year of funding under this program (HUPEREN) has include a major piece of capital equipment ( SEM/FIB Auriga from Carl Zeiss @1.5 million), funds for new faculty in the area of nanotechnology, lab fees for Howard faculty interested in using HNF, and small renovations of HNF.A picture of the Auriga is shown (Fig. 81). The AURIGA™ the new CrossBeam® Workstation (FIB-SEM) from Carl Zeiss SMT delivers on the nanoscopic scale. This funding will allow departments in chemistry, physics, biology, engineering and the medical school to work on nanotechnology research that is multi-disciplined in nature and expand the university's nanotechnology equipment and capabilities.

### 7.5.2 Progress in Attracting New Users:

The HNF staff is quite aware of their mission to bring in outside users. This year we have had over a 200 users as of January 2010. This represents a 15% increase in the number of users (this is with the cleanroom shutdown for one month to add a new laboratory fume hood). We believe that with the additional equipment and resources from HUPEREN, HNF will also add to the number of users. Three additional programs in the area of nanotechnology have been funded including the Center for Environment Implications of Nanotechnology with Duke University, Carnegie Mellon University, Howard University, and Virginia Tech University. Howard has also been rewarded an NSF-Integrative Graduate Education and Research Traineeship Program (IGERT) and the Fellowships for the Sloan Foundation for graduate students in the area of Chemistry, Electrical and Computer Engineering, Chemical Engineering, and Mechanical Engineering.

HNF is working actively to advertise and market to outside users from various populations and regions.We have been working with the Washington DC Small Business Development Center at Howard University and The Institute for Entrepreneurship, Leadership, and Innovation (ELI). Howard University became one of eight institutions selected by the Ewing Marion Kauffman Foundation to receive a multi-million dollar grant, as part of its Kauffman Campuses Initiative to develop an entrepreneurial climate across campus.These potential users include private companies, government labs and other universities in the area and the nation though NNIN. (The statistics show the addition of several small business users and with the new clean space we are sure this number will increase in the next year.) Some of the new users this year include:

- NASA-Goddard Space Flight Center
- NIST- CMOS Devices & Reliability Project Semiconductor Electronics
- Division
- University of Michigan
- Harvard University
- Epitaxial Technologies, LLC
- University of South Florida
- Northfolk State University

- University of Minnesota
- George Washington University
- Mercer University
- Center for Aesthetic Modernism

### 7.5.3 Staff

The staff support by HNF during 2010 include the following:

| Name | Title | % NNIN support |
|---|---|---|
| James Griffin | Lab Manager | 25% |
| Tony Gomez | Support Technician | 100% |
| Crawford Taylor | Research Associate | 100% |
| Tina Brower, Ph.D. | Post-Doc | 0 % |
| Maoqi HE, Ph.D. | Senior Research Associate | 0 % |
| William Rose, Ph.D | Senior Research Associate | 100% |
| Chichang, Zhang, Ph.D. | Post-Doc | 0 % |
| Andy Hai Tang | Associate Lab Manager | 0 % |
| Jude Abanulo, Ph.D. | Post-Doc/Lecturer | 0 % |

### 7.5.4 Education

HNF has an impressive portfolio of educational activities across K-Grey, both formal and informal.One major addition this year is the **NanoExpress**. **The NanoExpress** presents the complex and fascinating world of nanotechnology to the general public from K-Grey. The campaign was designed to provide information on the current state of research and development potential in nanotechnology. It also aims to promote the dialogue between the world of science and the general public. **The NanoExpress** is a trailer with a lithography area, 208 square feet of lab space and undergraduate and graduate lab assistants who help supervise hands-on experiments (Fig. 82). **The NanoExpress** touched over *8,911*visitors and experimenters this year. Experimental areas include: Introduction to Passive Nanoparticles, Introduction to Self Assembly, Introduction to Micro and Nanofabrication, "Chips are for Kids", Instruments for NanoScience and Technology and Shape Memory Alloys.The university purchased a new truck for the NanoExpress and WHUR the provided a new look. This year at the US Science and Engineering Festival we had over 3000 visitors during the two events.

*Figure 82; Nanoexpress*


The NanoExpress was on the road for more that 40 days this year. The lectures and laboratory format has been very well received at elementary, junior and high schools (15), two year college and universities (6), adult groups, national conferences, museums, etc. The highlight of the 2010 Nanoexpress program was the spring visit to nearby Gallaudet University, the nation's foremost institution for deaf education. As part of the program, Prof. Henry Snyder added under-titles to the Silicon Run video. The producers gave permission for the under-titling and received a copy of the final product experiments.

Working with our Research Experience for Teachers **(RET)** program we have develop two new labs, developed several excel-lets (interactive Excel spreadsheets), a "new' nanotechnology badge for Boy Scouts and a nanotechnology patch of Girls Scouts. The badge and patch are in the process of being approved for the fall 2011.Dr. Harris has also been working with a former student to develop 'The

NanoCard' an application for the iPhone about the various NNIN nodes and nanotechnology in general. The completion date is Fall 2011.

### 7.5.5 New Equipment

The NNIN mission is to "enable rapid advancements in science, engineering and technology at the nanoscale by efficient access to nanotechnology infrastructure". These missions are being accomplished by providing open shared facilities and the HNF site has provided some free users time to "get researcher hooked". The results of these experiments are not in yet but we hope this along with additional equipment will attract new users. New major equipment acquired during the year include:

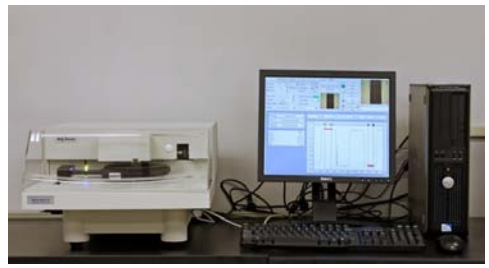


*Figure 83: Alpha Step*

**KLA-Tencor Alpha-Step IQ Profilometer -** The Alpha-Step IQ Profiler is a computerized, high-sensitivity surface profiler that measures roughness, waviness, and step height in a variety of applications(Fig. 83). It features the ability to measure micro-roughness, with up to 1Å (0.004 µin.) or less resolution, over short distances as well as waviness in a scan over a full surface length of 10-mm (0.4-in.). The computer offers powerful measurement control, data storage, analysis, and networking. The Alpha-Step IQ provides the following features:• Measurement of vertical features ranging from under 100 Å (0.4 µin.) to approximately 0.4mm (15.7 mils), with a vertical resolution of 0.012 Å or 0.24 Å respectively. A 2 mm extended range option is also available at a resolution of 1.19 Å. The horizontal resolution is only limited by the stylus radius and not by the number of data points. However, the minimum spacing between two data points is 0.01 µm. Measurement of many roughness and waviness parameters with roughness and waviness separated by user-selectable cutoff filters. Ability to fit and level data, allowing accurate measurements on curved surfaces. Ability to repeat a scan up to ten times and automatically calculate the average, thereby minimizing the effects of environmental noise on measurements. Accommodation of samples up to 150 mm (6 in.) wide and 21 mm (.83 in.) thick. Funded by NSF-ARRA.

*Figure 84: SCS6800 Spin Coater*

**SCS 6800 Spin Coater**: Features of the SCS 6800 Spin Coater Series include: Precise control of spin speed and acceleration/deceleration rates• Easy-to-use three-button keypad and LCD display on the front panel• Clear cover features a dispensing slot and safety interlock• Non-programmable model (8-inch) can store and execute a single recipe with up to four steps • Programmable models (8- and 12-inch) can store and execute up to three recipes with eight steps each •Optional features, such as a foot pedal, external software and an automated dispense system, are available on programmable models. Two of these units were funded by NSF-ARRA

*Figure 85: OAI Mask Aligner*

**OAI Model 800 Mask Aligner**: The **Model 800** is an optical topside and an optical and IR backside aligner(Fig. 85). The Model 800 can be configured with a 365nm UV light source or a 265nm deep UV light source by simply changing the mirrors and objectives. The mask aligner tooling can accommodate substrates up to 3-inches square, and the wafer chuck is positioned to allow for easy loading and unloading. Built on a vibration isolation platform, the fixed mask holder assembly guarantees alignment accuracy and repeatability. The operation is simplified using the easy-to-read, PLC touch-screen. Training time is short, an operator can learn to use the alignment tool effectively in than one hour. Funded by NSF-ARRA.

**Horiba DT-1201 ElectroAcoustic Spectrometer-**The DT-1201 AcoustoPhor Acoustic & ElectroAcoustic Spectrometer measures both particle size and zeta potential of concentrated colloids, suspensions and emulsions. It offers unparalleled analytical capabilities for advanced dispersion characterization of even complex sample types at process concentrations. The DT series of instruments use acoustic and electroacoustic spectroscopy to characterize a wide range of concentrated materials without dilution, thus providing meaningful results for real- world samples.

*Figure 87: ElectroAcoustic Spectrometer*

**JOEL JSM-7600F Scanning Electron Microscope-**The JSM-7600F is a state-of-the-art thermal FE-SEM that successfully combines ultra-high resolution imaging with optimized analytical functionality. In addition, the JSM-7600F incorporates a large specimen chamber. This uniquely designed chamber, which accommodates a 200 mm diameter specimen, is optimized for a large variety of detectors for secondary electrons, backscattered electrons, EDS, WDS, EBSD, CL, etc. Features •Ultrahigh resolution comparable to the cold cathode FE-SEM. •In-Lens Thermal FEG. •Aperture angle control lens automatically optimizes the spot size at both high and low currents for both analysis and imaging. •High probe current up to 200 nA (at 15 kV) for various analytical purposes (WDS, EDS, EBSD, CL, etc.) •Built-in r-filter enabling user selectable mixture of secondary electron and backscattered electron images. •Gentle Beam mode for top-surface imaging, reduced beam damage and charge suppression. •Eco design for energy conservation. Funded by NSF-ARRA

*Figure 86: JEOL SEM*

**Oxford INCA Energy Dispersive Spectroscopy- X-Max Large Area EDS SDD – now with NEW 124eV sensor:** The new X-Max Silicon Drift Detector (SDD) offers users over TEN times the solid angle of conventional EDS detectors without compromising on performance. Now you can have count rate, imaging, and analytical performance all at the same time.

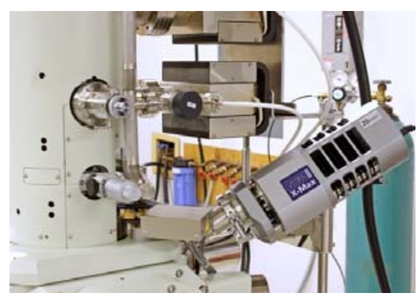


*Figure 88: Oxford INCA EDS detector*

Benefits include

- Proven accuracy at high count rates AutoID and quant are correct at 200,000cps
- The best sensitivity for light element analysis •Combines largest area with best resolution•The performance needed for analyzing smaller Nanostructures Maximizes X-ray collection under fine probe conditions
- The capability to analyze the most difficult samples
- Minimizes sample damage and contamination•And its backed by tested Inca Energy software for ease of use to achieve the right results.

Features include

- Unique single sensor large area SDD sensors •Up to 80mm² active area (100mm2 sensor size)
- Count rates > 500,000 cps •Throughput > 200,000 cps
- MnKα guaranteed @ 124eV, CKa guaranteed @ 48e
- Optimised electron trap •Vacuum enclosed sensor to reduce oxygen absorption
- Only one pulse processing channel required
- Standard tube diameter (no larger than that of a 10mm2 SDD detector) •Motorised slide as standard
- Pile up correction software for accurate analysis at high count rates.

This purchase was funded by NSF-ARRA

*Figure 89: Multipurpose Titrator*

**Malvern Instruments MPT-2 Multi-Purpose Titrator**-The MPT-2 autotitrator is an optional accessory compatible with all members of the Zetasizer Nanoseries. It is designed as a sample preparation station to automate changes in the sample conditions between measurements of size, intensity and zeta potential. The sample conditions that can be changed are: pH, conductivity, the concentration of an additive and the sample concentration. Funded by NSF

### 7.5.6 Nanotechnology Seminar Series

The Howard Nanoscale Science and Engineering Facility sponsors a monthly Nanotechnology Seminar Series. The seminar schedule are submitted to the ScienceNeta local internet newsletter sent to the Washington area science and engineering community. The series is sometimes co-sponsored with other organizations on campus. The following is a list of seminars in 2010:

- "*Fabrication and Characterization of Semiconducting Oxide Nanomaterials Using Horizontal Vapor Phase Growth Technique*," Dr. Gil Nonato C. Santos, Physics Department, De La Salle University, Taft Ave. Manila
- "*Japan's R&D strategy of nanotechnology and 4th Science and Technology Basic Plan (FY2011-2016)*", Dr. Toshio Baba, Director for Nanotechnology, Materials, and Monodzukuri Technology, Bureau of Science, Technology and Innovation Policy, Cabinet Office,
- "*Nanoimmunoliposome delivery of superparamagnetic iron oxide markedly enhances targeting and uptake in human cancer cells in vitro and in vivo*", Matthew D. Harmon, University of Connecticut/Howard University College of Medicine
- "*Nanotechnology: The Next Big Thing*", Gary L. Harris, Howard University, Howard Nanoscale Science and Engineering Facility
- "*MEMsPro*", Mary Ann Maher, Soft MEMS
- "*Smart Light*", Smart Lighting Engineering Research Center," Dr. Kenneth A. Conner, RPI
- "Origins of Medicinal Remedies in America: The Encounter between Africans and American Indians in the New World", Dr. Eloy Rodriquez, Professor and Research Scientist from Cornell University, co-sponosor with NSF-CREST & HHMI Scholars

- "Cancer Vaccines Targeting Malignant Brain Tumors: Opportunities for Advancement using Nanotechnology", Duane A. Mitchell, M.D., Ph.D. , Associate Director, Duke Brain Tumor Immunotherapy Program, co-sponsor with NSF-CREST
- "Multifunctional Fibers via Manipulation of Nanoscale Phenomena", Dr. Juan Hinestroza, Assistant Professor of Fiber Science at Cornell University, co-sponsor with HHMI Scholars
- "Nanoplatform-based Molecular Imaging,"Laboratory of Molecular Imaging and Nanomedicine (LOMIN), NIH National Institute of Biomedical Imaging and Bioengineering (NIBIB), Xiaoyuan (Shawn) Chen, Ph.D
- "Spintronic and electronic transport properties in graphene", Kyle Pi, University of California-Riverside, Department of Physics,, co-sponsor with John Hopkins University
- "Thermally Driven Sensitive Surface Phonon Polariton Modes in Thin-Film SiC", James Harmonds, Mechanical Engineering, Howard University

### 7.5.7 Renovations of HNF

The following renovation were funded under the Howard University Program for the Expansion of Research and Education in Nanotechnology (HUPEREN):

| Item | Cost | Comments |
|---|---|---|
| Basment renvocationfor FIB HNF | $56,000 | * the lab was close for three weeks to make these repairs |
| New exhaust hood (3) | $48,000 | Required to keep lab safe |
| Special security system/door lock | $3,000 | Required to keep lab safe |
| chairs/lab tables | $12,700 | Needed |

### 7.5.8 Research Highlights

The main research thrusts for HNF are: Electronics and Materials - wide band gap devices and applications to nanotechnology. Characterization Science - the universally required tool for advancing research and technology across the physical, biological, materials and medical sciences and engineering disciplines. Nanofiltration membranes and technology **- m**embrane processes such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF), which have applications in the fields of biotechnology, food science, chemical engineering, medical applications like artificial kidneys and more recently, environmental engineering for the separation and concentration of organic and inorganic materials.

- **Solution-deposited oxide-based transistors: Tiffany Hall, Howard Katz, Joshua Halpern, Jason Matthews.;** Solution-deposited oxide-based transistors are promising for use in transparent active circuits, such as in displays and solar cells, and also for educational purposes, because of the opportunity for students to connect materials they actually handle with the performance of resulting devices. The Katz group at JHU has developed methods for using oxides as semiconductors and dielectrics in alltransparent, sol-gel processed transistors. In particular, indium zinc oxide (IZO) had been used as a transistor semiconductor, but with poor contrast between on and off states (low on/off ratio) and poor reproducibility of working devices. Also, aluminum had been used as an electrode material, which required inconvenient vapor deposition. Tiffany Hall, a Howard University undergraduate student, working under the mentorship of Jia Sun and Thomas Dwidczyk in the Katz group, achieved significant advances in this technology. She was able to make devices work with silver paste instead of aluminum electrodes. She increased the rigor of the substrate pretreatment by performing oxidative etching before applying the IZO precursor solutions. She introduced temperature ramping to the post-deposition drying and curing stages. The result was in increase in the yield of working devices and an increase in the on/off from 10 to 100. IZO grain sizes were doubled, correlated with the improved electrical properties. This procedure is now much more suitable for use in classroom activities, and is being field-tested in a spring 2010 junior level class. Research planned for the coming year includes measurement of the thermoelectric properties of the oxide semiconductors and study of solid state structural and diffusion properties of the semiconductors.

- **Samariam doped GaN nanowires, Maoqi He, J. Halpern, G.L.Harris, and Karina Moore:**Considerable time was spent working on growing samarium doped gallium nitride nanowires. Samarium is a promising magnetic dopant for gallium nitride. Its vapor pressure approaches that of gallium near 1000 °C which is the upper limit of our growth range. To our knowledge there has been no previous published work on Sm doped gallium nitride. Limited to no doping was observed without a catalyst. The best incorporation occurred when a drop of 0.05 M NiO was put on an $Al_2O_3$ substrate and the temperature ofthe furnace increased to 975°C for 60 min at 300 Torr. The nanowires are roughly comparable to wires grown without Sm doping, being wurtzite in character, with a diameter of about 150 nm. The composition of was measured by EDX in at Howard and Johns Hopkins (Sm was 1.06% by weight and 0.106 % by number). It has been hard to reduce the oxygen atom content. We always observe samarium oxide on the samarium source, even though we are using research grade carrier gases (99.9999%) and ammonia. We improved the vacuum system so that we now routinely reach $10^{-6}$ Torr and should shortly improve that by another order of magnitude.
- **ZnO Nanowires Growth, Maoqi He, J. Halpern, and G.L.Harris**: We have grown ZnO nanowires on Au particles by passing molecular oxygen over Zn metal. The growth system was the same as we use for growing nitrides. In a typical experiments, as shown about 1 g of Zn (6 9s pure) was put in a BN boat. Oxygen gas was passed over the boat at a flow rate of 2 sccm. Gold particles, about 2 nm across were used as a growth catalyst. They were placed on a Si substrate, which was located downstream between 10-50 mm from the Zn source. Both the Zn and the substrates were placed in quartz liner. The quartz liner was put in 1 m long quartz process tube, the center half of which was inserted into a tube furnace. The Zn was located at the center of the three zone furnace. After evacuation oxygen at 2 sccm and 10 sccm Ar used as a carrier gas flowed through the system. The temperature of furnace was raised to 870°C for 1 hour while maintaining the pressure at 10 to 15 Torr. Nanowires and combs were observed to grow only in the region where the gold particles had been deposited. The teeth on the combs are 100 nm to 200 nm in diameter and 10-15 μm long
- **Synthesis and Characterization of Graphene Materials and Films , R.D. Little and JW Mitchell**; The investigation of the synthesis and functional derivitization of graphene, a one dimensional nanomaterial, was continued using vigorous oxidation of graphite in highly corrosive acids and oxidizing mixtures of permanganate. Methods were optimized to preclude the formation of the previously observed emulsions. Repeatable synthesis of 0.25 to 0.5 gm quantities of graphine oxide is permitting collaborations with external research partners. Graphene has unique properties that pose great potential for the use of surface absorbate/surface interactions, and the exploitation of electric field effects at surfaces to advance the analytical characterization science of nanomaterials. Hosten's and Mitchell's groups are interested in the investigation of graphene influence on surface plasmon resonance enhancements in silver nanoparticlestructures and the enhanced vibrational detection of molecutes by SERS.

- **Graphene Oxide Normal Raman Spectra, R.D. Little and JW Mitchell;** The normal Raman (NR) spectrum of graphene oxide (GO) is available. Pure graphene is known to give a signal at ca. 1565 cm-1. When the order of graphene is disrupted the 1565 cm-1 signal exhibits a blue shift and a second band centered at ca. 1360 cm-1 appears. The G band is centered at 1600 cm-1, while the D band emerges at 1365 cm-1. The oxidation of the graphene to form GO introduced oxygenated functional groups (i.e. hydroxyls, epoxides) to the surface of the layer. The encircled bands at 891, 981, and 1054 cm-1 are in good agreement with literature values for C-O stretching of various compounds. The weak feature at 620 cm-1 is due to the C-C=C bending of the GO sheet. The spectrum labeled GO liquid is the NR spectrum of the aqueous storage solution atop the GO suspension. This shows no discernible features.
- **Charge and Electric Field Potential Distributions at the Surface of Silicon-Silver Nanocomposites and at Patterned Silicon Surfaces, Chichang Zhangand C. Bates:** Bates and Mitchell initiated fundamental studies and experimental scrutiny respectively of the surface charge and electric field distribution at surfaces of Ag-Si nanocomposites, doped silicon, and patterned silicon wafers. The ultimate goal targets controlling conditions to effect electrophoretic deposition (EPD)/separations of nanomaterials. Using the representative schematic for EPD, Bate's group explained the charge states at the surface of the patterned silicon cathodes and the flat metal anode to be dominated by a polarization charge density effect. In the case of the patterned wafers, electrical potential field distributions at the surface would occur, at some distance, d, between the two electrodes. Calculations of the dimensions of d where potential variations across the surface create forces sufficient to impact nanometer separations are pending. Complete surface characterizations of Ag-Si surfaces have been accomplished by Kelvin Probe and atomic force microscopy. The former technique is the most superior for the distinction between conductive and semi-conductor regions of a nanocomposite material. In Mitchell's group, experimental investigations of EPD at Ag-Si nanocomposite surfaces include direct depositions of Ag from nanoparticle dispersions in ethylene glycol. Direct correlations of Ag thickness with EPD are being investigated by AFM. Surface mapping of charge distribution by AFM is also in progress as a component of a MS student's thesis investigation.
- **Synthesis and Characterization Science of Nanomatter, R.D. Little and JW Mitchell;** Thorough characterization science must establish the chemical and physical status of manufactured nanomaterials for assessing their environmental and biological effects, and monitoring their transformation during controlled laboratory experiments that simulate environmental conditions within various ecosystems. Mitchell is engaging the chemical engineering synthesis and characterization science of nanomaterials for bionanomolecular and intracellular research. Silver nanoparticles, stabilized with different molecular functionalities, are chemically engineered at scaled levels under pristine atmospheric and aqueous conditions. The most suitable processes for generating biocompatible formulations are being examined. Few, if any, previous investigations have examined the mass action effect chemistry and chemical dynamics occurring over the long term in aqueous nanoparticle systems with the objective of controlling conditions for the preservation of chemical purity and physical stability. Following synthesis, even under precisely controlled conditions , a resulting multicomponent nanoparticle system is produced with a quasi chemical equilibrium existing between excess Ag+ and stabilizer, nanoparticle oxides of Ag2O, AgO, clusters of neutral silver nanoparticles Ag0NP, Ag2NP, mixed ionized and zero valent clusters Ag NG+, and mixtures of AgNP's with different molar ratios of the stabilizing molecule Ag(NP)x. The equilibrium state may also be process temperature sensitive. Research to determine the stability of silver nanoparticles in aqueous media is paramountly important in view of the rapid application of silver in commercial products. Following the Centers pivotal work in the synthesis, and characterization of extremely stable Ag, - NP's, work continues

to perfect quantitative techniques for measuring Ag, - NP's at 10-8 molar levels and below. Resonance light scattering investigations have examined all of the necessary factors impacting accurate measurements. Additionally, the most sensitive spectrophotometric methodology currently known for determining Ag + at ppb levels has been refined for determination of free Ag+ in prepared silver nano particle systems. The tetrabomophenathaline system is now used in the group for assessing the purity and percentage completion of chemical procedures to generate nanoparticles. The improved determination of Ag+ in nanoparticles formulation by application of the fluorescence enhancement of Cd sulfide quantum dots were investigated and completed.

- **High Resolution Field Emission Scanning Electron Microscopy of Nanomaterials, JW Mitchell;** Ultra high resolution (20nm) SEM micrographs of Ag PVP nanoparticles were obtained on a Zeiss SEM-FIB focused ion beam system to evaluate the instrumentation for acquisition by Howard University. Micrographs of synthesized silicon nitride nanowires in the corresponding nanopowder matrix were also acquired. The exceptionally clear micrographs elucidate the size distribution, physical homogeneity, and verified the solid-liquid-vapor growth mechanism of nanowires. Acquisition of a system is being pursued vigorously in collaboration with the Department of Biology.
- **Growth of $CuInGaSe_2$ Thin Film Solar Cells,** *Mpho Musengu , Bokani Mtengi , Gary L. Harris, James Griffin, Howard University;* Copper indium diselenide (CuInSe2) and copper indium gallium diselenide (CuInGaSe2) thin film solar cells deposited by spray pyrolysis are a low cost way to provide solar energy. Although they are relatively cheap to fabricate, they suffer from low efficiencies because of their small grain sizes. In this work we investigated the conditions of growth rate and temperature in order to obtain stoichiometric layers of these materials. We also investigated the conditions necessary to grow cadmium sulfide (CdS) by chemical bath to be use as the n-type contact for the solar cell. Finally, we sought to determine if grain sizes can be increased by rapid thermal annealing (RTA) of the grown layers. CuInSe2 films were grown on a soda lime glass substrate coated with 150nm of molybdenum at 250-300ºC for 30-60 minutes. Electron dispersive spectroscopy (EDS) data for CuInSe2 indicated the presence of all three elements. CdS films were grown in a bath of cadmium chloride and sulfur chloride at 70ºC. EDS on CdS indicates the presence of both elements in equal abundance. Scanning electron microscopy (SEM) and optical microscopy indicated uniform growth of CdS films but non-uniform growth for CuInSe2. Rapid thermal annealing CuInSe2 to increase grain sizes was inconclusive at temperature up to 500ºC.
- **Bismuth spin filter, Prof. Tito Huber, Ajibola Adeyeye, Patrice Jones, and Yakushia Hill;** Spin transport has generated much interest for applications such as storage, logic, and quantum computing. Our approach to spintronics is to exploit the spin-dependent transport inherent in mesoscopic structures and nanostructures that exhibit Aharonov-Bohm (AB) interference phenomena in the presence of a magnetic polarization can be intrinsic or be induced by an applied magnetic field. Such devices could also be useful for energy conversion because they imply unobstructed transport of entropy represented by the large degree of ordering inherent in a spin polarized current.
- **Analysis of unconventional recording techniques in magnetic data recording nanotechnology, Prof. Mihai Dimian, Cyril Acholo, Undergraduate, Electrical and Computer Engineering, Howard Unversity/ (Possible) Prof. Chia-Ling Chien, Johns Hopkins University, Dr. Mark Stiles, NIST;** Magnetic data storage is approaching its fundamental limits for areal storage density, aswell as for data processing speed. There is an urgent need for reliable alternatives to current magnetic recording media which are based on longitudinal thin film, and to the conventional mechanism of magnetization reversal based on damping switching.

Availability of alternatives, such as perpendicular magnetic recording (recently implemented for hard disk drives), heat assisted recording, precessional magnetization switching, and spin polarized current assisted switching give us confidence in the future but an intense research effort is necessary to bring these techniques to market.

- **Developments in Nanoparticulate Drug Delivery Systems for Cancer Chemotherapy: Emmanuel O. Akala, Oluyomi Okunola and Simeon Adesina: Department of Pharmaceutical Sciences, School of Pharmacy, Howard University;** A lot of progress has been made in the understanding of cancer biology and to design effective anticancer bioactive agents.However, at the moment, there is an imbalance between the knowledge of cancer biology and the success achieved in cancer treatment: efforts in the treatment of cancer have not met with much success. One of the main reasons for this situation is the inadequacies in the ability to administer bioactive agents so that they selectively reach the desired targets (cancer cells) with no damage to healthy cells. This limitation is also true of contrast agents for imaging applications. Thus to increase efficacy per dose of the therapeutic agent and contrast agent formulation, there should be efforts in the direction of targeting selectivity.
To help meet the goal of eliminating death and suffering from cancer by 2015, the National Cancer Institute (NCI) is engaged in efforts to harness the power of nanotechnology to radically change the way we diagnose, image and treat cancer. In developing a cancer nanotechnology plan, NCI identifies major challenge areas of emphasis. This work highlights the developments in cancer nanotherapeutics (from first generation to the third generation nanoparticles for anticancer drug delivery systems). The efforts of our research group in fabricating multifunctional polymeric nanoparticles.

- **Cancer Nanotechnology Center at Howard University, *Paul C. Wang, Biochemistry Department, College of Medicine, Howard University;*** Nanotechnology is expected to revolutionize the diagnosis and management of cancer and will ultimately lead to personalized medicine.A multipronged effort from basic scientists, engineers and clinicians will be necessary for fulfilling this promise. Howard University is a premier HBCU with a rich tradition of producing scientists, engineers and clinicians with Ph.D. and other advanced degrees. The Cancer Nanotechnology Center at Howard University for training highly skilled and motivated researchers to propel this exciting field forward and reap rich rewards for mankind. The center is in the early stages of its development and will be relying on the support of the HNF. There are several other schools involved including George Washington University, Catholic University (Biomedical Engineering), and several other HBCUs.

- **Device Fabrication and Characterization of GaN Devices, Stuart Mitchell,Technologies and Devices International Oxford Instruments Inc;** In this program, HNF provides support characterization and device fabrication for TDI. TDI, a wholly owned subsidiary of Oxford Instruments, is a world leader in the development of Hydride Vapour Phase Epitaxy (HVPE) processes and techniques for the production of novel compound semiconductors such as GaN, AlN, AlGaN, InN, InGaN. Using TDI HVPE technology, Oxford Instruments can produce templatesfor applications such as High Brightness Light Emitting Diodes (HBLEDs), Laser Diodes and High Electron Mobility Transistors (HEMT).

- **Center for the Environmental Implications of Nanotechnology(CEIN), Kimberly Jones, Civil and Environmental Engineering, Howard University;** The Center will address interactions of naturally derived, incidental and engineered nanoparticles and nanostructured materials, devices and systems (herein called “nanomaterials”) with the living world. Headquartered at Duke University, CEINT is a collaboration between Duke, Carnegie Mellon University, Howard

University, and Virginia Tech and investigators from the University of Kentucky and Stanford University.

- **Doping GaN Nanowires with Mn for Magnetic Applications, J.B.Halpern, C. Thomas, M. He, G.L. Harris and J. Griffin, Howard University;** Using Mn metal power as a Mn source, NH3, as a reactive gas and N2 as a carrier gas we have been able to grow and dope nanowires of GaN. The purpose of doping the GaN nanowires with Mn is to produce nanowires that are magnetic and can be used in spintronics. GaN and Mnpowder are heated for two hours at 850ºC. The length of the wires was measured with typical values between 20 to 200µm. the diameter of the wires range from 20 to 200nm. The flow rates ofthe gases, growth temperature and distance from the source will be presented in detail. EDS and local photoluminescence have been performed of the as grown samples. Over 5% on Mn was found in the GaN wires. The PL spectrum indicates the presentsof both GaN and a impurity level associated with Mn in GaN. We will also report on the structural, magnetic and electrical properties of these nanowires. This work is being supported by NSF under the Partnership for Research and Education in Materials Program.
- **The Growth of Silicon Germanium and Polytypes of Silicon Carbide Nanowires, G.L. Harris , J. Griffin, M. Lambert and J.B.Halpern, Howard University;** Silicon germanium (SiGe) has played an important role in the semiconductor industry because of it's inexpensive production and high power capabilities. Silicon carbide (SiC) has also played an important role due to its high thermal conductivity and wide energy band gap. In this work SiGe nanowires and polytypes of SiC nanowires were grown.Nanowire growth took place a horizontal chemical vapor deposition (CVD) reactor.Polytypes of SiC were grown on silicon substrates with nickel as a catalyst using 15sccm of propane (C3H8) and 50sccm of silane (SiH4).The polytypes were achieved by varying the temperature of the reactor during growth from 1050˚C to 1330˚C and holding for 15 minutes and from 1330˚C to 1050˚C and holding for another 15 minutes. By doing this we were able to change the phase of the nanowires from cubic SiC (3C-SiC) to hexagonal SiC (6H-SiC) and for some back to 3C-SiC.

### 7.5.9 Recent Publications for Users


1. "Hands-on Preparation and Testing of Solution-processed Semiconductor Devices in the Undergraduate Classroom" Jia Sun, Orla Wilson, Michael Reese, Byung J. Jung, Thomas Dawidcyk, Mingling Yeh, Bal M. Dhar, Bhola N. Pal, Phylicia Trottman, Ian McCue, Lily Berger, G. Ross Blum, Erik Heinemann, David McGee, Jonah D. Erlebacher, and Howard E. Katz. Journal of Materials Education (invited), 31, 271-284 (2009)
2. "Observation of three-dimensional behavior in surface states of bismuth nanowires and the evidence for bulk-Bi surface quasiparticles". T. E. Huber, A. Nikolaeva, L. Konopko, and M. J. Graf. *Phys. Rev. B* 79, 201304 (2009)
3. "Size Effects in Quantum Single Crystal Bismuth Wires in Glass Cover". D.V. Gitsu, T.E. Huber, L.A. Konopko, and A.A.Nikolaeva. *Journal of Nanoelectronics and Optoelectronics*, 4, 40-51 (2009)
4. "Bi nanowires: Magnetism and the semimetal-to-semiconductor transition". R C Johnson , J R Riley,T E Huber and M J Graf. *J. Phys.: Conf. Ser.* 150 022030 (2009) doi: 10.1088/1742-6596/150/2/022030
5. "Aharonov-Bohm Oscillations in Single Crystal Bi Nanowires". D.V. Gitsu, T.E. Huber, L.A.Konopko, and A.A.Nikolaeva. *Journal of Nanoelectronics and Optoelectronics*, 4, 124-133 (2009)

6. “Berry's phase manifestation in Aharonov-Bohm oscillations in single Bi nanowires”. D V Gitsu, T E. Huber , L A Konopko and A A Nikolaeva. *J. Phys.: Conf. Ser*. 150 022013 (2009). doi:10.1088/1742-6596/150/2/022013

7. “Discovery Learning Tools in Materials Science: Concept Visualization with Dynamic and Interactive Spreadsheets in Materials Education”. S.A. Sinex and J.B. Halpern, edited by M. Marinho Patterson, D. Dunham, E. Marshall, J. Nucci (Mater. Res. Soc. Symp. Proc. Volume 1233, Warrendale, PA, 2010), PP03-04.

8. ”Negative magnetoresistance in transverse and longitudinal magnetic fields in Bi nanowires”. A A Nikolaeva, L A Konopko, T E Huber, E P Sineavsky, R A Khamidullin and A C Tsurkan. *J. Phys.: Conf. Ser*. 150 022065 (2009. doi: 10.1088/1742-6596/150/2/022065

9. “Effects of Substrate Relaxation on Adsorption in Nanopores: With a Little Help from the Substrate”.Silvina M. Gatica, Hye-Young Kim *J Low Temp Phys* 157: 382–394 (2009) DOI 10.1007/s10909-009-9898-7

10. “To Wet or Not to Wet: That Is the Question”. SilvinaPores”. Hye-Young Kim, Silvina M. Gatica, George Stan and Milton W. Cole,*J Low Temp Phys* 156 1–8 (2009). DOI 10.1007/s10909-009- 9884-0

11. “Condensation of Fluids Confined in Non-rigid S. M. Gatica, Milton W. Cole *J Low Temp Phys* 157: 111–136 (2009) DOI 10.1007/s10909-009-9885-z

12. "Metal-Mediated Crystallization in Si-Ag Systems “, Chichang Zhang and C.W. Bates, Jr., Thin Solid Films, p. 5783, vol. 517, (2009).Published

13. "Friction of Silver Coatings Prepared by Electrophoretic Deposition", Mohsen Mosleh, Thomas Gabre, Jabari Calliste, and James W. Mitchell, "Friction of Silver Coatings Prepared by Electrophoretic Deposition", International Journal of Surface Science and Engineering, p. , vol. , (2009). Accepted,

14. "An Evaluation of Microcrystalline Cellulose from Nigerian Elephant Grass; Efficient Processing of MCC"J. Fortunak and J. W. Mitchell, Journal of BioResources, p. , vol. , (2009). Accepted,

15. ’"BaCO3 Mesocrystals: New Morphologies Using Peptide-Polymer Conjugates asCrystallization Modifiers."T. Wang, J. Mitchell, H. Brner, H. Clfen, M. Antonietti, , Phys. Chem. Chem. Phys, p. , vol. , (2010). Submitted,

16. "Synthesis of Amphiphilic Triblock Copolymers as Multidentate Ligands for Biocompatible Coating of Quantum Dots", T. Wang, R. Sridhar, A. Korotcov, A. Hai Ting, K. Francis, J. Mitchell, P. Wang, Colloids & Surfaces, p. , vol. , (2010). Submitted,

17. "A New Approach to Prepare Well-dispersed CaF2 Nanoparticles by Spray Drying Technique."L. Sun, L. C. Chow, J. E. Bonevich, T. Wang, J. Mitchell.,J. Biomed. Mater. Res. Part A, p. , vol. , (2010). Submitted,

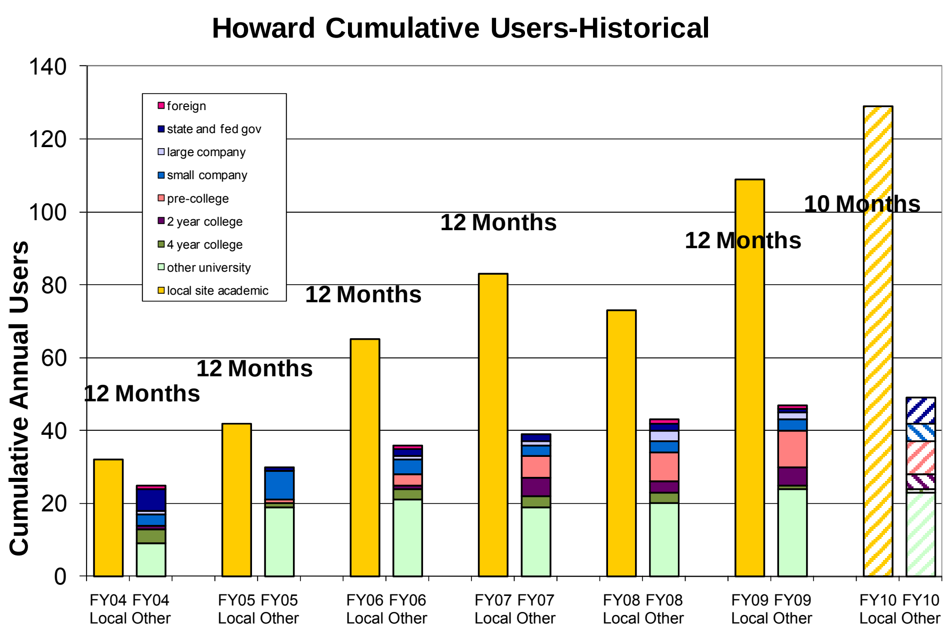
18. "Methanol electrocatalytic oxidation mediated by a[Ni/Al-carbonate]-based hydrotalcite in alkaline medium", U. C. Udeochu, N. K. KariKari, J. C. Ganley, D. Raghavan, C. M. Hosten,Journal of Applied Electrochemistry, p. , vol. , (2010). Submitted,

19. "TERS and DFT of 4-trimethylsilylethyssulfanyl-4,4-di(phenyleneethynylene)benzene thiol adsorbed on silver", M. Fletcher, D. Alexson, M Moore, S. M. Prokes, O. Glembocki, A. Vivoni, C. M. Hosten, Spectrochimica Acta, p. , vol. , (2009). Submitted,

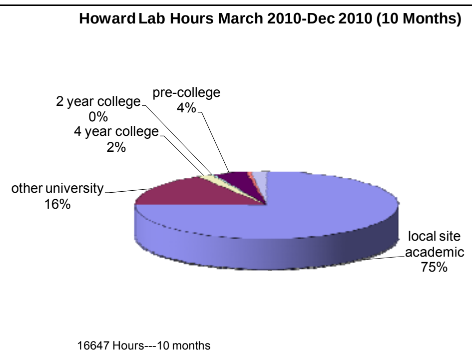
20. "Prediction of excited state energies for molecular nitrogen using quantum Monte Carlo methods", Floyd A. Fayton JR., Ainsley A. Gibson, John A. W. Harkless, International Journal of Quantum Chemistry, p. 43, vol. 1, (2009). Published,
21. "Enaminones 10. Molecular modeling aspects of the 5-methylcyclohexenone derivatives.", A. Gibson, J. Harkless, M. Alexander, K.R. Scott, Bioorganic & Medicinal Chemistry, p. 5342, vol. 17, (2009). Published,
22. "Characterization of Nonequilibrium Nanoparticle Adsorption on a Model Biological Substrate", J. J. Park, Michael C. Weiger, Silvia H. De Paoli Lacerda, Denis Pristinski, Matthew L. Becker, Jack F. Douglas, Dharmaraj Raghavan, Alamgir Karim, Langmuir, p. , vol. , (2010).Accepted
23. "Biological Responses of Osteoblast-like UMR-106 Cells to the modified PHBV Matrix: Effect of porosity and collagen dip coating", H. Liu, D. Raghavan, S. Abegaz, and J. Stubbs III,Journal of Biomedical Materials Research, p. 922, vol. 92, (2010). Published,
24. "Adsorption Study of Cdse/Zns Quantum Dot with Model Substrates : Influence of Substrate Surface Chemistry & pH"D. Raghavan, A. Karim, Langmuir, p. 443, vol. 25, (2009). Published,
25. "Chapter 7 : Thermally Stable Polymer Nanocomposites", Advances in Polymer Nanocomposites Technology, D.Raghavan and C. Chenggang, p. , vol. , (2009). Published,
26. "Development of reactive thin film polymer brush membranes to prevent biofouling", Ramamoorthy Malaisamy, David Berry, Diane Holder, Lutgarde Raskin, Lori Lepak, Kimberly L. Jones,Journal of Membrane Science, p. , vol. , (2010). Accepted,
27. "Method development for measuring biodegradable dissolved organic nitrogen in treated wastewater", E. Khan, M. Awobamise, Kimberly L. Jones, S. Murthy, Water Environment Research, p. 779, vol. 81, (2009). Published,
28. "First-Principles Studies of the Electronic and VibrationalProperties of Boron-Nitride Diamondoids"Kyungwha Park, Tunna Baruah, Mark R. Pederson, and Steven L. Richardson, Journal of Chemical Physics, p. , vol. , (2010). Submitted,
29. "First-Principles Studies of the Electronic and Vibrational Properties of sila-Diamondoids"Rajendra R. Zope, Tunna Baruah, Mark R. Pederson, and Steven L. Richardson,Journal of Physical Chemistry B, p. , vol. , (2010). Submitted,

## 7.5.10 Howard Site Statistics

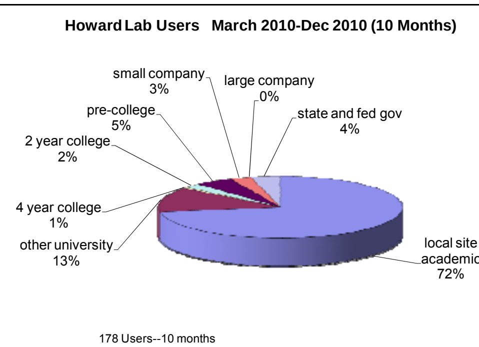
a)Historical Annual Users



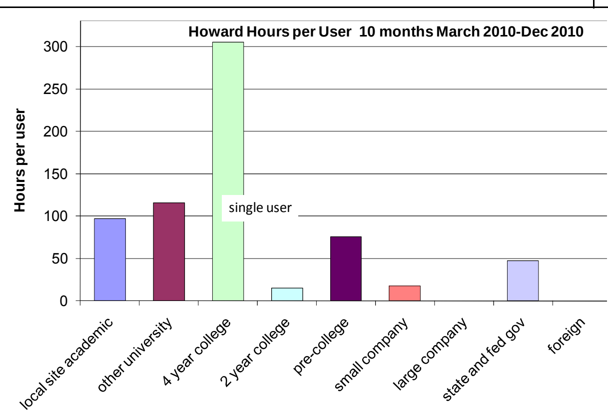

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

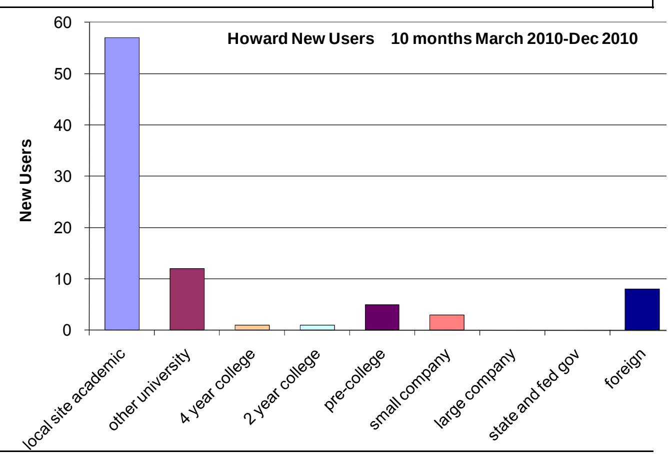



*Figure 90: Howard Selected Site Statistics*

### 7.5.11 Howard User Institutions

None Provided

## 7.6 Penn State University Site Report

### 7.6.1 Site Description and Technical Capabilities

The Penn State NNIN site provides users with access to facilities that enable fabrication of a wide range of electrical, optical, and microelectromechanical devices to support fundamental and applied research in diverse fields spanning electronics to medicine. The primary focus of the Penn State Nanofabrication Laboratory within the NNIN is to provide specialized instruments and technical support in the areas of chemical and molecular-scale nanotechnology and complex ferroelectric oxide device micro- and nanofabrication. To this end, we have transitioned self assembled monolayer (SAM)-based chemical patterning methods and deterministic nanomaterials assembly techniques from Penn State Materials Research Science and Engineering Center (MRSEC) into the NNIN. The strong coupling between traditional top-down nanofabrication and bottom-up molecular self assembly provides a unique capability within the NNIN that can be used in applications where it may be necessary to flexibly derivatize surfaces with specific chemical and biological functionality. Our site is building on Penn State's strength in complex ferroelectric oxide material thin film deposition and device processing to establish a comprehensive and integrated set of instruments to support the more stringent fabrication requirements associated with these material systems, which include Pb-based oxides. Our NNIN-supported technical liaison and staff are working in collaboration with Penn State faculty at the Keck Smart Materials Integration Laboratory to develop and document robust baseline processes for complex oxide MEMS system devices similar to the MEMS exchange for Si based devices. The Penn State site is also beginning to add advanced instruments and processes developed in the MRSEC to deposit doped amorphous Si thin films for a variety of energy applications and infrared thin films for on-chip optical devices. These specialized technical capabilities were advertised at workshops, technical meetings, and on our NNIN web site.

### 7.6.2 External and Internal Research Highlights

**Solid-State Muscles for Microrobots: F. Li and J. V. Clark, Schools of Electrical and Computer Engineering and Mechanical Engineering, Discovery Park, Purdue University, West Lafayette, IN.**

Researchers at Purdue University are developing miniature, insect-like robots that could lead to 'microids' that move their legs and mandibles using solid-state muscles. Mechanical simulations indicate these synthetic insects would have significantly better dexterity than previous microscale robots (Fig.91). The microids are designed to have the "tripod gait" used by most insects −only three of six legs are on the ground at a time− which enables stability while traversing uneven terrain and harsh environments such as sand or water. Each leg or mandible comprises a bundled triad of slender beams made of lead zirconate titanate (PZT), a piezoelectric material that generates electricity when compressed. This feature could enable the microids to harvest energy by taking advantage of vibration in the environment to recharge. Currently, the researchers are working on fabricating a simplified proof-of-concept microid at the Penn State NNIN site using its specialized complex oxide baseline processes. This work was reported at Nanotech Conference & Expo 2010.

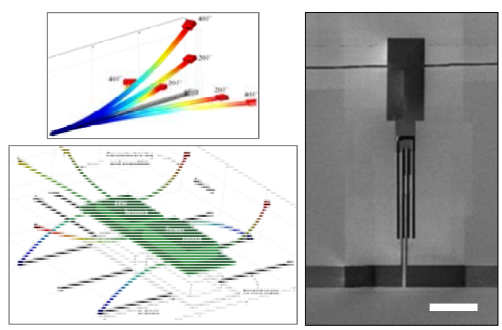


*Figure 91* Left*: Illustration of an integrated microid system showing triplet of PZT fibers (top).* Right*: FESEM proof-of-concept device with a "Tripod Gait Leg" made of PZT MEMS.* made of PZT MEMS structure

**Enhancing Amorphous and Nanocrystalline Silicon Deposition Rates for Low-Cost Thin Film Solar Cells: P. T. Hurley and R. G. Ridgeway, Air Products and Chemicals, Inc., Allentown, PA.**

Researchers at Air Products and Chemicals, Inc. are developing advanced low-temperature plasma enhanced chemical vapor deposition (PECVD) processes to increase the growth rates and reactant utilization for amorphous hydrogenated silicon (a-Si:H) and microcrystalline silicon (μc-Si) thin films for solar cells. This is being accomplished by incorporating new additives into the precursor gas mixture at the Penn State NNIN site. The modified processes provide a more controlled bonding environment during thin film deposition, leading to TF-Si with quality comparable to mainstream processes (Fig. 92). The new processes and additives are compatible with current manufacturing methods, allowing for early and rapid deployment by thin film (TF) Si manufacturers, whose production is expected to be ~5.2 GW by 2012. If all of the TF-Si manufacturing facilities adopt these additives and save ~$0.115 per watt, this would result in an annual savings of ~$600 million to the photovoltaic industry.

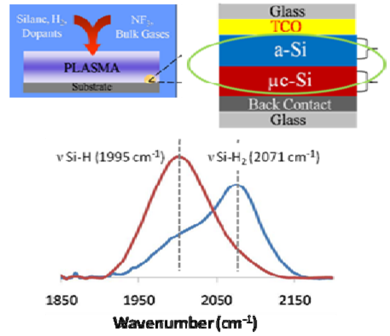



*Figure 92* Top*: Tandem TF-Si solar cell grown by PECVD.* Bottom*: Fourier transform infrared (FTIR) spectrum of a-Si:H thin film deposited at high rates using additives.*

**Low-Cost Pyroelectric Infrared Detector Arrays: C.-H. Wu, Bridge Semiconductor, Pittsburg, PA.**

The integration of pyroelectric infrared focal plane arrays (IR-FPA's) with Si CMOS read-out integrated circuits (ROIC's) is enabling the development of high performance, low-cost infrared detectors and cameras. Ultimately, the image quality is expected to be superior to other uncooled thermal imagers, including resistive microbolometers. The Penn State NNIN Site is being used to deposit, pattern, and etch doped lead zirconate titanate (PZT) pyroelectric films to fabricate the IR-FPAs for several prototype uncooled thermal imaging systems.Video frame-rate imaging has been demonstrated upon integration of the IR-FPA's with custom designed CMOS ROIC electronics.The IR-FPA's and fully integrated thermal imaging cameras developed in the NNIN are currently being transitioned into commercial products.(Fig. 93).

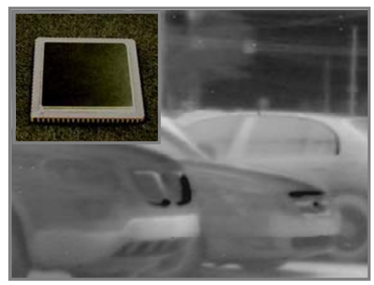


*Figure 93; Thermal image from a prototype camera using PZT thin films.* Inset: *IR-FPA on ROIC.*

**Deterministic Nanowire Assembly: Materials Research Science and Engineering Center to NNIN: T. Morrow, M. Li, J. Kim, T. S. Mayer, and C. D. Keating, Departments of Chemistry and Electrical Engineering, Penn State University, University Park, PA**

Researchers at Penn State are developing hybrid nanomanufacturing processes to add new capabilities and functions to silicon (Si) integrated circuits (ICs). The process begins by fabricating > $10^8$ nearly identical nanometer-sized parts –sheets, wires, or spheres of a desired material– under optimal conditions, and suspending them in a fluid. Different populations of these components are then delivered, one by one, to predetermined positions on a Si substrate. A programmable AC voltage that is applied to assembly

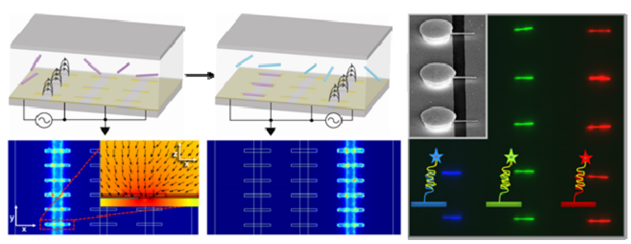


*Figure 94* Left*: Programmed deterministic assembly scheme and 3D electromagnetic field simulation showing high electric fields within lithographically defined microwells.* Right*: Fluorescence optical microscope image and FESEM (*inset*) of nanowire device arrays integrated by electric-field assisted directed assembly method.*

electrodes patterned on the Si substrate directs individual parts to a specific region of the substrate, and then positions them with the submicron accuracy needed to connect a part to a specific feature on the substrate. Assembly follows seconds after delivery, and component densities can exceed $10^6$/cm$^2$. Conventional top-down fabrication is then used to convert the assembled parts into functional devices and circuits.The fluorescence microscope image in Fig. 4 show high yield assembly and integration of three populations of nanowires functionalized with different biomolecule probes. Binding selectivity to complementary DNA targets was retained following assembly and integration.This research was reported in articles published in *Nature Nanotechnology* and *Science*.Currently, new instruments are being developed at the Penn State NNIN site to allow users to apply this technology to assemble and characterize their own nanowires and nanomaterials.

### 7.6.3 Facilities, Acquisitions, and Operations

**Facilities:** The Penn State Nanofabrication Laboratories consist of approximately 6000 sq. ft. of clean room space and over 3000 square feet of supporting non-clean laboratory space located at our Materials Research Institute (MRI), Materials Research Laboratory (MRL), and Electrical Engineering West Building. The largest clean laboratory in MRI contains three clean process bays and adjoining semi-clean cluster areas that support all aspects of deposition and etching, three interconnected rooms to support micro- and nanolithography, and a ballroom that houses metrology equipment. The second Keck Smart Materials Laboratory cleanroom in MRL contains instruments specialized for complex oxide device processing. The third laboratory in EEW contains two additional process bays that support MEMS processes. Penn State will complete construction and take possession of the 275,600 gross sq. ft. Millennium Science Complex (MSC) in July 2011. The Penn State NNIN site will be relocated into a 10,000 sq. ft. class 100/1000 clean room with an additional 6500 sq. ft. of non-clean support space beneath the cleanroom commencing at that time. The move is projected to be complete in one year. This building will bring together the core instrument laboratories and the faculty/center research laboratories that support our NNIN focus areas, which will allow Penn State to better serve the network in the future.

**Acquisitions:** A significant number of new instruments were purchased and either added to the current Penn State NNIN site facilities in 2010 or are targeted for installation in the new MSC cleanroom. The new instruments bring significant improvements in pattering, thin film deposition, metrology and etching that are integral to our focus areas. The specific tools are added capabilities are described below:

- **Kurt Lesker CMS-18 Sputter Tool:**This custom designed sputtering tool was purchased with funding from the NSF NNIN Major Research Instrumentation program. The system includes two RF and two DC sources and a load locked chamber for in situ deposition of complex oxide and metal thin films. The 150 mm capable rotating stage can provide an RF bias of up to 100 W.Substrate heating is included with temperatures up to 800oC to optimize the deposition conditions to control film morphology and stress. The tool is available for deposition of several fully characterized complex oxide films.
- **PlasmaTherm LLC Versalock 700 Dual Chamber ICP Etcher:** The system is a modular cluster plasma processing system composed of a load module, a transport module, a remote operator station and two Inductively Coupled Plasma (ICP) etch modules. Each processing module is equipped with a 10-in lower electrode, He backside cooling, a 1000 lps turbo pump, a gas enclosure including eight process gas lines and an end point detection system. Installation was completed in April 2010 and the tool is available for external use via the NNIN network.
- **Tegal 6540 Plasma Etch System Second Chamber:** An additional HRe-™ reactor with dual-frequency RF power technology and magnetic plasma confinement was added with funding from a DURIP Award. The installation of the new chamber was completed in October 2010 and is providing additional capacity and redundancy in our complex oxide focus area.

- **KLA–Tencor P-16 + Stylus Profilometer:**This system was purchased with NNIN ARRA funds and was delivered and installed in May 2010. The system provides advanced step height and film stress measurement capabilities. The tool is fully functional and available for external use.
- **Nikon L200 Inspection Microscope:** This general purpose inspection tool was purchased with NNIN ARRA funds.It was delivered and installed in May 2010 and is open for external use.
- **Thermco 2604 Four Stack Oxidation LPCVD System:** The four stack unit with wet and dry oxidation, silicon nitride and doped and undoped polysilicon deposition capability was purchased with NNIN ARRA funds and will be installed in the MSC cleanroom for operation in Q4 of 2011.
- **Wave 4W-LANS Custom Multiple Target Ion Assisted Deposition System**: The system is a computer controlled and fully programmable, load locked, multi-target, ion assisted deposition system with an Ultra Low Energy High Intensity Ion Source (ULEHIIS). It is equipped with a water cooled rotational stage that can accommodate 100mm substrates, ports designed for in-situ ellipsometry and a residual gas analysis (RGA) system. The system was purchased with NNIN ARRA funds and NNIN equipment funds. The tool is currently being assembled at the manufacturer's site and will be fully tested and processes developed prior to installation in the MSC cleanroom. The tool will be available for external use in Q1 of 2012.
- **Vistec 5200ES Electron Beam Lithography System:** This advanced electron beam nanolithography instrument is capable of direct patterning of features on substrates having a variety of sizes and thicknesses, with demonstrated sub-10 nm pattern resolution and sub-15 nm stitching and overlay accuracy. The instrument is equipped with a z-lift stage that allows software-controlled dynamic stage height adjustments for patterning on substrates with extreme topography and curvature. This unique capability is not available at any other national user facility. The tool was purchased with NSF MRI ARRA, Pennsylvania State Nanotechnology, and Penn State University funds. The system will be installed in the new MSC cleanroom and is scheduled to be qualified for use in the NNIN network in Q4 of 2011.
- **WAFAB Custom Electroplating Bench**: The system is a multi-bath fully integrated plating bench. It has a single advanced, fully programmable power supply that can be easily used with any of the three baths. The baths have rate controlled filtered circulation and specially designed electrode fixtures for plating full 150mm wafers to wafer pieces. The system was purchased with NNIN ARRA funds and will be installed in the MSC cleanroom for operation in Q3 of 2011.
- **Lithography and Lithography Support Instruments:** Several instruments were purchased from Motorola including a GCA 8500 i-Line optical stepper, compact SVG coat/bake and bake/develop tracks, two Brewer Science resist apply and bake tracks, a Blue M oven, and a Fusion resist UV/thermal curing and processing station. The equipment will be installed in the MSC cleanroom for operation in Q3 of 2011.

**Operations:** Oversight of the Penn State NNIN site is provided by the Materials Research Institute, which was established in 1996 to support interdisciplinary materials and device research and outreach to industry. The unit reports directly to the Vice President for Research and brings shared resources including information technology, outreach, and web design personnel as well as professionals who have experience coordinating workshops and industrial outreach events. One additional support staff member was hired during the past year to further enhance our ability to interface with external users. Mr. Ted Gehoski joined as a process engineer to assist in the development of processes for our NNIN focus areas and to work on external customer remote projects.

### 7.6.4 Education, Outreach and SEI

**Education:** The Penn State Nanofabrication Laboratory undertook activities to (1) introduce high school students to nanotechnology, nanofabrication, career opportunities, and educational pathways; (2) provide training to teachers about the discipline of experimental sciences and enhance their enthusiasm for having students pursue careers in science; and (3) provide hands-on nanotechnology summer research with state-of-the-art equipment for undergraduate students.

Three teachers participated in the NNIN RET program: a science teacher from Cross Country Elementary and Middle School in Baltimore Maryland, a pre-service teacher from the College of Education at Penn State, and a State College Area High School science teacher. The teachers researched the antibacterial properties of Ag nanoparticles under the supervision of Dr. Christine Keating, a Professor in the Department of Chemistry, and Dr. Steven Keating, a Senior Lecturer II, in the Department of Biochemistry and Molecular Biology. The teachers created engaging, hands-on and affordable lessons to introduce high school students to the field of nanotechnology as well as demonstrating its relevance to their lives. The teachers included 1 under-represented minority.

Penn State hosted 5 undergraduate students for a summer research program as part of the NNIN network REU program. In addition to training of students in the operation of equipment necessary to complete their summer projects, the students participated in weekly professional development training, weekly seminars, a Penn State symposium with several REU programs, and the NNIN convocation. The REU program supported 1 woman and 2 underrepresented minority students.

The Pennsylvania Nanofabrication Manufacturing Technology capstone semesters had 60 undergraduate participants (33 associate and 27 baccalaureate) students from across PA complete an 18 credit capstone semester in the spring and summer 2010 semesters. The defining feature of the partnership is the sharing of the nanofabrication facilities, staff, and faculty at the Penn State University Park Campus with educational partners across the Commonwealth. As part of the NSF National Center's Work, the nanofabrication facility and staff participate in the educator workshops, which are targeted at community college instructors across the country where "Teaching Cleanroom" was taught. Five of these on-site workshops were taught in 2010, with 71 educators attending the 5 workshops.

**Outreach:** The Penn State NNIN site continues outreach activities to inform potential users in academia, national laboratories, and industry of our general technical capabilities and specific focus areas. Our user outreach activities for 2010 are summarized below:

- ***Tradeshow displays:***The Penn State NNIN Site displayed a booth at tradeshows including the NSTI Nanotech Conference and Expo 2010 in Anaheim, CA in June 2010. The booth was visited by nearly 200 attendees.
- ***Special Events:*** The Penn State NNIN site participated in two special outreach events in 2010. The Penn State Materials Day 2010 was attended by over 100 participants, representing over 30 companies. The NNIN site was featured prominently with capabilities presentations and posters being given by the staff.The Penn State NNIN Staff also participated in Penn State Exploration Day an outreach event for families that attracted several thousand participants for hands on demos on a wide array of scientific topics, including nanotechnology.
- ***Facility Tours:***The Penn State NNIN provided more than 25 outreach tours for over 300 participants. A sample of academic and industrial participants included, Phillips Medical Systems, Air Products, Corning Inc., Agilent Technologies, 3M Renewable Energy Division, General Electric, Istanbul Technical University, King Faisal University of Science and Technology, University of Pennsylvania and Nippon Electric Glass Co. LTD.

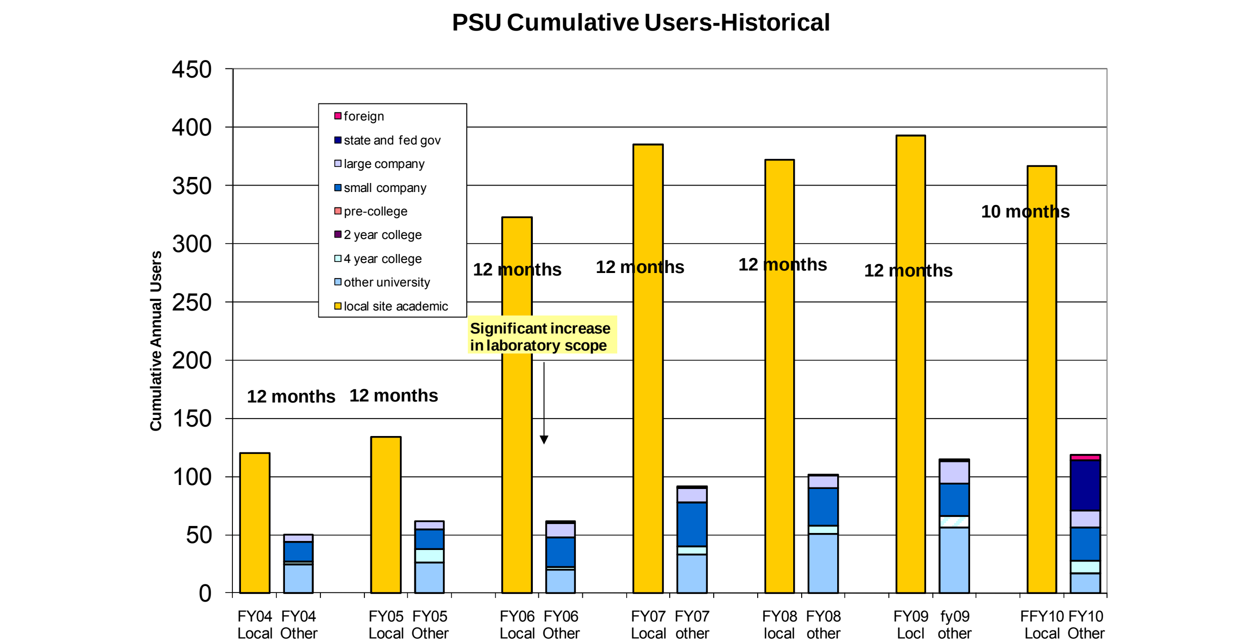
- ***Industrial Visits:***The Penn State NNIN site was described at nanotechnology-focused industrial and government visits: GE, 3M, Air Products, Raytheon, Valspar, Inc., 113 Industries, United Technologies, Nippon Electric Glass Co., Chinese Academy of Science, National Institute of Materials Science –Japan. These visits were attended by scientists, engineers, and executives.

**SEI:** The Penn State NNIN site is co-organizing a series of brown bag lunch seminars and discussions on a variety of SEI topics of interest to our user community. The first such interactive seminar was conducted in December 2010 and there were 25 attendees. In addition, the Penn State NNIN is collaborating to assemble all SEI interested groups at Penn State into a centralized organization known as the Center for Nanofutures. The intent of this effort is to promote scholarship in the area of SEI and to bolster research programs and proposals in nanotechnology related SEI research.

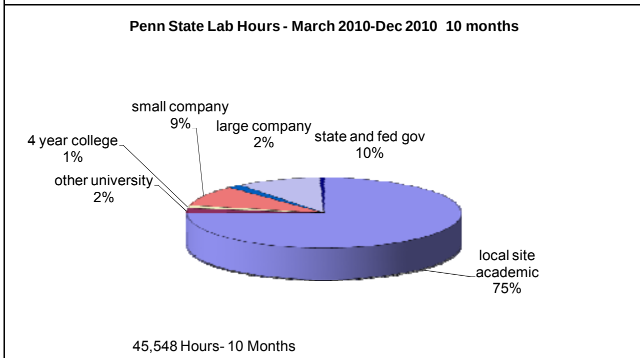
------End of Penn State Text Report-----

## 7.6.5 Penn State Selected Statistics

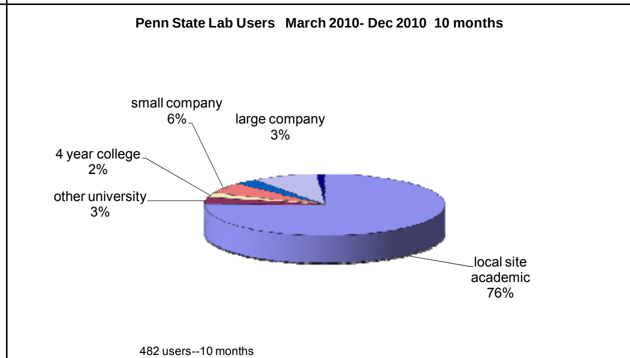
a)Historical Annual Users



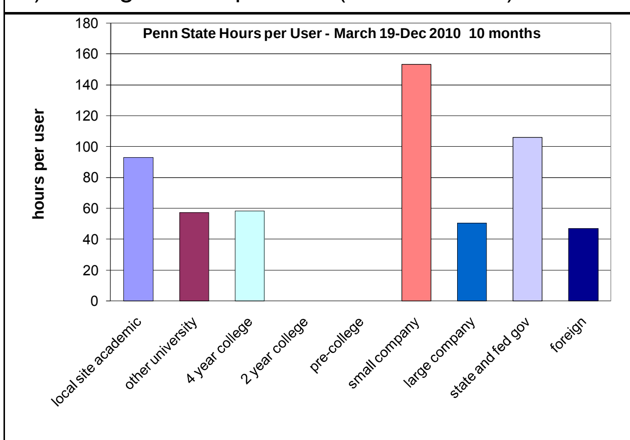

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

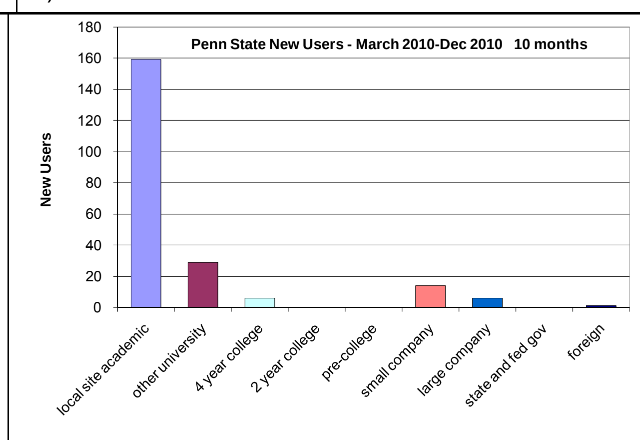



*Figure 95: Selected Penn State Site Statistics*

## 7.6.6 Penn State User Institutions

| Outside US Academics | Small US Companies | Large US Companies |
|---|---|---|
| Amherst College | Advanced Cooling Tech. | Air Products and Chemicals Inc |
| Bucknell University | Aquion Energy | BTU International |
| California State University, Los Angeles | Asbury Graphite Mills Inc. | Carpenter Technology |
| Carnegie Mellon University | Bio Armor Inc | Empower Materials |
| Case Western Reserve | Bridge Semiconductor Corp | GEIT |
| City College Of New York | Bullen Ultrasonics Inc | Henkel Corporation |
| Cornell University | Colonial Metals Co | LGS Innovations |
| Delaware State University | Flexible Medical Systems, LLC | Molecular Imprints |
| Dickinson College | Fosaaen Technologies, LLC | New York Wire Company |
| Juniata College | Game Changers, LLC | Northrup -GrummanCorp |
| Lock Haven University | General Opto Solutions, LLC | OlympusNDT |
| Louisiana Tech University | Leversense, LLC | PPG Industries Inc |
| Oklahoma State University | Mezmeriz, Inc. | SCHOTT North America |
| Purdue University | MI Windows & Doors Inc. | Spectrum Control Tech., Inc |
| Rutgers University | Phoebus Optoelectronics LLC | Standard Steel LLC |
| Temple University | Rational Affinity Devices LLC | Total Lubricants USA, Inc. |
| Texas A & M University | SeprOx Corporation | Tyco Electronics |
| University of Delaware | Solarity | Varian Semiconductor |
| University of Illinois | Spectrum Devices | |
| University of Maryland | Strategic Polymer Sciences, Inc. | |
| University of Nebraska, Lincoln | The Ultran Group | |
| University of Pittsburgh | TRS Ceramics | **State and Federal Government** |
| University of Virginia | Ultool, LLC | Applied Research Laboratory |
| University of Wisconsin--Plattville | Viracon | Electro Optics Center |
| Villanova University | | |
| Wayne State University | | |

## 7.7 Stanford University Site Report

### 7.7.1 Facility Overview

2010 was a successful and productive year at SNF.Total users of the lab for calendar year 2010 were an average of 225 per month, an increase of 7% over calendar year 2009.The monthly total of industrial and outside academic users was an average of 60, down 2% relative to 2009, in part due to economic conditions.The lab installed two new RTA tools from Allwin Corporation. The SNF education/outreach staff developed and performed 3 remote access activities and provided content for the July, 2010 2-week pilot workshop for teachers across the country.The Stanford NNIN Computing Facility, consisting of a 64 node, 512 CPU linux computer cluster, is now fully utilized with a total of 30 users, 19 internal and 11 external.An ethics in nanotechnology online survey was added to the new user orientation at SNF

### 7.7.2 Research Highlights

Titles of some of the research highlights for 2010 include:

- Benjamin Tee and Professor Zhenan Bao, Departments ofElectrical Engineering and Chemical, Stanford University - “Highly Sensitive Structured Elastomers as Rubber Dielectric Layers for Organic Transistors”.
- Zihong Liu, Professor Zhenan Bao, Professor Yoshio Nishi, Stanford University – “Organic Semiconductor Contact Engineering via Fermi Level Depinning”.
- Dr. Junil Park, Dr. Sang-Yun Lee, BeSang Inc. and Professor Yoshio Nishi, Department of Electrical Engineering, Stanford University - “Multi-Layer Stacked 3-Dimensional Integrated Circuit Technology”.
- Daniel Bernards and Professor Tejal Desai, Department of Bioengineering and Therapeutic Sciences, University of California at San Francisco - “Nanoporous Biodegradable Polymers for Delivery of Protein Therapeutics”.
- Dr. Dinh Ton, Dr. Gideon Yoffe, Dr. Thomas Schrans, and Dr. Bardia Pezeshki, Kaiam Corporation, Newark, California – “MEMS-based Alignment of Single Mode Optical Packages”.
- Professor Pierre Khuri-Yakub, Department of Electrical Engineering, Stanford University - “Capacitive Micromachined Ultrasonic Transducers (CMUTs)”.
- Professor Gregory Kovacs and Dr. Laurent Giovangrandi, Department of Electrical Engineering, Stanford University – “In Vitro Electrophysiologic Model For Cardiac Stem Cell Integration”.
- Ying Chen, Dr. Jim McVittie, and Professor Yoshio Nishi, Department of Electrical Engineering, Stanford University, Dr. Ho-Cheol Kim and Dr. Chiu Ting, IBM Research, San Jose, California – “Synthesis of $TiO_2$ Nanoframe for a Prototype Solar Cell”.
- Fei Liu and Professor Bruce Parkinson, Department of Chemistry, University of Wyoming – “Interdigitated Electrode Arrays for Evaluation of Electrocatalysts”.
- Chih-Ming Lin and Professor Albert P. Pisano, Department of Mechanical Engineering, University of California at Berkeley – “Temperature-Compensated Aluminum Nitride Lamb Wave Resonators”.
- Professor S. Roy, University of California at San Francisco, Dr. K. Goldman, H-Cubed, Inc., Dr. A.J. Fleischman, Cleveland Clinic – “Silicon Nanoporous Membranes for Hemofiltration”.
- Masaharu Kobayashi, Dr. Blanka Magyar-Kope, Professor Krishna Saraswat, Professor Philip Wong and Professor Yoshio Nishi, Department of Electrical Engineering, Stanford University, Dr.

Toshifumi Irisawa, Toshiba Corporation – “Uniaxial Stress Engineering for High-Performance Ge NMOSFETs”.

- Professor Olav Solgaard, Department of Electrical Engineering, Stanford University, “Fiber Sensors for Challenging Environments”.
- Kaoru Sanaka, Alexander Pawlis, and Professor Yoshihisa Yamamoto, Departments of Applied Physics and Electrical Engineering, Stanford University – “Single-Photon Sources using ZnSe:F”.
- Dr. Romana Schirhagl and Professor Richard Zare, Department of Chemistry, Stanford University – “Cell Sorter Based on Integration of Porous Membranes into Microfluidic Devices”.
- Dr. Eric Hall, Dr.Romana Schirhagl and Professor Richard Zare, Department of Chemistry, Stanford University – “Single-Cell Analysis on a Microfluidic Platform”.
- Dong Rip Kim, Chihwan Lee, and Professor Xiaolin Zheng, Department of Mechanical Engineering, Stanford University – “Direct Growth of Nanowire Devices”.

## 7.7.3 Equipment, Facility and Staff Highlights

### 7.7.3.1 Equipment

- In 2010, SNF installed two Allwin AW610 table top rapid thermal processors replacing two older units.The new systems have larger chambers, more power and additional gas channels with mass flow control.They have the ability to reach high temperatures in a fast ramp step.These systems are used by labmembers with gallium arsenide and small pieces which cannot use the existing AG4100X systems, which are clean 4” wafers only.
- Five new tools, funded through American Recovery and Reinvestment Act (ARRA) stimulus funds, are at various stages of installation and permitting.The new equipment includes two plasma enhanced chemical vapor deposition (PECVD) systems, a plasma vapor deposition (PVD) system, an electron beam evaporator and a dual chamber atomic layer deposition (ALD) system.

### 7.7.3.2 Facility

The Stanford Nanofabrication Facility has recently been awarded a substantial grant for renovation/improvement of the laboratory, from the NSF Academic Research Infrastructure Program, part of the American Recovery and Reinvestment Act of 2009.The renovation project includes update of the facility to meet current code requirements, expansion of the infrastructure to support new chemicals and gases, and a new "bottom up nanosynthesis" lab, designed to support solution chemistry for nanomaterial synthesis chemical modification.The renovation will facilitate flexible installation of new tools and the capability to handle new materials safely, and meet the on-going demands of the lab researchers.

The Center for Nanoscience and Technology building opened in summer 2010.An FEI Titan aberration corrected transmission electron microscope (TEM), a JEOL 6300 electron beam lithography system, and a Cameca NanoSIMS have been installed.

### 7.7.3.3 Staffing

Staffing in the facility continues at the same level as calendar year 2009. There are two student helpers in the lab.

## 7.7.4 Educational/Computational/Societal and Ethical Implications of Nanotechnology Highlights

### 7.7.4.1.Education/Outreach Activities

SNF has again participated in a wide variety of educational and outreach activities.In the 5- year NanoTeach program, funded by NSF through a DLR grant and by NNIN and involving the Georgia Tech site and Mid-continent Research for Learning and Teaching (McREL), SNF is developing and testing a combination of workshop and online professional development experiences for high school science teachers to incorporate nanotechnology into their curriculum.

This past year SNF developed and performed 3 remote access activities and provided content for the July, 2010 2-week pilot workshop for teachers across the country. Assessment by an external evaluator determined that the SNF activities were the highest rated of all activities for this successful program.SNF is now assisting the teachers in their incorporation of nanoscience content into their classrooms.SNF again participated in the week-long Summer Institute for Middle School Teachers, organized by the NSEC Center for Probing the Nanoscale.SNF also teamed with them for the March NICE NanoDays program at Stanford again utilizing remote access activities, this time for fifty 7th and 8th graders from Mountain View's Girls Middle School.SNF had a Laboratory Experience for Faculty professor in the summer of 2010.Professor Jennifer Lu from UC Merced worked "nanohybrid films for energy conversion and harvesting".

In the area of mass media, SNF has been working with Silicon Run Productions in their NSF- funded program to produce a film on nanoscience and nanofabrication, and will also team with them in their upcoming remake of their very successful Silicon Run film series.SNF is assisting in the design of a large nanotechnology display in the new nanoscience building on campus. In addition SNF has hosted several local school groups for presentations and tours of the facility, and hosted 5 REU students last summer.

### 7.7.4.2 Computational Infrastructure

The Stanford NNIN Computing Facility (SNCF) consisting of a 64 node, 512 CPU linux computer cluster is now fully utilized with a total of 30 users, 19 internal and 11 external.Projects on the cluster include ab initio NEGF transport simulations for nano-electronics and spintronics, electronic structure methods based on Density Functional Theory (DFT), Configuration interaction (CI), Coupled Cluster (CC), Many Body Perturbation (MP), Quantum Monte Carlo (QMC), and force field based molecular dynamics.Through the introduction and optimization of simulation tools, breakthroughs have been achieved in unraveling the fundamental mechanism for multiple-exciton generation, a process that can potentially double the maxim theoretical photo-conversion efficiency in third generation photovoltaic materials.

SNCF hosted a workshop "Bridging the gap between theory and experiment: which theoretical approaches are best suited to solve real problems in nanotechnology and biology?". The workshop was interdisciplinary in character: academic and industrial researchers from the physics, chemistry, biology and engineering disciplines discussed the emerging impact of the synergy between experimental and computational advances in several nanoscience areas, including the interface with bio-molecules.

### 7.7.4.3Societal and Ethical Implications of Nanotechnology

An on-line ethics and nanotechnology survey was designed and launched in 2010 to be used as part of SNF's new user orientation.The survey poses issues of ethics to the participant about the ethical implications of his or her work as an educational tool and to provide data to Professor McGinn for analysis to identify future points of emphasis in ethics education.Other NNIN sites have expressed interest in using the survey for their laboratory ethics education.

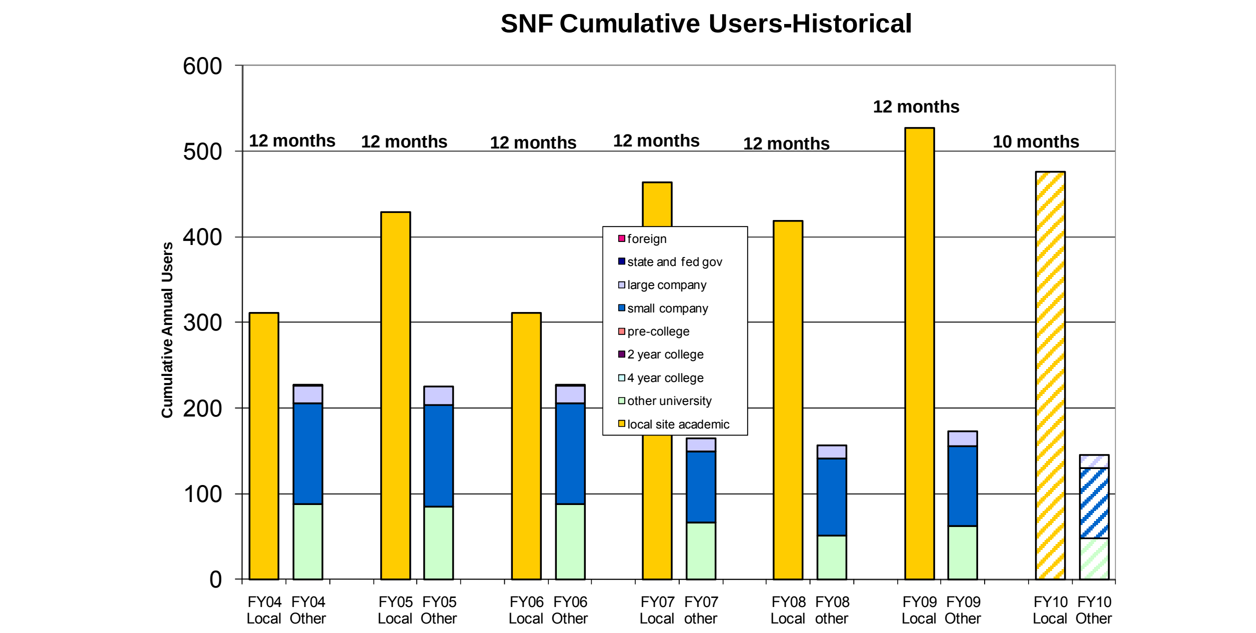
In Summer 2010 Professor McGinn has prepared a new course entitled “Research Ethics for Engineers and Scientists” that will be offered in the spring quarter of 2010-2011.Professor McGinn also published the following:

1. Robert McGinn, “Ethical Responsibilities of Nanotechnology Researchers: A Short Guide”, Nanoethics, 4, 1 (2010).
2. Robert E. McGinn, “What is Different, Ethically About Nanotechnology?Foundational Questions and Answers”, Nanoethics, 4, 115 (2010).

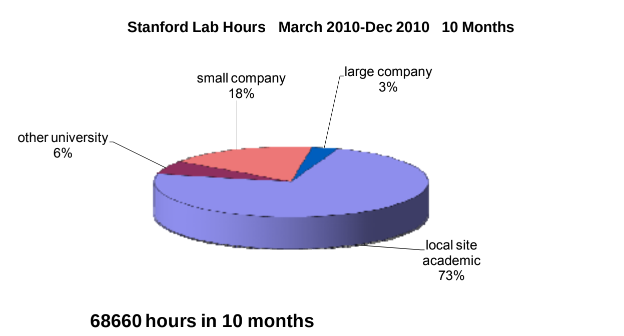
*--End of Stanford Text report---*

## 7.7.5 Selected Stanford Use Statistics

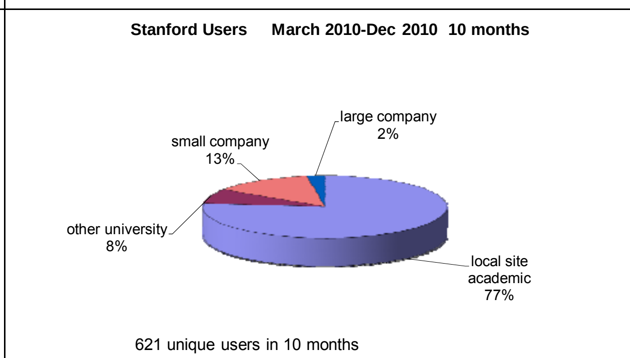
a)Historical Annual Users



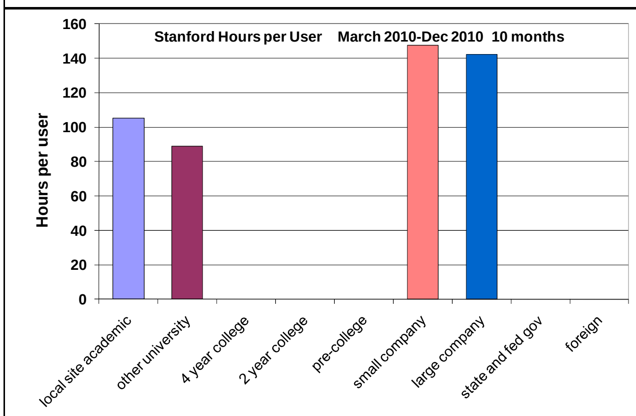

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

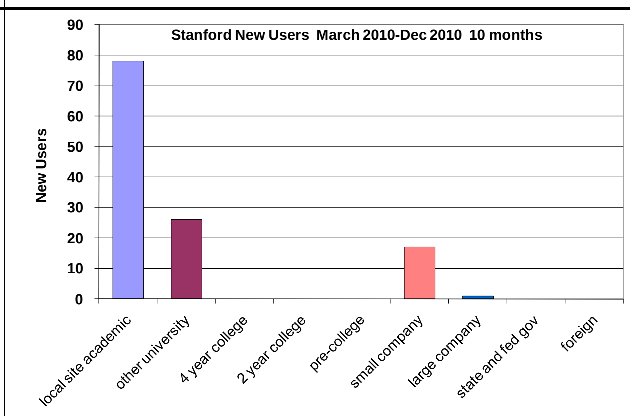



*Figure 96 Selected Stanford Site Statistics*

## 7.7.6 Stanford User Institutions

| Stanford User Institutions by Type (March 2009-Dec. 2010) | | | |
|---|---|---|---|
| US outside academic | Small companies | Large companies | International |
| Arizona State | Acorn Technologies | Aerospace Missions Corp | Hong Kong University of Science and Technology |
| Beloit College | Active Optical Networks | ALLVIA | National University of Singapore |
| Georgia Tech | Akxel Microsystems | Alpha and Omega Semiconductor | Universitat Basel |
| Middlebury College | ALCES Technology | Applied Biosystems | University of Calgary |
| Molecular Biology Consortium | ALTA Devices | Hewlett Packard | University of Prince Edward Island |
| Montana State University | Amprius | IBM | University of Toronto |
| Princeton University | Asylum Research | Intel | |
| Santa Clara University | Bay Materials | JDS Uniphase | Other |
| Southern Methodist University | BeSang Inc. | SRI International | Stanford Linear Accelerator |
| Stevens Institute of Technology | Corium International | | |
| UC Berkeley | Cranepine Medical | Small companies | Small companies |
| UC Los Angeles | DxRay | MagArray | REC Technology US |
| UC Merced | Eksigent Technologies | Mcube | Reel Solar |
| UC Riverside | EPIR Technologies | Nano Liquid Devices | SBA Materials |
| UC San Francisco | Fortemedia | NanoGram | Siargo |
| UC Santa Barbara | Glide/Write | Nanomix | Silexos |
| UC Santa Cruz | Grandis | Nanosense | Solar Junction |
| University of Michigan | Halcyon Molecular | Nanosys | Soltaix |
| University of New Mexico | Intermolecular | NeoMEMS Technologies | Sundiode |
| University of Texas at Arlington | InVisage | NthDegree Tech Worldwide | TetraSun |
| University of Washington | Jacksons Processing Solutions | Nupga | ThinSilicon |
| University of Wisconsin | Kaiam | OndaVia | Translucent |
| University of Wyoming | Kateeva | Phoenix Biosystems | Tricorntech |
| | Kovio | Physical Optics Corp | Twin Creeks Technologies |
| | Kumetrix | Procept | Ubimos Technologies |
| | LW Microsystems | Process Development Solutions | Unity Semiconductor |
| | *--continued* | QuSwami | Yung Chieh Tan |
| | | *--continued* | Zeno Semiconductor |

## 7.8 University of California Santa Barbara Site Report

### 7.8.1 Site Overview

The UCSB Nanofabrication facility operates out of a 12000 ft2 class 100/1000 cleanroom environment.UCSB has extensive facilities and research for nanotechnology including: electron beam lithography down to <10nm resolution; optical projection lithography to 350nm (soon to be 150nm); advanced ICP etch tools for a wide range of materials including ceramics, dielectrics, metals, silicon, SiC, III-V nitrides, III-V phosphides, and III-V arsenides; thin film deposition techniques including evaporation, RF and DC reactive sputtering, ion beam deposition, atomic layer deposition, and ICP-based PECVD; Field Emission SEM and EDX; Scanning Phase Microscopy.UCSB fosters a very collaborative research environment between researchers in many disciplines including Materials Science, Chemistry, Physics, Biology, Chemical, Electrical, and Mechanical Engineering. UCSB internal research strengths include: compound semiconductor electronic and optoelectronic devices in the GaAs, InP GaN-based materials systems; polymer and organic electronic and photonic devices; quantized electron structures and THz physics; spintronics, single electronics, and quantum computation; quantum optics; MEMS/NEMS, bio-instruments, and microfluidics.Of note are the recent National Research Council Rankings of Research Doctoral programs, by department, in the US.According to the overall rankings, The UCSB Materials department ranks first in the nation, the Electrical Engineering and Chemical Engineering departments rank in the top 5, and the Physics and Mechanical Engineering departments rank in the top 8 nationwide.

UCSB houses a wide range of well-funded centers of excellence in areas of electronics, optoelectronics, energy efficiency, materials, biology and physics.These centers are funded by a wide variety of government agencies and industrial partners and often involve significant academic collaborations not reflected in user statistics. The centers include: The Optoeelctronics Technology Center, The Solid State Lighting and Energy Center, The Materials Research Laboratory,the Mitsubishi Chemical - Center for Advanced Materials, the Institute for Energy Efficiency, The Institute for Collaborative Biotechnologies, The California Nanosystems Institute, the Center for Polymers and Organic Solids, the Institute for Terahertz Science and Technology, the Center for Energry Efficient Materials (CEEM), and the Center for Spintronics and Quantum Computation.Researchers from these centers utilize the nanofabrication facility and provide resources and knowledge that benefit the entire user community.Many of the centers coordinate weekly and other special technical seminars and workshops.To leverage these resources, announcements and links are posted on the UCSB Nanofabrication Facility website and by fliers outside the facility entrance so that our large multi-disciplinary user community is invited and encouraged to attend these events.

### 7.8.2 Research Examples

The primary mission of the facility is to provide the resources and expertise to enable research into devices on the micro and nano-scale.Research results over a wide range of disciplines are obtained by internal and external researchers of the UCSB facility.Below are some highlights of projects using the laboratory from three different research groups and affiliations.

**External Small Company User: Life Sciences/Optics: Broadband Sources for Optical Coherence Tomography , Vijay Jayaraman, Praevium Inc.:**

Optical Coherence Tomography (OCT) constructs subsurface images of biological samples by measuring echo time-delay of backscattered and back-reflected light. OCT can be configured as spectral domain (SDOCT) or swept source (SSOCT) systems employing either broadband superluminescent diodes (SLDs) or widely tunable lasers, respectively.Praevium, under funding from the National Cancer Institute and commercial partner Thorlabs, has developed both record bandwidth SLDs and record tuning range vertical cavity surface-emitting lasers (VCSELs) which enhance imaging resolution of emerging OCT systems.Figures 97 and 98 show measurements of an ultra-broadband tunable 1310nm VCSEL for cancer imaging along with an OCT image of a tadpole heart taken with a Praevium 170nm broadband SLED.

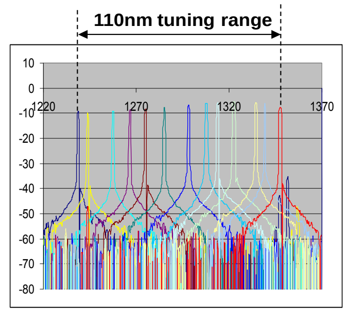



*Figure 98: VCSEL Spectrum*

*Figure 97: OCT image of tadpole heart*

**Internal User: Physics: Quantum ground state and single-phonon control of a mechanical resonator: *Aaron O'Connell et. al. Cleland and Martinis group, Physics Dept., UCSB***

Researchers in the UCSB physics department have demonstrated the controllable creation of single quantum excitations (phonons) in a quantum-bit coupled to a microwave frequency mechanical oscillator.This is a first step towards complete quantum control of a mechanical system.An optical micrograph/SEM composite image of the system is shown along with measured results of the creation and absorption of phonons with Maxima corresponding to the qubit being in its excited state and minima corresponding to state transfer to the resonator, creating a single phonon. (*Nature Vol. 64, April 2010).(Fig. 99)*

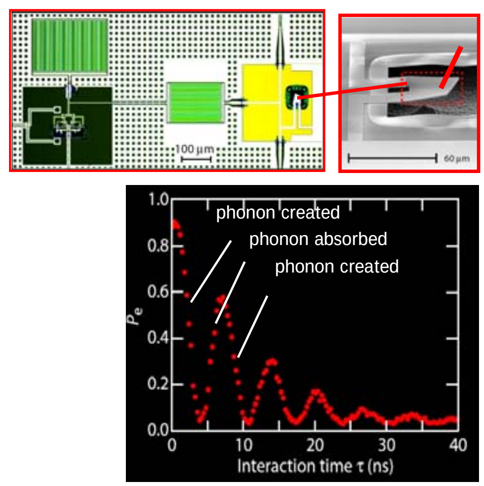



*Figure 99: Quantum State Mechanical Resonator*

**External Academic User: Optics/Electronics: Coupled vertical gratings on silicon for applications in WDM, *Dawn Tan in Fainman Group, University of California at San Diego***

Utilizing electron beam lithography resources at the UCSB facility, researchers at UCSD have been conducting research into coupled vertical gratings in SOI-based optoelectronic devices for use in wavelength division multiplexing networks.The ability to take advantage of the mature complementary metal oxide semiconductor fabrication infrastructure ensures the cost effectiveness of fabricating on SOI.The figures below show an SEM of a coupled grating add-drop filter of 60nm gap width along with a graph of the add (red)-drop(blue) transmission

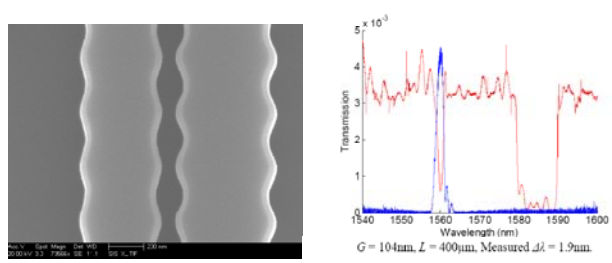



*Figure 100: Grating and specturm*

spectra . A large free-spectral range of >70nm and channel bandwidth tailoring has been demonstrated.(*Proc. of SPIE Vol. 7607, Jan 2010). (Fig. 100).*

### 7.8.3 Operations and Capital Acquisitions

The UCSB facility hosted 493 research users over the span of Mar. through Dec. 2010.This includes 50 external academic user, 132 small company users, and 34 large company users for a net 44% external cumulative user base.The external academic user numbers have increased from 40 in 2009 to 50 through Dec. 2010.The largest increase in user numbers came from the small company sector, with several companies ramping up R&D efforts and six new small companies using the facility.Average lab hours per month have leveled off at close to 6000.The number of cumulative remote users has stayed steady near 30, but the number of remote hours per month has increased significantly from 40 to 65.There were 18 new projects since last reporting, bringing the total number of new external research projects is up to 194 since the inception of the NNIN, 85 of them from academic institutions (4 foreign) and 109 from industry.The UCSB facility continues to house a diverse community comprised of significant numbers of users from Physics (11%), Materials (20%), Electronics (18%), MEMS/Mechanical Engineering (10%), and Optics (33%).

UCSB continues to improve process offerings through capital purchases.These purchases expand process capability and increase capacity to accept new users. In 2010, equipment purchased in 2009 were received and installed and other systems were purchased.These systems include:

- Advanced Vacuum PECVD.Purchased in early 2010 and received and installed in late 2010.The new system was obtained to increase capacity for PECVD Silicon nitride and oxide films and to add a low stress nitride process to the facility (ARRA and facility funds).
- Oxford FlexAL Plasma Atomic Layer Deposition.Installed in 2010.System is fit with silicon, aluminum, titanium, hafnium, and zirconium precursors for metal-oxides and nitrides. (facility and NNIN funds).
- JEOL 7600F FESEM. Installed in 2010.Purchased for nanoscale imaging of insulating films without need for metal coatings, a needed capability for many users (ARRA funds)
- Xactix XeF2 etch system.Installed in 2010. Purchased for dry release etching of MEMS structures (ARRA funds)
- FineTech Lambda flip-chip bonder.Purchased and installed in 2010.System purchased to replace older research devices equipment and to provide increased substrate size, alignment accuracy (0.5um), bond force range, and formic acid environment for solder bump bonding.Used in many hybridization applications (NNIN and facility funds)
- ASML 5500/300C DUV (248nm) stepper. Purchased and received in 2010.Installation in Feb-Mar 2011.Equipment expands optical lithography to deep sub-micron (0.1-0.2um) regime and increases capacity in the lab. ASML system accommodates piece parts.(facility funds)

The UCSB facility has added two FTE for equipment/facility/user support in 2010.

### 7.8.4 Education, Diversity, and SEI

In 2010, UCSB hosted NanoDays at the Santa Barbara Museum of Natural History, having hands-on activities for 490 community members of the general public. This event reached all ages, including building a giant model of a carbon nanotube, to using an actual atomic force microscope (AFM) to see the nanoscale features of a butterfly wing.

UCSB trains talented, motivated people of all ages who want to learn nanotechnology in an educational clean room. In 2010, 2-day chip camps reached 112 students and 19 teacher and community members, providing opportunities for females (61%) and underrepresented (27%) students to learn basic nanofabrication processing techniques. Chip camps serve as a pipeline for students into longer research experiences.

In 2010, UCSB provided research experiences that actively engaged 6 college students, and 4 secondary science teachers in a clean room laboratory, so they could contribute to real-world nanoscale research. These activities are part of the larger NNIN REU and RET programs. All research experiences are similar in that they participate in nanoscale research over a summer, and later they present it through an oral presentation, a poster presentation, and through a written report (or, in the case with teachers, curriculum is developed based on that research). The experiences differ in the target participants, and the length of time during the summer. The particulars of these programs are summarized below.

### Undergraduate Research Experiences (REU):

- Research Experience for Undergraduates (REU) recruits 6 students (33% females) from all over the US

### Research Experience for Teachers (RET):

- 6-week summer research for local secondary science teachers: 3 male, 1 female, 1 Hispanic
- classroom follow-up: 112 high school students: 47% females; 42% minority
- curriculum dissemination at the National Science Teachers Association annual conference: we brought 4 teachers: 3 females; 1 Hispanic

Our Research Experience for Teachers (RET) program has three components:

1. the research and curriculum development (done over a summer—teachers do research and then develop curriculum based on that research)
2. follow-up (impact measured in the number of students who the NNIN Coordinator sees the teacher do the activities that the teacher developed as part of the program)
3. dissemination of nanotechnology activities both locally and nationally: Teachers who participated in UCSBs 2009 RET program shared their curriculum with other teachers at the 2010 NSTA annual meeting in Philadelphia.

The following education programs had a component addressing the societal, environmental, and ethical implications of nanotechnology.

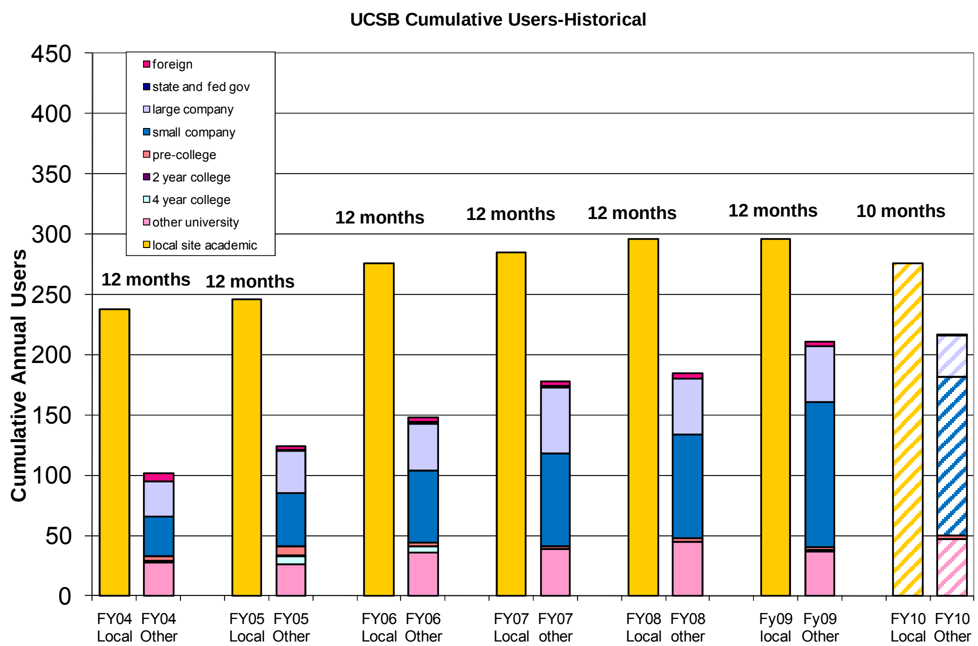
In support of SEI activities, UCSB has engagement on several fronts.New users are currently directed to the video presentation on the main NNIN SEI site as part of their lab orientation.To improve on this, a new on-line, interactive lab orientation presentation encompassing safety, lab policies, lab culture, and SEI is now being developed.A new user version and a shorter refresher version for existing users will be made.UCSB will collaborate with other sites for the SEI content.In further support of SEI related activities, UCSB is co-sponsoring a 5 part lecture series, beginning in January 2010, on research ethics, the final lecture being a specific lecture on ethics in nanotechnology research.The series was put together by the UCSB Office of Research. We are advertising the lecture and encouraging our users to attend.In addition, educational programs incorporating an SEI component reached 583 people as listed below:

- The NanoDays event was done in collaboration with UCSBs Center for Nanotechnology in Society, and the Center for Environmental Implications in Society. Volunteers from these organizations manned tables and explained possible impacts of nanotechnology on society, reaching 490 people (all ages; 198 children/students, 292 adults/seniors).

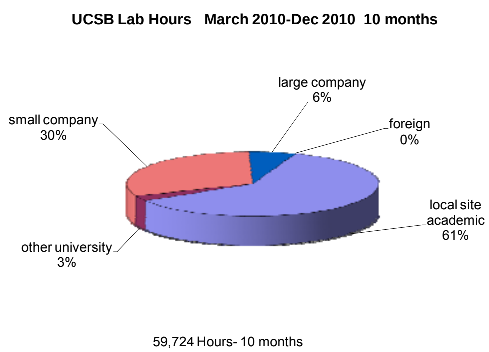
- Chip camp with 64 students from Santa Barbara Junior High School had an hour long interactive discussion, breakout session, and presentation (the students presented) about the SEI of nanotechnology.
- Curriculum developed by an RET participant (done in an RET follow-up) had an hour-long activity with 11 students on advances in airport scanning technology, and a discussion ensued about the societal and economical impacts of airport scanning technology, and the need to balance privacy and safety.

## 7.8.5. USCB Selected Statistics

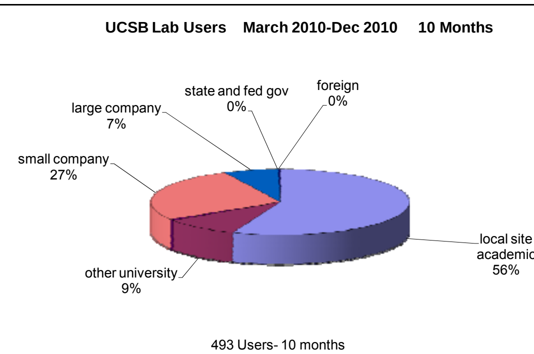
a)Historical Annual Users



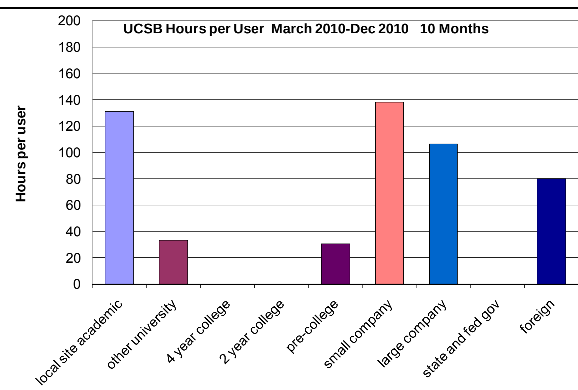

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

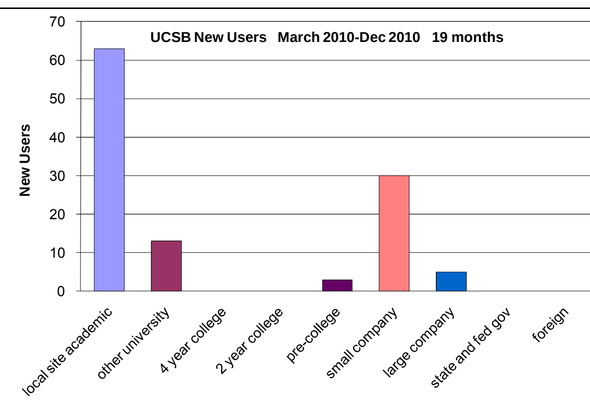



*Figure 101: Selected Site Statistics from UCSB*

## 7.8.6 UCSB User Institutions

| | | |
|---|---|---|
| *UCSB* | | |
| March 1, 2010 - Dec 31, 2010 10 months | | |
| **Outside US Academic** | **Small US Companies** | **Large US Companies** |
| California Institute of Technology | AdTech Optics | Intel |
| Montana State University | Advanced Integrated Photonics | Cree |
| Pennsylvania State University | Advanced Nanostructures | Emcore |
| Stanford University | Advanced Research Corp | FLIR |
| University of California, Berkeley | Advanced Scientific Concepts | Hewlett-Packard |
| Univeristy of California, Riverside | Aerius Photonics | Lockheed Martin, SB Focal Plane |
| University of California, Santa Cruz | Applied Nanostructures, Inc | Nano and Micro Technology Consultants |
| University of California, San Diego | Asylum Research | Northrop Grumman Corporation |
| University of Arizona | Aurrion | Raytheon |
| University of Colorado, Boulder | Calient Networks | Robert Bosch LLC |
| University of Minnesota | Cbrite | Veeco Metrology, LLC |
| University of Southern California | Cynvenio Biosystems | |
| University of Texas Austin | Etamota Corporation | |
| University of Washington | Freedom Photonics | |
| Washington State University | Grandis, Inc. | |
| Washington University St. Louis | Haylcyon Molecular | **International** |
| Wayne State University | Illumitex | Institut Catala de Nanotecnologia |
| | Inlustra Technologies | University of Augsburg |
| | Innovative Micro Technologies | North Maharashtra University |
| | Invenios | |
| | Kaai | |
| | Kavana Technology | |
| | Lumenz | |
| | OptiComp | |
| | Ostendo Technologies | |
| | Pacific Biosciences | |
| | Praevium Research | |
| | QmagiQ | |
| | Santa Barbara Nanotech | |
| | Semisouth Laboratories | |
| | Soraa | |
| | Superconductor Technologies, Inc. | |
| | TelAztec | |
| | Transphorm | |
| | Uriel Solar | |
| | | |

## 7.9 University of Colorado Site Report

### 7.9.1 Summary

In its second year of operation, the Colorado Nanofabrication Laboratory (CNL) experienced further growth in part due to the availability of the newly renovated facility and the addition of several processing tools that were funded with ARRA funds. The number of users increased by 50% while the hours of use increased by 100%. The education and outreach activities were expanded with a specific emphasis on energy which is one of Colorado's focus areas. A successful symposium on Photovoltaics was held in October 2010 with solid participation by researchers from the National Renewable Energy Laboratory (NREL) and the Colorado School of Mines (CSM). New education and outreach activities include the participation in Nanodays, the addition of several SEI events and joint REU activities with CSM and NREL.

### 7.9.2 Technical Focus Areas

The technical focus areas are linked to local research strengths in precision measurements and energy.Initiatives in each area are discussed next:

#### Precision measurements

Related research activities in Colorado are concentrated at NIST and JILA, a joint institute supported by NIST and the University of Colorado. We started interactions with both institutions by exploring the needs of potential users and identified new capabilities that are within reach. Specifically, we found that there is a large interest in rapid prototyping with modest resolution as provided with a maskless lithography system, fast turn-around maskmaking for optical lithography and $XeF_2$ vapor etching and chlorine-based RIE etching for high-Q resonators and GaAs waveguides. E-beam lithography and UV compatible filters are also of interest. Discussions with current and potential users are ongoing as we are looking to match their needs with existing capabilities, potential upgrades and planned equipment acquisitions. We are also soliciting REU projects from these researchers, which initiates interaction and advertises our capabilities to this research community.

#### Energy

Energy research in Colorado is rapidly growing with a clear focus at NREL and multiple Colorado-based initiatives such as RASEI, a multi-university research initiative, the Center for Revolutionary Solar Photovoltaics (CRSP) and the Renewable Energy Materials Science and Engineering Center (REMRSEC) at the Colorado School of Mines. The REMRSEC at CSM has been identified as a complementary NSF-funded research effort in Colorado. Their focus is on materials including nanoparticles and chalcogenides for thin film solar cells, advanced membranes and clathrates for hydrogen storage. NREL has a long track record pursuing photovoltaics and hold numerous records for highly-efficient solar cells. They are set up as an independent research unit with their own funding and facilities, but welcome interaction with Universities across the globe. We have reached out to both NREL and CSM REMRSEC researchers and invited several of their researchers to our "Symposium on Nanotechnology and Energy", with emphasis on Photovoltaics. This symposium provided visibility of the CNL to this community. In addition, we coordinated several REU activities with that of the CSM REMRSEC and will continue to do so in the future. Furthermore, we identified transparent conducting oxides, such as ITO and ZnO to be of interest to the local photovoltaic research community and developed deposition processes for both.

### 7.9.3 Research Highlights

The following are examples of research results that were obtained by users of the CNL facility during the past year:

- **Single Aperture Astronomy with a Diffracting Pupil, Prof. Tom Milster, University of Arizona.** This project aims to overcome the astrometric errors caused by optical distortions on imaging telescopes. This new technique enables sub microarcsecond astrometry with medium-size (<2-m) space telescopes, and can be used simultaneously with coronagraphy for exhaustive characterization of exoplanets (mass, spectra, orbit). The technique uses an array of 10 μm dots over the primary mirror causing diffraction spikes on the image due the polychromatic nature of the source. The spikes are used as reference for the astrometry measurements and encode any aberration of the optical system. Prototype mirrors with the small diffractive dots have been manufactured by lithography and first results, obtained with the diffractive mirror, demonstrate the diffraction spikes which calibrate distortions in the optical system.
- **Graphene-based Quantum Interference Control Devices, Brian Benton, University of Minnesota, IOWA.** This project involved the fabrication of a single-layer of graphene suspended above a silicon substrate as quantum interference control detectors. The detectors are fabricated with optical lithography resulting in 10 μm long, 2 μm wide graphene bridges. Such detectors allow for direct detection of the carrier-envelope phase evolution in ultrashort optical pulses.

### 7.9.4 Operations

Focus of year two was: 1) further completion of the facility through additional remodeling and acquisition/installation of equipment, 2) process development that benefits current users and supports focus areas, and 3) increased visibility of CNL. This effort yielded a sustained level of growth during year two and is expected to enable further growth in the following years.

Additional remodeling of a 750 sq ft lab was completed in October 2010 and serves as space for additional deposition systems and packaging tools.

Additional equipment that became available to the users includes a Temescal 4-pocket E-beam evaporator, a Plasmatherm dual chamber SLR series RIE, a Plasmatherm PECVD 790 deposition system, a wirebonder, the STS ICP etcher, the IMS SF-100 Xpress maskless lithography system and an AFM upgrade including pen dip lithography. The last three tools were purchased with NSF funding through the ARRA program.

Further equipment was obtained from researchers across campus, who donated their used equipment to the CNL user facility. This includes a dual chamber deposition system, a ball bonder, and a stereo lithography system. An equipment proposal was submitted to NSF for an ALD system, which is to be placed in the CNL user facility.

Visibility of the facility has been increased through educational activities such as Nanodays, the Photovoltaics symposium, and the REU program. CSM and NREL were specifically targeted as they represent a significant group of potential users with research activities that match our energy focus area. Interaction and joint activities were pursued with the REMRSEC at CSM and the photovoltaics researchers at NREL, including lab tours, discussion of the facilities and a joint poster session.

The operational changes and improvements have resulted in a significant increase in the number of users and number of hours of use. For the period of 3/1/10 – 1/31/11, the number of users increased to 98 which is a 50% increase over last year and half of our five year goal. Annual use of the facility has increased to 15,000 hours, more than twice that of last year and already approaching our five year goal.

Of the 98 current users, 40% perform research on MEMS, while newly trained users are more evenly divided between MEMS (21%), electronics (17%), optics (25%) and material science (17%).

As the facility has been renovated and upgraded, the operational focus is further shifting towards attracting external users, especially those performing research in our focus areas. Two new initiatives are process development aimed at such activities such as electro-plating, conducting oxides and gray scale lithography, and the establishment of a remote user access program. To date, 20% of our users are external and 2% of the use is by remote access.

### 7.9.5 Diversity oriented initiatives

Overall, we have aimed to be inclusive in all of our activities, particularly with respect to underrepresented groups, specifically hispanics and woman.

Outreach activities have been identified as a prime opportunity to promote diversity, from the REU program, the Symposia, to Nanodays, and K-12 oriented presentations and activities. Inclusion of women has been straightforward so far, while inclusion of minorities has been identified as requiring further improvement. Through CSM we have been able to get in touch with the local hispanic community, through which we will advertize our education and outreach events, with an initial focus on lab tours of the CNL and technical presentation at their events.

### 7.9.6 Education oriented contributions

Our main focus in education is on establishing educational activities that can be repeated on an annual basis, thereby gradually improving their scope, quality, effectiveness and efficiency from year to year.

This year's REU program included 5 NNIN REU's, two students working on SEI and a chemical engineering REU which was funded by a CNL user's REU supplement. The REU students were placed in different departments and CNL staff worked with the advisors to ensure a feasible and successful project. A mentor training was added this year and the student training schedule was accelerated to maximize the available time for research. Three full-day events were organized jointly with the REU program of the REMRSEC at CSM, including technical presentations, lab tours, a poster session, an SEI discussion and one-on-one interaction.

The annual workshop covering basic nanofabrication processes was held for the second time June 8-11, 2010. The lectures were recorded and are available to registered users throughout the year as streaming video with slides. The hands-on lab experiments are available as supplemental training for CNL users.

A Symposium on Nanotechnology and Energy with emphasis on Photovoltaics was held Oct. 25-26, 2010 in Boulder, CO. It consisted of 19 oral presentations, a poster session and lab tours. Plenary speakers included Prof. Martin Green from UNSW and Dr. Arthur Nozik from NREL. A total of 121 people registered for the symposium, about half were local participants, the other half primarily from NREL and CSM.

A special effort was made by CNL staff to participate in other NNIN and local outreach activities, including the REU convocation in Minneapolis, the Society for Hispanic Professional Engineers Meeting in Cincinnati, a panel discussion on how to get a job in a tough economic environment at CSM, presentations at Evergreen Middle School, and participation in the international Winter School for Graduate students in Bangalore, India. The experience gained from these activities will be used in our own education and outreach activities.

### 7.9.7 Society and ethics oriented activities

Our society and ethics oriented activities received a big boost as we engaged Prof. Carl Mitcham of the Colorado School of Mines. His research and scholarly work is on the philosophy and ethics of science, technology, and engineering. Last summer, Prof. Mitcham moderated several sessions on SEI for CNL users including one in combination with the SEI webcast by CNF.

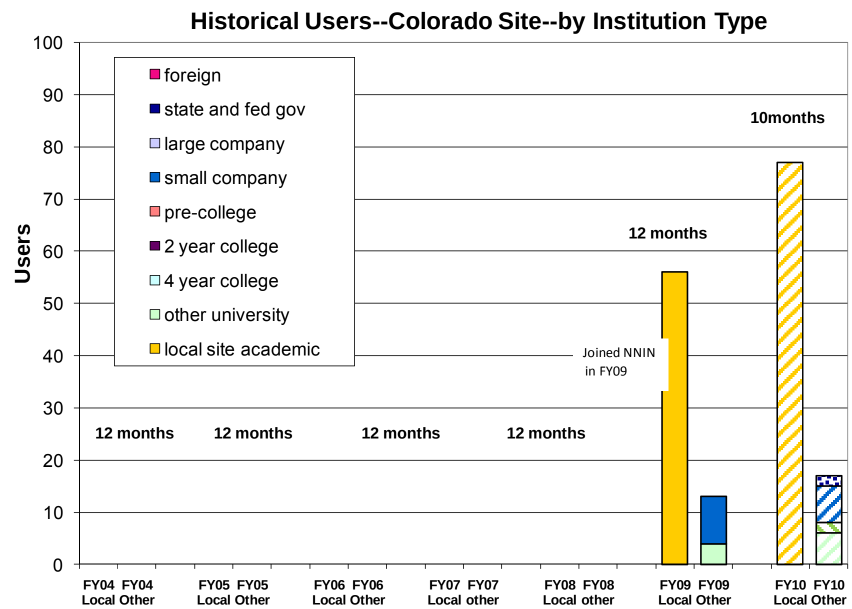
He also supervised 2 SEI REU students during the summer, which were co-funded by the CNL and the REMRSEC at CSM. Both students are electrical engineering majors with a strong interest in SEI. This work resulted in an ethics checklist and a completed social impact survey as well as a newly developed SEI training section for the CNL website.

The SEI material was first included in the annual workshop in June 2010 and is being incorporated into all user training. SEI posters highlighting these activities, including the awareness posters developed by Cornell have been posted in the facility.

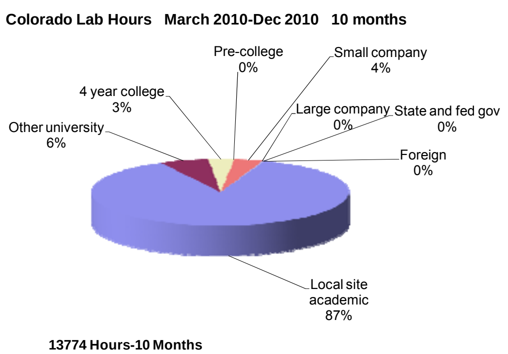
---End of Colorado Site Text Report---

## 7.9.8 Selected Univ. of Colorado Site Statistics

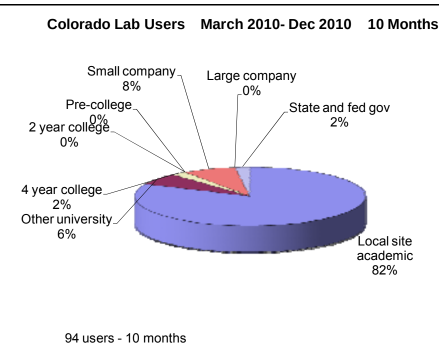
a)Historical Annual Users



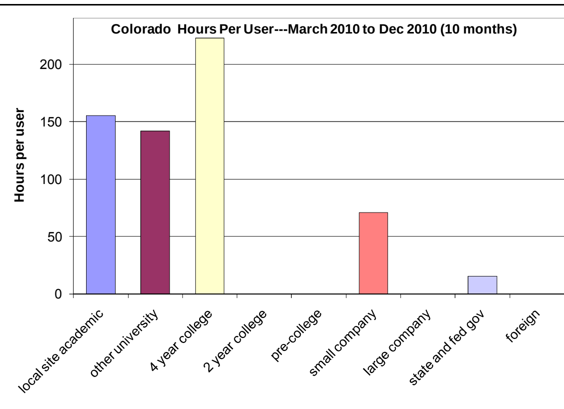

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

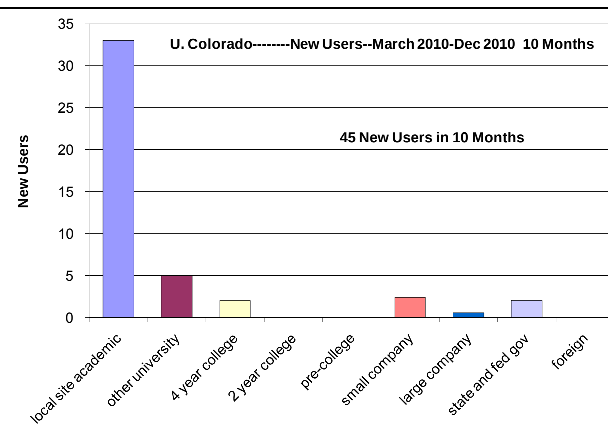



*Figure 102: Selected Colorado Site Statistics*

### 7.9.8 University of Colorado User Institutions

| Outside US Academic | Small company | State and Federal |
|---|---|---|
| Arizona State University | Aymont Technology, Inc. | JILA |
| Grinnell College | BiOptix LLC | NREL |
| Rose Hulman Institute of Technology | Oliver Licensing | NIST |
| University of Arizona | Phase Three Product Development | |
| University of Buffalo | TDA Research, Inc. | |
| University of Minnesota, Twin Cities | TrueNano, Inc. | |
| University of San Diego | Vescent Photonics | |

## 7.10 University of Michigan Site Report

### 7.10.1 Technical Focus Area

The Michigan Lurie Nanofabrication Facility (LNF) focuses primarily on micro electro mechanical systems (MEMS), complex integrated microsystems, and micro and nanotechnology. Applications of integrated sensors/actuators and microsystems include health care, biology and biochemistry, medical implantable microsystems, chemistry, environmental monitoring, and homeland and infrastructure security.

Michigan has hired domain experts to lead its efforts both in geosciences and in computation and nanoscale modeling. Dr. Helene Craigg from the Center for the Study of Matter at Extreme Conditions at Florida International University, was hired as the geosciences domain expert. She has expertise in physical properties of minerals and nanomaterials, high pressure and characterization techniques. Dr. Behrouz Shiari comes to Michigan from Carleton University in Canada, where he was working on multiscale modeling for nanomechanics. He leads the Michigan site efforts on modeling of MEMS/NEMS and micro/nanofluidics devices.

Michigan's goals on geosciences include outreach to the geosciences community, catalyzing new collaborations between geo and nano researchers, educating the geo community on the application of nanotechnology in their geo research, and providing support for new users from the geo community.Several collaborative projects were initiated between geo and nano researchers during this past year, following the workshop on "Nano-enabled Sensing Microsystems for Geo Sciences" (February 2010): some of these projects are still in the initial phase of gathering preliminary data, and several moved on to formalized proposals. At this stage, two proposals have been funded: "Micromachined Sensors for Multi-functional and Autonomous Analysis of Geofluids: A New Approach to the Design and Performance of Chemical Sensors in Extreme Environments" (U of Michigan and U of Minnesota, funded by NSF) and "Raman-based Barcoding for the Identification of Toxic Marine Pathogens and Phytoplankton" (West Coast Center for Oceans and Human Health, U of Maine and U of Washington, funded by NOAA).Our activities in outreach included our participation in the annual American Geophysical Union Conference in December 2010. We hosted a booth and were able to interact with about 40 new different researchers. In addition, NNIN will have a booth at the Aquatic Sciences Meeting (ASLO2011) and will host a workshop on nanotechnology in geosciences: "Boost Your Research in Aquatic Sciences with the NSF National Nanotechnology Infrastructure Network (NNIN)".

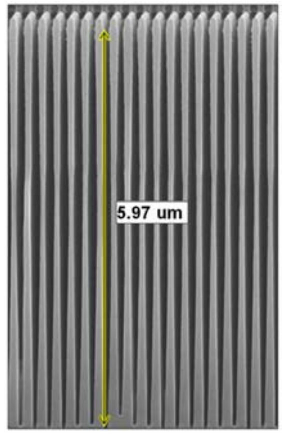
As part of our efforts in the NNIN/C program, we have installed the "Michigan Nano Computational Cluster" (MNC2). The cluster consists of 14 nodes, each containing a hexa-core Intel Xeon X5660 processor running at 2.66 GHz, 24 GB of memory. MNC2 contains 168 processing cores linked with Gigabit Ethernet, 12 TB of disk space. Fifteen software packages were added to the NNIN/C@U-M computational resources for users: MNC2 currently hosts simulation tools for micro/nanoscale systems including codes for first principles calculation, photonic devices, molecular dynamics, multiphysics, and multiscale. NNIN/C@U-M started a series of workshops on MEMS/NEMS modeling and simulation at both local and national levels. During this past year, we hosted two free, local workshops that were used to inform users of MEMS/NEMS modeling community's activities, but also to provide a platform for networking amongst researchers interested in MEMS/NEMS development. In addition, NNIN/C@U-M is also planning a national symposium on Advanced Modeling Methods of MEMS/NEMS and Micro/Nanofluidic Devices on April 19-20, 2011.

The Michigan site of the NNIN has also continued expanding its user community through many different events and activities: seminars and workshops on and off-site, participation in technical conferences, partnerships and discussions with local business organizations, etc. As a consequence, the LNF user community has significantly grown over this past year, both in number of users and in terms of the number of research groups, universities and companies served.

## 7.10.2 Research Highlights

Below are a few highlights for this past year from some of the LNF users.

Dr. Pran Mukherjee from the MIT Kavli Institute of Astrophysics and Space Research has been optimizing new Silicon DRIE processes in the LNF for diffraction gratings required for next-generation space x-ray telescopes.Critical-angle Transmission (CAT) gratings designed by MIT's Space Nanotechnology Laboratory are one such advance, combining the advantages of transmission and reflection gratings. Silicon-on-insulator wafers enable double-sided processing of thin films supported by a bulk silicon support structure. This all-silicon design removes any thermal expansion coefficient mismatches between the grating and its supports.The silicon oxide mask is patterned using interference lithography on an optically matched material stack, and deep-reactive ion etching is used to form both the grating and its support structure. (Fig. 103).



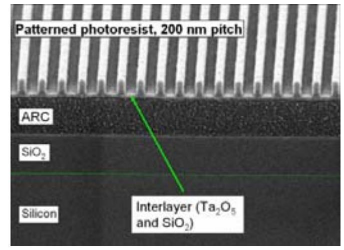




*Figure 104* Top: Electron micrograph of the patterned mask stack prior to any etch steps.
*Left: Cross-sectional electron micrograph of silicon grating etched by deep-reactive ion etching.*

Prof. Yon Xu's group at Wayne State University has been using the LNF for a variety of projects over these past several years. The goal of one recent project is to discover multi-site retinal stimulation paradigms that are capable of maximizing the amount of spatial information transmitted to the brain, and thus would have the greatest potential for generating spatially-structured visual percepts in blind humans. Parylene stimulating electrodes for this study were partially fabricated at LNF. A 10 μm thick parylene C layer is first deposited.Then platinum traces and electrodes are evaporated and patterned using lift-off method.Finally another 10 μm thick parylene C layer is deposited and patterned to expose the electrodes and contact pads.

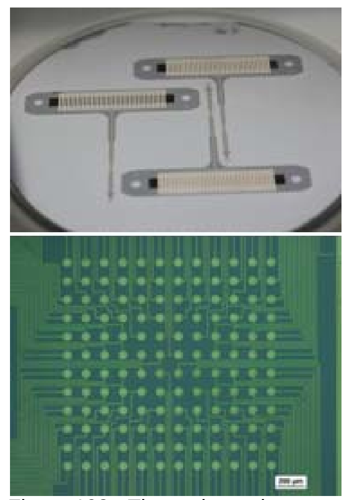


*Figure 103: Three electrode devices (left) and 12x12 array of parylene stimulating electrodes (top).*

Prof. John Hart's Mechanosynthesis Group at the University of Michigan focuses on research related to carbon nanotubes (CNTs). Lithographically defined patterns of vertically aligned CNTs are transformed into three-dimensional (3D) geometries by self-directed capillary action initiated by liquid condensation.Because this process, called capillary forming, is governed by the local capillary force distribution inside each assembly of CNTs, heterogeneous structures can be created simultaneously, and individual structures can be deterministically designed based on the process conditions. (fig. 105)

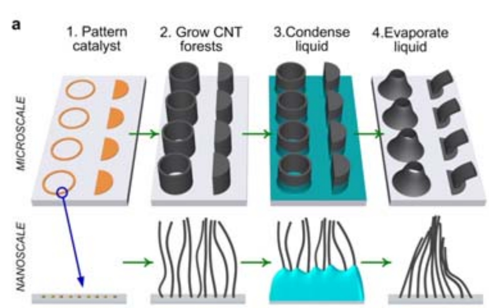



*Figure 105:* Fabrication of 3D CNT microstructures by capillary forming

The group has demonstrated that capillary formed CNT structures are over 100 times stiffer than as-grown CNTs, and enable self-directed formation of 3D CNT/polymer nanocomposites with stiffness exceeding conventional microfabrication polymers.This work may find future applications in cost-effective fabrication of biomimetic surfaces, metamaterials, multi-scale circuits, and novel sensors and actuators.

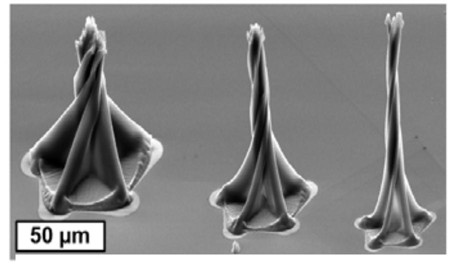
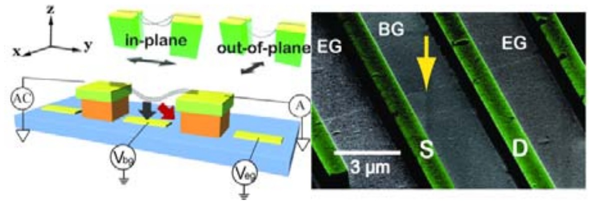



*Figure 106:* CNT micro-trusses

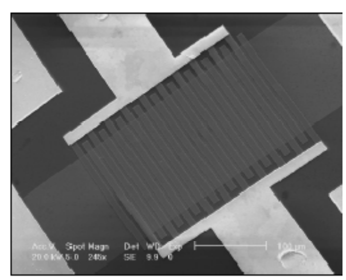
Another example of carbon nanotube based research is from Prof. Zhaohui Zhong's group at the University of Michigan. The gate-induced frequency tuning of nanoelectromechanical (NEM) resonators is known to be governed by two mechanisms: the elastic hardening effect which increases the resonance frequencies, and the capacitive softening effect which decreases the resonance frequencies. In a conventional nanotube resonator design, only the bottom-gate is used for frequency tuning. The nanotube vibrational motions are perpendicular to the electric field direction, resulting in negligible spring softening. To this end, his group reports the capacitive spring softening effect observed in single-walled carbon nanotube NEM resonators. The nanotube resonators adopt dual-gate configuration with both bottom-gate and end-gate capable of tuning the resonance frequency through capacitive coupling. Interestingly, downward resonance frequency shifting is observed with increasing end-gate voltage, which can be attributed to the capacitive softening of spring constant. Furthermore, in-plane vibrationalmodes exhibit much stronger spring softening effectthan out-of-plan modes. His dual-gate design should enable the differentiation between these two types of vibrational modes, and open up new possibility for nonlinear operation of nanotube resonators.




*Device geometry of dual-gate SWNT resonators and qualitative sketch of how electrostatic force interacting with CNT when $V_{bg}$ or $V_{eg}$ is applied*

*Figure 107: SWNT Resonators*

Prof. Mina Rais-Zadeh's group uses the LNF for her device fabrication, and has also been working with our NNIN/C domain expert on the numerical modeling of such devices. Micromechanical filters in which two acoustic resonators are coupled through an elastic medium are known to have a better out of band rejection and lower insertion loss within a compact area. Analysis of such acoustically coupled filters is non-trivial, and there is no analytical or empirical solution to obtain the filter transfer function pre-fabrication. In this project, a finite element model is developed to simulate the filter scattering parameters for the thin-film piezoelectric-on-substrate (TPoS) filter configuration. The number of geometric variables in such filters is quite large and to study the effect of each individual variable, a detailed simulation setup was established to iterate through the different variables. The analysis of this simulated data is used to develop a comprehensive design strategy for the given TPoS filter configuration. The most significant contribution of this project is in the reduction in cost and time required for filter development. While the presented work focuses on the TPoS filter configuration, the model can be easily adapted for a wide range of acoustically coupled filter topologies.



*SEM image of a TPoS filter with electrode fingers. Stack consists of 5 um 1 um AlN and 100 nm Mo electrodes.*

*Figure 108: TOoS Filter*

Prof Kenn Oldham's group at the University of Michigan Microdynamics Laboratory focuses on the design, fabrication, and control of high-performance microactuators, such as highly-integrated systems utilizing thin-film piezoelectric materials, for instance. This group is developing autonomous terrestrial micro-robots inspired by biological systems. By integrating the high work density of thin-film lead-zirconate-titanate (PZT) materials with complex, high-aspect ratio silicon structures, micro-robotic legs with large ranges of motion in multiple degrees of freedom can be realized.Current activities include pre-processing of silicon wafers prior to thin-film PZT deposition to create more robust structures and full robot prototypes, as well as studies of foot-terrain interaction of robots on on the order of 10 millimeters in length. To provide feedback for closed-loop control, Prof. Oldham and his students have demonstrated high-resolution piezoresistive and piezoelectric sensors integrated directly with the primary actuators for collocated sensing of actuator movement

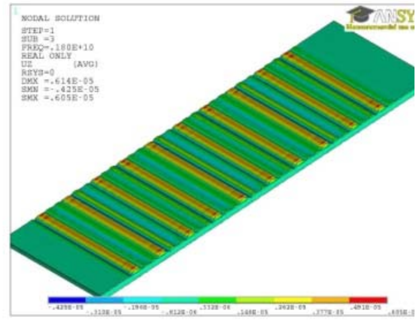



*Figure 109: Finite element model of the piezoelectric layer deflection at 180 GHz frequency*

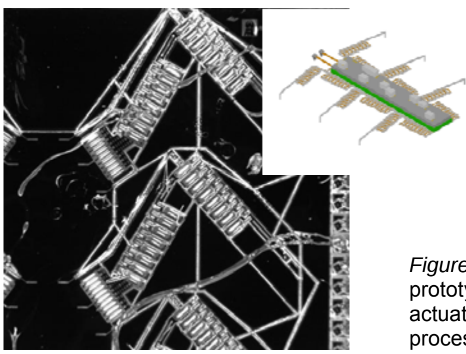


*Figure 110:* Concept drawing and prototype terrestrial robot with dummy actuators for high-yield, high-aspect ratio process testing.

## 7.10.3 Acquisitions, Changes and Facility Operations

The Lurie Nanofabrication Facility now occupies about 12,000 sq.ft and several new pieces of equipment have been acquired and/or installed during this past year.Tools that were installed during the previous year are now operational.This includes the Tegal AMS-2004 AlN Sputter System, a single-wafer, load-locked sputter tool dedicated to producing high-quality Piezoelectric aluminum nitride films (AlN.) It uses Al conditioning and dual-AC target technology to eliminate the disappearing anode issues seen in standard DC and AC sputtering systems. This allows the system to deposit consistent, micron-level films with high purity, tunable stress and high quality crystalline orientation (FWHM < 2 degrees.).

In addition, the NanoInk DPN 5000 Dip Pen Nanolithography tool is now available to the LNF user community. It is a fully integrated system that allows researchers to rapidly and easily create nanostructure. Materials are transferred onto a surface by a scanning force microscope tip. Molecules are transferred from the tip to the surface through a water meniscus that forms in ambient conditions as the tip nears the surface. DPN enables the controlled deposition of a variety of nanoscale materials. The figure shows a lateral force microscopy image written on a gold surface by the DPN of mercaptohexadecanoic acid (MHA). The line is about 20 nm. We are also exploring DPN of iron nitrate (Fe(NO3)3) for use as the catalyst for CNT growth.

*Figure 111:Pattern of mercaptohexadecanoic acid (MHA) on the gold surface*

The new Hitachi SU8000 ultra high resolution SEM features a triple detection system along with a semi-in-lens type of objective lens to maximize surface and sub-surface information provided by the secondary and backscattered electron signals. A new top detector is a further advance on the popular upper backscattered electron detector used in the S-5500. By combining the top detector with the proven upper detector with ExB filter technology, Hitachi has now developed a new signal detection system for optimum contrast visualization of signals, generated from the sample especially under low-accelerating voltage conditions best suited for observation of nanomaterials. These signals include secondary electrons, low-angle backscattered electrons and high-angle backscattered electrons, which are acquired for observation of surface structures.

The Olympus LEXT OS4000 laser interferometer is a non-contact, non destructive method to measure dimensions and roughness. This tool displays 3D images while providing true dimensional data. With a repeatability of 0.02 micron and accuracy of 2% for the 100X objective, the tool has a 100x100 mm motorized closed loop stage with stitching capabilities and can accommodate samples of a variety of heights and sizes. The tool is equipped with digital zoom and lighting, 5X, 10X, 20X, 50X and 100X confocal objectives and a Nomarksi prism which enhances the surface morphology of the images complementing the laser images. The polarizer also facilitates the measurement of transparent materials. The light source is a 405 nm LED. This allows the measurements of submicron features accurately. The tool is fast and user friendly; ideal for characterization of processes such as etching, plating, polishing.

The LNF is also releasing a new deep glass etcher: the SPTS' Omega® APS process module is an ICP-based high density plasma source, designed to etch materials which are difficult to etch using conventional RIE or ICP sources. The process chamber is of metallic construction and is heated to reduce the level of deposition on it, thereby increasing process stability and increasing the mean time between cleans by more than a factor of 10. Through the use of permanent magnets, the plasma is confined contributing to an increase in plasma density necessary for the successful etching of strongly bonded materials, and also hinders undesirable deposition inside the chamber. This system is capable of etching deep, high aspect ratio features in glass, quartz, silicon nitride, SiC, and other hard to etch dielectric materials.

### 7.10.4 Diversity Oriented Contributions

To increase underrepresented minority participation in nanotechnology, we sponsored a booth and 90-minute presentation at the NSBE regional meeting in Indianapolis, IN, and supported the NNIN showcase for students event at the SHPE conference held in Cincinnati, OH. We have also given talks at smaller minority-serving undergraduate institutions.

The LNF also plans to continue participating in the Laboratory Experience for Faculty (LEF) in 2011 and has recruited two minority faculty members interested in participating. The 2010 LEF program at Michigan has resulted in a sustained collaboration between the faculty research group (Prof. Andre Taylor, Transformative Materials and Devices group, Yale University) and Prof. Steve Forrest at the University of Michigan.

### 7.10.5 Educational Activities

The LNF has continued its education mission through diverse programming that reflects the K-Gray spectrum of learning.

K-12 and general public:

- Spring/Summer Nanocamps specifically designed for middle and high school students which directly impacts over 100 students (~40% from underrepresented groups).During these one-day camps, students learn about key concepts of nanotechnology through a variety of hands-on demonstrations, including wafer patterning inside the cleanroom facility and SEM imaging of various

*Figure 112: Outreach Activity*

objects of interest (e.g. a fruit fly).The spring event was strategically scheduled to support the NISEnet NanoDays program and modules from the NanoDays kits were incorporated.

- Additionally, with the understanding that it is important to increase the awareness and understanding of nanotechnology among the public at-large, the families of Nanocamp attendees are now provided with facility tours and the Nanocamps end with a dynamic nanotechnology-related presentation by university faculty.
- Visits by school classes from elementary and secondary institutions.During these visits, high school students are provided opportunities to speak with a panel of undergraduate student volunteers to get a better understanding of the steps that are required to adequately prepare themselves for STEM majors that are relevant to nanotechnology. Elementary students have fun playing games that teach them how to don cleanroom suits and the phenomenon of self-assembly.
- In our continued effort to assist K-12 teachers with resources to help introduce nanotechnology into their classrooms, we are hosting a session at the 58th Annual Conference of the Michigan Science Teachers Association on February 26.This event will be used to recruit K-12 science teacher to a follow-up onsite workshop.
- Special NNIN award at a regional science fair for secondary students and contributed judges.Space was reserved in the following NanoCamp for all winners of the award.

#### Undergraduate Students

- Development of partnership with Oakland Community College (OCC) in support of a nanotechnology program.Our efforts in this regard include providing cleanroom training to OCC faculty on standard unit processes, such as lithography and etching, in order to allow them to better their course material.We are also discussing a program that will allow OCC students to work in the LNF as a capstone experience.
- 6 undergraduate students participated in the Michigan REU program this summer. In addition, two Japanese graduate students from the NNIN iREG program worked at the LNF during the summer.

#### Graduate Students and Professionals

- Several workshops and seminars on topics including tip-based lithography, optical characterization techniques (e.g. ellipsometry) and computation techniques for NEMS, MEMS and micro/nanofluidics were collectively attended by more than 100 faculty, industry professionals and graduate students.
- We also worked with regional sections/chapters of professional organizations such as IEEE, ACS and AVS to increase the visibility of the network among these particular communities. More specifically, NNIN staff provided additional support of the AVS Michigan 37th Spring Symposium entitled ***"White-LEDs for Automotive and General Lighting Applications"*** which was held on-site.Additionally, we also provided a faculty presenter for the ACS Fall Scientific Meeting entitled "***Making Stuff: The Science of Materials"*** which was held at Central Michigan University.

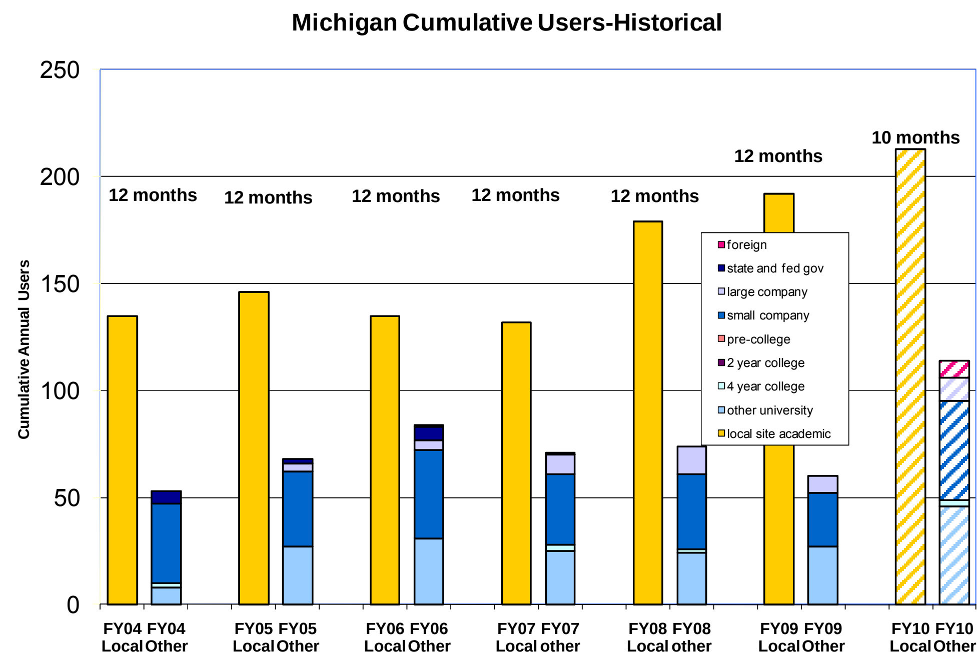
### 7.10.6 SEI highlights

In support of the Societal and Ethical Issues (SEI) thrust of the NNIN, we are now requiring new users to attend a roundtable focused on ethics in nanotechnology.Feedback on this approach has been overwhelmingly positive, with many researchers leaving with new perspectives on the impact of their research and the role that they play in shaping the public's understanding of their respective nanotechnology-related fields.

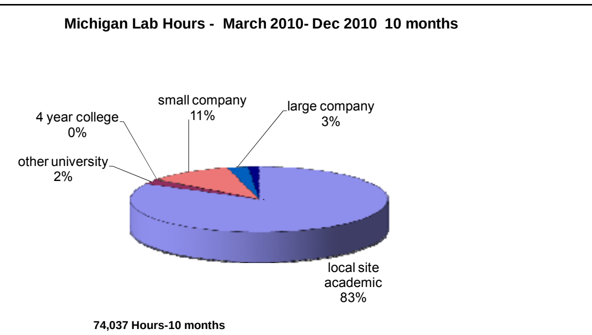
The presentation used to initiate this dialogue is a modified version of the presentation provided by prof Katherine McComas at Cornell.We are currently in the process of personalizing the discussion further by working with Prof. Robert McGinn to extract our site-specific data that was included in his work entitled ***“Ethics and Nanotechnology: Views of Nanotechnology Researchers.”***We will also leverage our interactions with Oakland Community College to further develop the discussions.

## 7.10.7 University of Michigan Selected Statistics

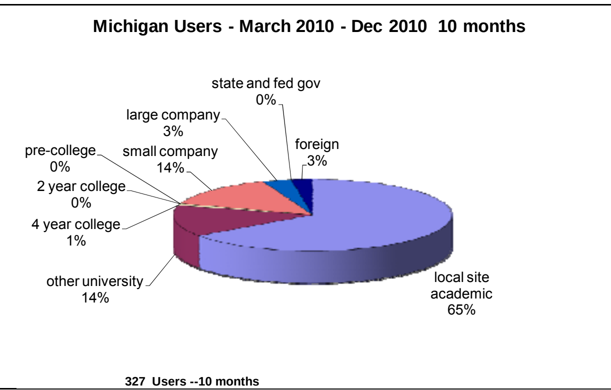
a)Historical Annual Users



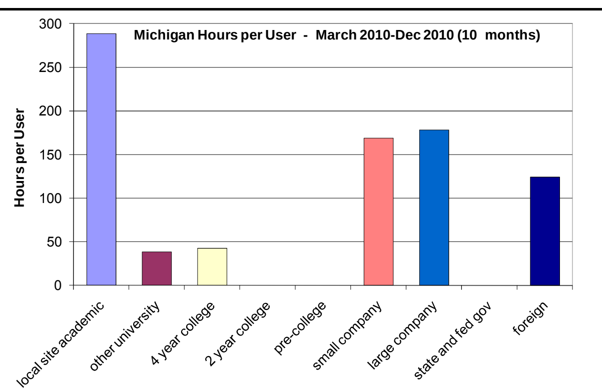

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

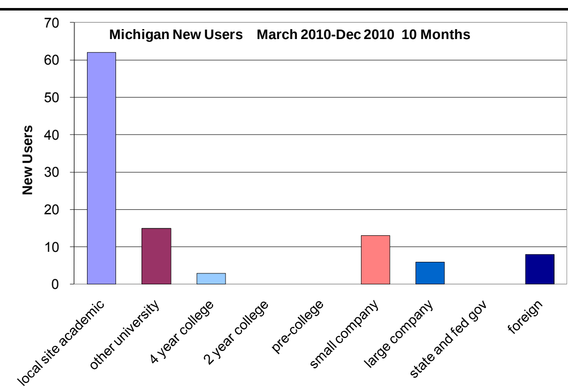



*Figure 113: University of Michigan Selected Site Statistics*

## 7.10.8 University of Michigan User Institutions

| NNIN Site: | *Michigan* | |
|---|---|---|
| **Outside US Academics** | **Small Companies** | **Large Companies** |
| Arizona State University | Advanced Micro Fab, LLC | Adobe Systems |
| Cornell University | BioArray Solutions, Inc | IMRA America, Inc. |
| Kent State University | Dexter Research Center, Inc | Toyota |
| MIT | ElectroDynamic Applications | Stryker Instruments |
| Michigan State | ePack | Universal Display Corporation |
| Montana State | Evigia Systems, Inc. | |
| North Carolina A&T | EVJump Solar | |
| Oakland Community College | Integrated Sensing Systems | **International** |
| Oakland University | JST Manufacturing | King Abdullah University of Science and Technology |
| Ohio State University | Lumedyne Technologies | Korea Institute of Science and Technology |
| Purdue University | MEMSIC | Kyung Hee University |
| Rensselaer Polytechnic Institute | Midwest MicroDevices | |
| Stanford University | Nanoselect, Inc | |
| University of California at Irvine | Neuronexus Technologies | |
| University of Nebraska | Ovonyx | |
| University of Texas Austin | PicoCal, Inc. | |
| University of Toledo | Picometrix | |
| University of Washington | Promerus | |
| Virginia Polytechnic Institute | Reliable Analysis | |
| Wayne State University | Silicon Resources | |
| Western Michigan University | Solargystics | |
| | Sonetics Ultrasound, Inc. | |
| | STIgma Free | |
| | | |

# 7.11 University of Minnesota Site Report

## 7.11.1 Summary of Initiatives and Activities

The Minnesota node focuses on serving a large set of external users in a variety of areas including electronics, MEMS and alternative energy. A primary performance metric is the number of external users.The node engages in an aggressive recruiting process.Over the last year our number of external users increased about 10%.We expect to finish the current fiscal year with about 90 external users from more than 50 distinct institutions.Our fraction of external academic users has risen significantly under NNIN sponsorship (currently about one third), with about half of these institutions being academic. The amount of lab fees that we receive per external user, however, is low. This puts a significant burden on our staff in terms of training and providing service to these users. We have hired Dr. Jim Marti as an external user coordinator to help us increase our number of new users.

Our new Canon i-line stepper, capable of 400 nm lines and spaces with ~100 nm overlay accuracy, is fully functional after a difficult start-up program.Adoption of the system continues to increase as users migrate from the older and much less capable contact printers.Contact printers continue to be the system of choice for very large feature sizes and when wafer fragments must be processed.

In support of improving our nano capabilities, the node has been successful in a recent NSF MRI program. This has enabled us to purchase a 100 keV direct write electron beam lithography tool.After an internal selection process, a Vistec EBPG system was acquired. This system has been installed and has gone through acceptance testing.The first users are now being trained.Capable of 50 MHz operation and with a 6 nm demonstrated resolution, we expect this system to be one of the most capable in the country for research users. We plan to use this system to not only service existing users, but also to improve our recruitment of new external users to the facility.

In the area of alternative energy, most of the research emphasis is in the area of thin film (second generation) and multijunction thin film (third generation) devices.The Minnesota node has just bought up a UHV deposition system dedicated to thin film solar cell work. Minnesota teamed with Colorado in October 2010 to present a PV workshop to advertise these and other complementary capabilities of the NNIN network.

## 7.11.2 Selected External and Internal Highlights

### Flexible Electrodes for Cortical Recording in Rats

Professors David Bahr and David Rector (Washington State) have developed a flexible electrode system for cortical recording in rats.The device was partially fabricated at the NNIN facility at the University of Minnesota, with the remainder being done at Washington State.The system uses gold on kapton to provide a flexible system that can be implanted between the skull and dura in rats for recording electrical activity in the brain during whisker activity in the rat.Adhesion testing and subsequent implantation were successful.The array has been used for over one year.

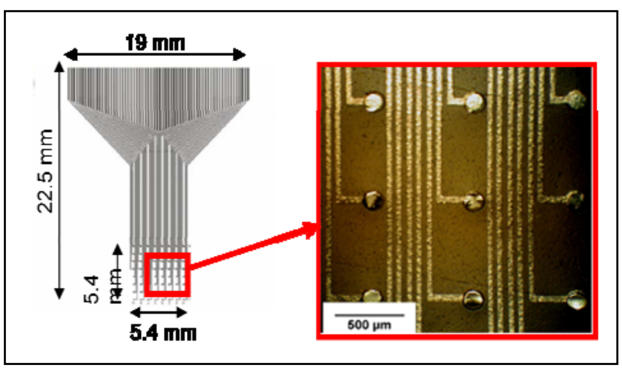



*Figure 114: Flexible electrode assembly*

## Micro Chemical Reactors and Integration of Microfluidics and Optics

Professor Stanley Pau from the University of Arizona used the Minnesota NNIN facility to help build integrated waveguides with microfluidic channels arranged in a spiral geometry for spectroscopic applications. Light is fed into the microfabricated system using fiber optics and collected after passing through the system. In one such device Professor Pau developed SU-8 based fluidic immuno-spectroscopic lab-on-a-chip devices for rapid quantitative detection of biomolecules.Similar structures have also been used as planar electrolyzers for hydrogen and oxygen generation.

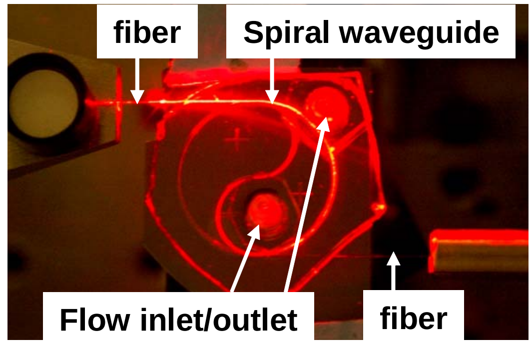



*Figure 115: Lab on chip*

## Novel Microfabricated Device for in situ Nanomaterial Testing

Professor Jun Lou from Rice University has used the Minnesota NNIN facility to build novel microfabricated devices for in situ nanomaterial testing.These devices allow the researchers to perform In situ tensile and single fiber pullout experiments on nanomaterials and nanocomposites respectively within an SEM/TEM chamber. Load application (and measurement) and deformation measurement for the specimens are performed with the aid of a nanoindenter. The design converts a compressive nanoindentation force applied to a shuttle to uniaxial tension on a specimen attached to a sample stage. The devices were fully fabricated at the Minnesota Nanofabrication Center.

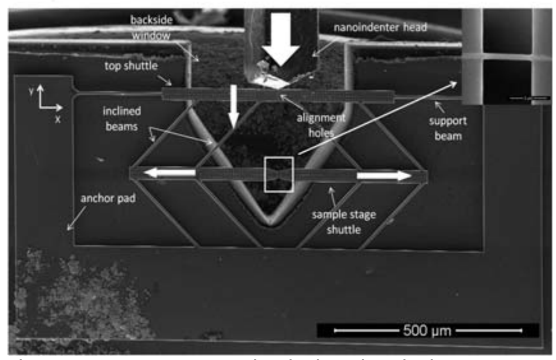



*Figure 116; Nanomechanical testing device*

## Photo-acoustic NeedleScope

Professor Shai Ashkenazi from Minnesota (Biomedical Engineering) created miniature ultrasound device to mount on the tip of a biopsy needle for image-guidance.This was done by depositing the materials needed for an opto-acoustic sensor on the tip of an optical fiber using e-beam evaporation.The sensor is paired with a fiber transmitting at 532nm.It was found that the sensor exhibits optical and mechanical resonance suitable for opto-acoustic ultrasound detection.The transmitting fiber emits intensities at a wavelength required for photo-acoustic generation in blood.These fibers have been successfully paired to create a complete transmit/receive ultrasound transducer.

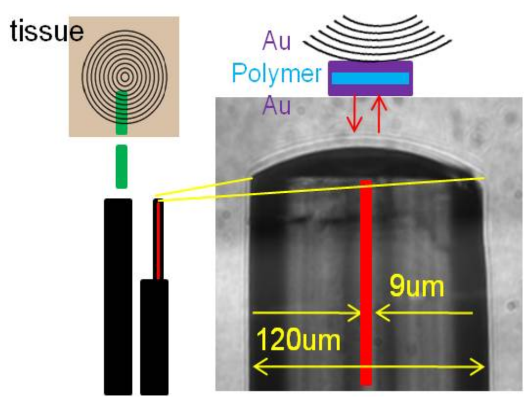



*Figure 117: Photo-acoustic Needle Scope*

### 7.11.3 Equipment and Facility Highlights

#### New Clean Room

Minnesota is working toward the design and construction of a new building which will include a new clean room.The facility (5000 $ft^2$ under filter, 10000 $ft^2$ gross) will more than double our existing space.Construction of the new facility, which will become the nano lab (the existing facility will continue to operate focusing on MEMS and teaching), is expected to begin in the summer of 2011, with move-in in early 2013.

#### Automated JEOL SEM

A JEOL JSM-6610LV SEM was purchased with ARRA funds.This system has several very useful features including EDX, 12" sample capability, and low vacuum mode for soft samples. Perhaps most importantly, it has a fully automated electron gun (focus, brightness, stigmation, and contrast). Inexperienced or infrequent users can get crisp images in a “one-button” operation mode. Furthermore, one can save gun settings to facilitate measurement of similar samples within a research group.

#### Vistec Electron Beam Lithography System

A Vistec EBPG5000+ tool was purchased, installed and is operational.This state-of-the-art nanopatterning tool has a 50MHz clock speed for fast writing, and can define features down to the 8nm size.A 100 KeV maximum beam voltage allows the system to pattern a wide range of resist types and thicknesses with negligible scattering of the beam. The beam current can be adjusted from 0.2 nA to over 100 nA, a feature which allows the user to optimize for either write speed or resolution, depending on the application. In addition to the standard laser-interferometer stage for positioning, the system uses a laser height sensor to dynamically determine the distance between the beam and the sample and adjust the focus accordingly.In system acceptance tests, sub 6 nm lines and sub 10 overlay were demonstrated in 25 nm of HSQ resist.

#### Resist Spin Coater for Stepper Processes

A new Brewer Science CEE resist spin coater was purchased for application of i-line resists for the canon stepper.The tool includes the edge bead removal option to keep the backside clean.

#### Spray Develop Station

A new Brewer Science CEE resist spray develop station was purchased to allow resist developing in an automated process that reduces developer usage and hazardous waste generation as compared to currently used immersion development processes.

#### Staffing

Matt Lowe was hired in August to take care of the information systems in NFC.One of his projects in NFC will be to port our lab operating software, Coral, to a new and more reliable hardware platform.In addition, we have hired Dr. Bryan Cord. Bryan holds PhD EE from MIT where he worked on electron beam lithography and e-beam resists. Bryan will be working with all of our users to ensure that they get the most out of the new Vistec electron beam lithography system.

### 7.11.4 Diversity

#### Tours & Presentations

On June 17, 2010 NNIN’s Outreach Coordinator, Dr. Jim Marti, gave tours of the NFC and presented a 2.5 hour class on nanotechnology to a group of 25 high school girls from schools around Twin Cities metro area.This class was part of a University-sponsored Exploring Careers in Science and Engineering event aimed at attracting a more diverse population to the fields of science, and engineering.

### Recruiting a more Diverse User Group

From early December through January 10, Dr. Marti contacted minority and female faculty members at ten colleges and universities around the state of Minnesota to invite applications to NNIN's Laboratory Experience for Faculty (LEF) Program.Two female faculty members, new to the NFC, have expressed interest in the program for the summer of 2012. These contacts helped the NFC reach out to new potential users and to build a more diverse user group.Dr. Marti will follow these new contacts up with visits and presentations at several colleges to further ties with these and other faculty.

## 7.11.5 Education Outreach Efforts Summary:

### Washington Tech Magnet School visit (w/ Katherine Cramer, CSE Outreach), March 5, 2010

Lecture and demos to inform and educate 30 middle school students on nano concepts, materials & fabrication.This was conducted in conjunction with the College of Science and Engineering's outreach department.

### NanoDays 2010 on campus, April 1, 2010

Demonstration/activity tables Activities and materials from the NISE Net NanoDays kits utilized with volunteer grad students staffing the tables.

Lab tours: Small groups were assembled for scheduled tours of faculty labs in Electrical Engineering, Chemical Engineering & Materials Science, and Mechanical Engineering.Tours were led by volunteer grad students in these research groups.

Nanofabrication Center staged lithography demonstrations outside cleanroom windows to demonstrate on a large scale what is happening in the lab at the nanoscale.

About 85 people from grade school to adults attended.

### Minnesota Science Museum NanoDays 2010, April 3, 2010

NNIN's Outreach Coordinator, Dr. Jim Marti, presented nanotechnology and microlithography demonstrations to the general public. Nanofabrication Center Director, Steve Campbell presented a Nano Outreach talk at NanoNight public forum, and other University of Minnesota faculty volunteered at the "Sit with a Scientist" forums.

### Introduction to Nanotechnology at the College of Science and Engineering's Exploration Day, May 5, 2010

The NNIN presented an introduction to nanoscale and science/technology topics to 70 public school children attending "Exploration Day" at the University of Minnesota's College of Science and Engineering. Topics covered included scale, types of nanotechnology, applications, lithography, activities on nanocoatings and self-assembly.

### BioMEMS and Microfluidics Short Course, May 20-21, 2010

This was the fifth offering of our overview of microfluidics for biomedical applications.Intended for those interested in becoming involved in the microfluidics field, but need a basic outline of what is possible and how the devices are designed and built.This course consists of a full day of lectures and discussions as well as a full day of clean room and laboratory experiences for 14 participants.

### Exploring Careers in Science and Engineering, June 17, 2010

The NNIN presented a 2.5 hour class on nanoscience and technology to about 20 high school girls from around the metro area.This was part of the University-sponsored Exploring Careers in Science and Engineering event aimed at attracting a more diverse population to explore careers in math, science, and engineering.

### Exploring Careers in Science and Engineering, June 17, 2010

The NNIN presented a 2.5 hour class on nanoscience and microlithography to about 25 high school students from around the metro area.This was part of the University-sponsored Exploring Careers in Science and Engineering event aimed at attracting a more diverse population to explore careers in math, science, and engineering.

### NNIN REU Summer Internship, summer 2010

Five NNIN REU students were selected to spend their summer at the U of Minnesota.Projects included DNA Electrophoresis, Microfluidic Immune System-on-a-Chip, Nano-Imprint Lithography, Photonic Crystals, Magnetic Tunnel Junction Based Spintronic Devices.

### NNIN REU Summer Internship Convocation, August 11-14, 2010

The University of Minnesota hosted this year's Convocation to provide a forum in which interns can share their results and network with their peers from other sites. It is an opportunity to experience the breadth of nanotechnology through the experiences of fellow students. The 3 ½ day research convocation included technical talks by all interns, presentations by Dr. Rathbun on NSF Fellowships and the iREU program, evening social activities, and a poster session.The Convocation was attended by 95 interns and 19 NNIN site staff.

### 6th Annual Minnesota Nanotechnology Conference, Oct 7-8, 2010

This two-day workshop at the University of Minnesota offers presentations and discussions on topics including materials, devices, energy and medicine. The conference, which was attended by approximately 210 people, also included a reception and poster session after Tuesday's talks.The reception allows opportunities to network, view the poster exhibit, and talk one-on-one with researchers about their work.This conference reaches more than 50 undergraduate and community/technical college students.It exposes them to this research and these discussions and allows them to network and discover education options in nano and related science/engineering areas. Two special Short Courses were offered to Conference attendees during the 2010 event:

### Introduction to Thin Films, Oct 7-8, 2010

This course was aimed at those new to thin film deposition and characterization.Lectures aimed to teach about thin film applications and the most common thin film deposition methods, and demos gave hands-on experience by depositing and testing thin films using the tools in the NFC.

### Nanofabrication for Beginners, Oct 7-8, 2010

This course was designed to give those who are new to nanotechnology or are from other technical fields, an overview in applying micro- and nano-fabrication techniques to their products or processes.

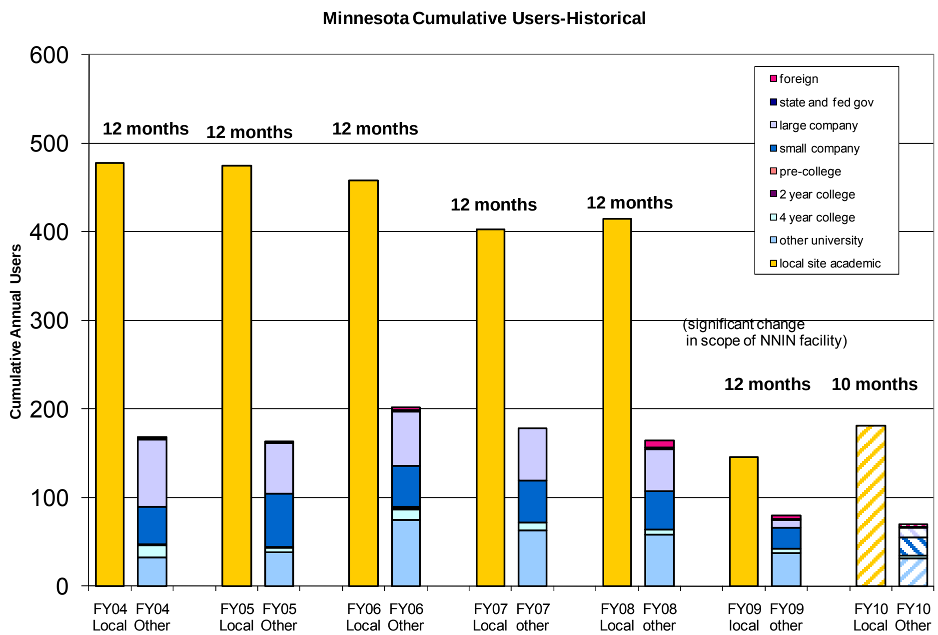
## 7.11.6 SEI Activities

During summer 2010, we developed a rough draft SEI Discussion Guide and Module intended to be delivered to Nanofabrication Center users at the University of Minnesota.The draft consisted of basic SEI content and discussion questions.Part way through summer, graduate student Jonathan Brown, at the Humphrey Institute of Public Affairs, facilitated an SEI discussion and delivered an SEI presentation and discussion with two groups of REU students.Content and questions from the draft Discussion Guide were incorporated into each presentation/discussion, and the Guide was refined in regard to students' responses to discussion questions.During October 2010, Jonathan and Dr. Jennifer Kuzma phoned-in to the NNIN SEI workshop hosted by Washington University in St. Louis.Presentations during the workshop led to improvements in our Module including the addition of pre- and post- surveys and Discussion Goals.The finalized Module consists of the following: Discussion Goals, Format (describing implementation of the SEI Discussion), Discussion Guide (with lecture material and discussion questions), and the Evaluative Surveys.The Discussion Guide is designed to take 90 minutes but can be shortened with the exclusion of select discussion questions and expedition of content delivery.During 2011, the Module will be implemented monthly, starting in February, with 60-minute 15-person sessions led by Jonathan or another graduate student.

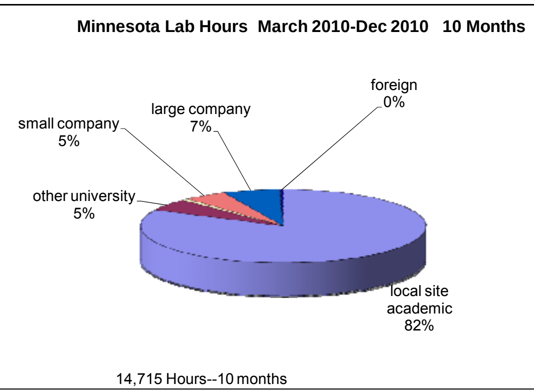
*---End of University of Minnesota Text Report----*

## 7.11.7 Minnesota Selected Site Statistics

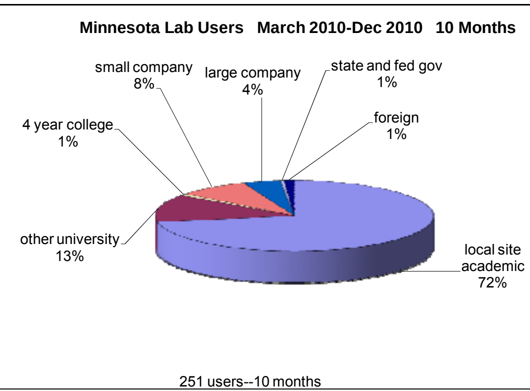
a)Historical Annual Users



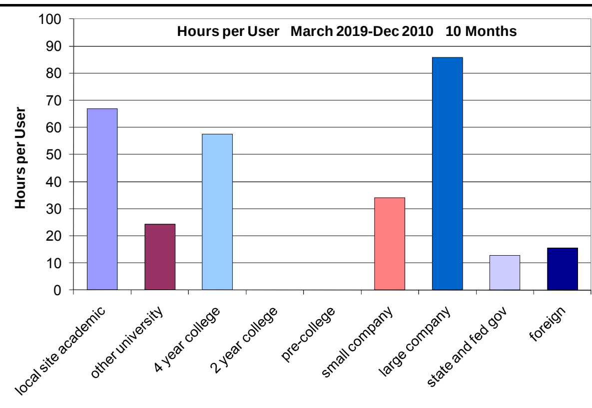

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

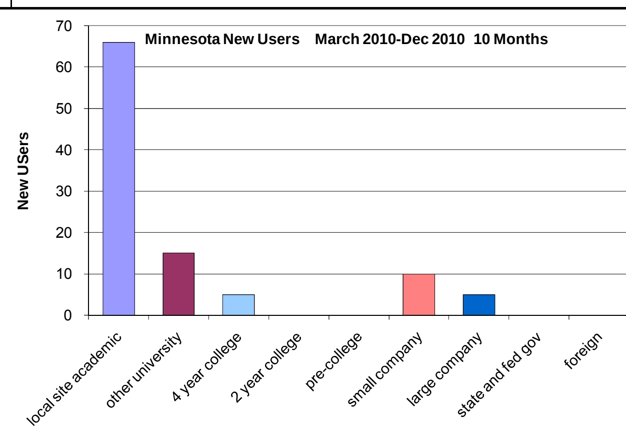



*Figure 118* University of Minnesota Statistics

## 7.11.8 University of Minnesota User Institutions

| Outside US Academic | Small Companies | Large Companies |
|---|---|---|
| Clemson University | Advanced Research Corporation | 3M Company |
| Colby College | Avicenna Technology, Inc. | Cargill, Inc. |
| Iowa State University | BH Electronics, Inc. | Cima Nanotech |
| Michigan Technological University | Bioforce Nanosciences | Entegris |
| Montana State University | Chameleon Scientific | Medtronic, Inc. |
| Old Dominion University | Cymbet Corporation | Seagate Technology |
| Rice University | Hysitron, Inc. | Starkey Laboratories |
| Saint Cloud State University | Interfacial Solutions | Valspar |
| South Dakota State University | Kevin Roberts Consulting | |
| Texas A&M | Koral Labs | **International** |
| University Massachusetts Amherst | Molecular Imprints | ETH Zurich - Inst Robotics & Intel Sys |
| University of Arizona | NVE Corporation | Imperial College London |
| University of California - Davis | Polyera Corp | |
| University of Illinois | Sage Electrochromics | |
| University of Iowa | SVT Associates, Inc. | **State & Federal** |
| University of Minnesota - Duluth | TLC Precision Wafer Technology | Argonne Nat. Lab |
| University of Nebrask Lincoln | Vixar | |
| University of Toronto | | |
| University of Washington | | |
| University of Wisconsin - Madison | | |
| University of Wisconsin La Crosse | | |
| | | |

# 7.12 University of Texas Site Report

## 7.12.1 Technical leadership areas: Initiatives and Activities

The UT-Austin technical leadership areas comprise nanofabrication instrument design and process research through techniques such as nano-imprint lithography (NIL), electron beam lithography and chemical & molecular-scale methods with major emphasis in the expansion of applications impacting scalability of complementary metal-oxide-semiconductors (CMOS), biomedical sensors and renewable energy devices. Some examples of research undertakings advanced in the MRC in these areas are described below.

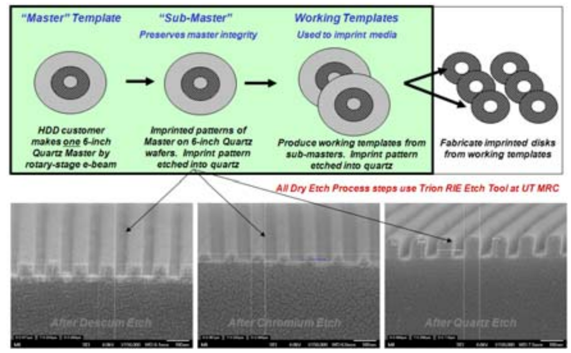



*Figure 119: Template Replication for Hard Disk Drive Industry manufactured by Molecular Imprints Inc.*

### Step-and-Flash Imprint Lithography for Digital Storage and Therapeutic Devices

One of the core-strengths of the MRC for nano-imprint patterning involves Step-and-Flash Imprint Lithography (S-FIL™) methods. S-FIL processes are conducted on the IMPRIO100 tool, acquired from the MRC-hosted start-up Molecular Imprints Inc. (MI). The templates for the IMPRIO can be fabricated using the 50keV JEOL 6000FS/E E-beam writer. Wide diversity of templates with different geometries, spacing and size features are available to the NNIN users. Researchers can also design their own master template to meet their research needs.

The ever-growing demand for hard drives with greater storage density has motivated a technology shift from continuous magnetic media to patterned media hard disks, which are expected to be implemented in future generations of hard disk drives to provide data storage at densities exceeding 1012 bits/in2. Step and flash imprint lithography (S-FIL) technology has been employed to pattern the hard disk substrates. Template Replication Method for SFIL-mediated imprinting of disks is demonstrated with substrate throughput currently as high as 180 disks/h (dual sided). These processes are applied to hard disk substrates with both discrete tracks and bit-patterned designs. The Template Replication Method invented by MI supports areal densities beyond 1Tb/in2 in order to satisfy the global demands of modern society for digital storage.

*Figure 120 Molecular Imprinting of Semiconductor Nanotracers designed by Nanohmics.*

Targeted imaging and therapeutics draw much attention in the research and treatment of cardiovascular and cancer diseases; they hold the key to allow early diagnosis, stimulate better understanding of pathology, and emerge as a solution to enhance therapeutic efficiency. Dr. Steve Savoy and coworkers at Nanohmics have used the nano-imprint IMPRIO100 system for fabricating semiconducting nanotracers for use in direct electrical detection of target reagents. Step-and-Flash Imprint Lithography was the technology of choice for the fabrication of high-throughput, high-resolution semiconducting nanotracers aimed at direct electrical detection of target reagents.Targets include both solution nucleic acids, where the target hybridizes with complementary sequences coupled to the nanotrace surface, as well as direct detection of volatile organic compounds (VOC) for multiplex vapor signature identification applications. High-throughput, reliable and atomic sized nanotracers can pinpoint different molecules and medicines.

Nanochannels have wide applications in bio analysis, molecule separation, drug delivery etc. Controlling the position and alignment of building blocks in molecular assemblies of functional elements is a challenging task in "bottom-up" chemical methods for nanodevice manufacture. Here, an approach is defined for in situ creation of horizontal nanochannels that permits control over orientation and dimensions at an exceptional range of < 15 nm. Professor Paul Ho and his students developed a highly reliable self-aligned sub-lithographic masking method to fabricate silicon nanochannels.This method is applicable to standard optical lithography. Due to the wet anisotropic etching of silicon, the nanochannels have ideal rectangular shape. The atomically smooth sidewalls provide extremely uniform surface properties. The channel width can be tightly controlled within 2nm.With this method, arrays of 9cm-long nanochannels have been demonstrated.

## Nanofabrication for Clean and Renewable Energy

Crystalline Si solar cells comprise the largest segment of the PV market. Using optimal silicon thickness can reduce costs substantially and enable new applications due to flexibility of thin crystalline silicon. Dharmesh Jawarani and Leo Mathew, co-founded AstroWatt, an Austin-based venture backed company, developing a proprietary solar cell technology. To meet the growing global demand for renewable energy Astrowatt employs thin c-Si photovoltaic cells with high efficiency solar cells made from 30 micron thick c-Si thin films have been fabricated by AstroWatt at MRC. These cells use only a thin layer of c-Si, making them flexible and could dramatically reduce the cost of Si used to make these devices. The solar cell architecture has several innovative features to make it a very high efficiency photovoltaic device. A novel cost-effective process was developed to make flexible 30um crystalline silicon wafers. This technology has also been demonstrated for other substrates such as Ge and GaAs. Back-contact and hetero-junction solar cells have been fabricated on these foils. The cells can be mounted flat or with curvature.

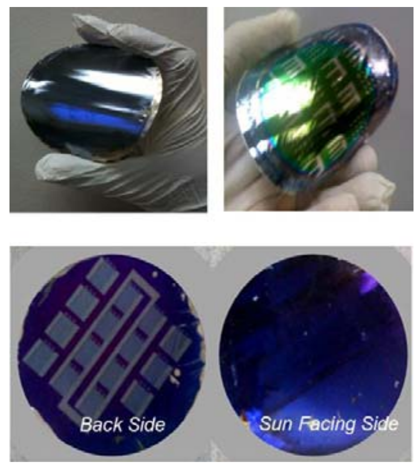



*Figure 121 Thin Crystalline Silicon Solar Cells exfoliated by Astrowatt Inc.*

## Research Highlights

- The research goal of Dr. Uttam Ghosh and his colleagues at Sheetak, (a start-up doing their R&D at the MRC) is to realize high-efficiency electronic energy converters that exploit non-equilibrium anisotropic transport effects (NEAT) and energy selective tunneling at semiconductor-metal interfaces. These NEAT devices are an enhanced version of thin film thermoelectric coolers, and will be incorporated in the cooling engines designed by Sheetak for compact refrigerator and air-conditioner OEMs in US and India. The NEAT project has been recently selected for funding by the ARPA-E for improving air conditioners in buildings and homes.Dr. Ghosh uses advanced PVD and CVD methods to deposit bismuth chalcogenides and fabricate cooler elements with phonon-blocking tunneling layers that reduce the thermal conductance without affecting the electronic conduction processes.
- Many existing/new therapeutics are limited by effects related to delivery. A family of small implantable drug delivery devices which slowly releases therapeutic agent from a reservoir over a period of months have been manufactured by biomedical engineers of the start-up Nanomedical Systems, located at the University of Texas-NNIN site. The created platform adapts to wide

variety of drug/application configurations. Constant and controlled delivery rate – set by advanced silicon semiconductor processing technologies. A nanochannel delivery system (nDS) embodied on a silicon chip regulates the diffusion of therapeutic molecules from the implant. Use of extensive and novel cleaning procedures reduce defective devices at the nano-dimensions.

- Ferrari Group at Biomedical Engineering Department of Univ. of Texas, Houston has used NNIN facilities to develop vertically-aligned nanowires by metal assisted electroless etch. Segments with different porosity along nanowire axis were revealed. Tunable photoluminescence and color was confirmed for different geometries and dimensions. Nanowires can load nanoparticles to engineer functionality. Their biodegradable nature enables applications for drug delivery and biolabeling. Applications for resorbable electronics are also envisioned for these nanostructures. These nanowires display a shallow volume, which also permits their use as nanoneedles.

### 7.12.2 Acquisitions, Changes, Operations

The Microelectronics Research Center of The University of Texas at Austin recently acquired a new set of state-of-the-art instruments that complement its existing nanofabrication strengths, while also expanding capabilities for manufacture and test of nanoscale devices and materials. Some of the new tools are:

- Oxford Plasmalab System 100 ICP-RIE, including a 13.6 MHz driven parallel plate reactor with wide process temperature range ( 30-400 °C) and plenty types of gases available (SiCl4, SF6, Ar, O2, N2)
- Plasma Therm Deep Silicon Etcher (DSE), with plasma power up to 500 W at 13.56 MHz, background pressure of5e-6 mbar and tunable atmosphere ofSF6, C4F8, O2, Ar and N2
- Dual-Beam FEI Focused Ion Beam (FIB), donated by Intel Corporation. This tool combines a scanning electron microscope (SEM) with a thermal emission tip for high resolution imaging and a gallium metal ion beam source for nanoscale fabrication. An attached gas injection system enables site-specific metal deposition and circuit edits.

In addition to research, the MRC facility supports education, and industry endeavors by offering a world-class scientific environment of open-access.

### 7.12.3 Diversity Activities

MRC contributes to education programs that focus on under-represented communities in science and engineering. MRC Graduate Research Assistant Michael Ramon participated in the Society of Hispanic Engineers (SHPE) Conference 2010, on October 29th in Cincinnati, Ohio. This event involved discussions with the attendants in the career fair and the nanotechnology showcase. The audience of this conference included more than 5,000 students, professionals, corporate representatives, educators and community leaders from all over the United States. The University of Texas participated in the NNIN-sponsored Laboratory Experience for Faculty (LEF) program, which enabled research experience for a faculty member belonging to a minority serving institution. Last year, Physics Professor Andrey Chabanov from The University of Texas at San Antonio (UTSA) was hosted at the MRC to advance a research program studying electromagnetic wave phenomena in periodic and disordered media and their applications in photonics. The LEF program permitted Dr. Chabanov and his undergraduate and graduate students to become regular NNIN users.


*Figure 122 Professor A. Chabanov worked at the MRC under the LEF program.*

### 7.12.3 Education

Since 2004, MRC has accommodated Research Experience for Undergraduate (REU) scholars. Last summer UT Austin supervised 5 undergraduate students along the NNIN REU program. The REU participants consisted of one female and four males, working with UT professors and postdoctoral and graduate students, acting as mentors on research projects in diverse areas such as simulation, biomedicine and nanoelectronics. In addition to the REU students, UT Austin also hosted a graduate student from the Japanese Nanonet (a network similar to NNIN, guided by the National Institute for Materials Science, NIMS). The visiting student engaged in developing low-temperature, solvent-based deposition processes for fabricating high-efficiency photovoltaic devices. The project involved the synthesis of nanocrystals containing alloys of Cu(In,Ga)Se2 (CIGS) and Cu2ZnSnS2 (CZTS); and subsequent assessment ofperformance using a solar simulator and other spectroscopic and electrical characterization tools.

*Figure 123: Zeta Instruments Optical Profiler used for 3D Imaging Workshop.*

UT-Austin's education program organized 4 minor events (tours) and 2 major events (workshops) in 2010.

- On Nov 2010, MRC hosted a surface measurement systems workshop jointly with Zeta Instruments Inc. Zeta Instruments engineers introduced 3D surface imaging techniques by means of optical profilers enabling quantitative R&D and failure analysis. Attendees brought their samples to explore micrometer-sized features.
- UT-Austin organized the 7th nano-imprint lithography workshop on April 2010. Lectures and hands-on sessions have been given to 9 attendees. 60% of the participants were not-affiliated to The University of Texas at Austin.
- MRC UT-Austin offered cleanroom tours during the year. During these guided tours, MRC 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, K-12 students and teachers, Texas Legislators, Government Officers (DOE reviewers of MURI program) and Industry and External University conference participants.

### 7.12.4 Social and Ethical Issues (SEI)

The MRC safety coordinator, Darren Robbins, schedules twice-a-week orientation sessions for new users. The SEI component is embedded in this training, and is fulfilled using an in-house developed presentation that discusses the benefits and risks of using nanomaterials, analyzing the case of silver nanocrystals as antibiotic and therapeutic tools in living beings. A comprehensive review of safety procedures (emergency exits, cleanroom protocol to dispose acids, solvent and other chemicals, safety gear to handle chemicals,etc.), follows the Social and Ethical Issues (SEI) discussion. Questions andcomments from the new trainees are stimulated during the discussion. Previously, a recorded video of Prof. Doug Kysar was used to disseminate self-awareness and self-reflection concerning the influence of nanotechnology research. SEI posters designed by Professor Katherine McComas are being displayed in strategic locations of the facility in front of the clean-room entrance and the main lobby, to increase

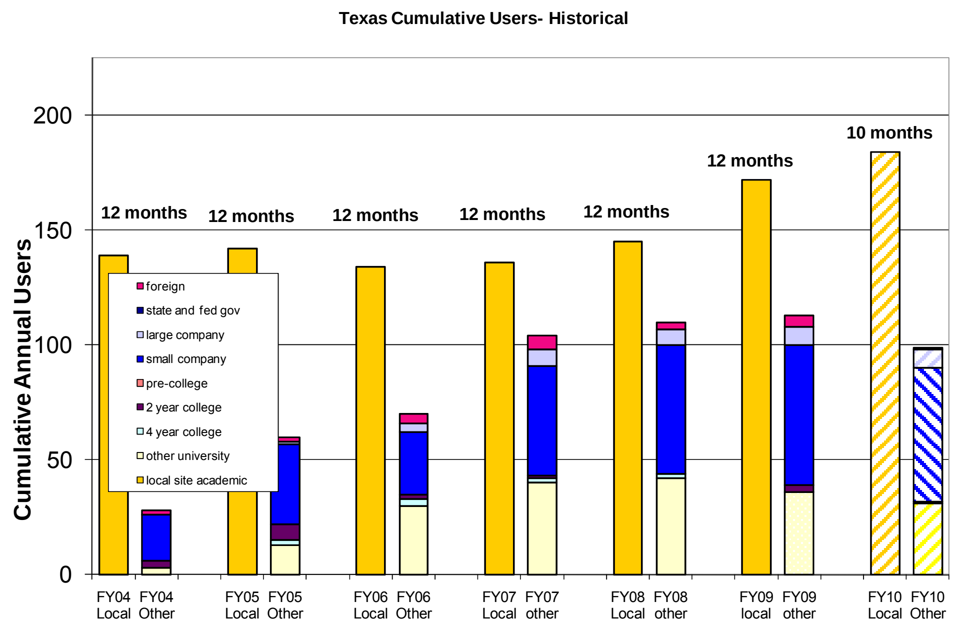
*Figure 124: SEI Training conducted weekly at the MRC*

the exposure of the users to SEI topics, including broader impacts of cutting-edge nanotechnology investigations and the role and responsibilities of researchers about the environment.

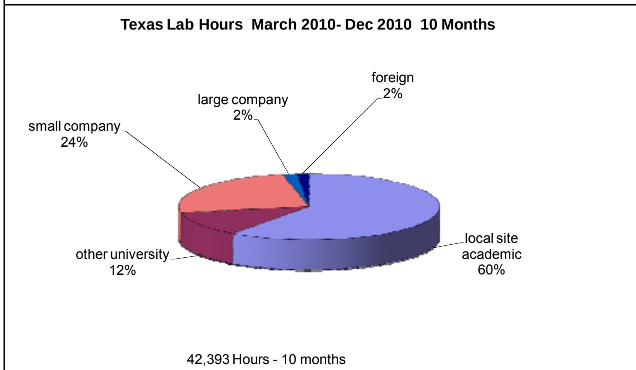
*---End of Texas Text Report--*

## 7.12.5 University of Texas Selected Site Statistics

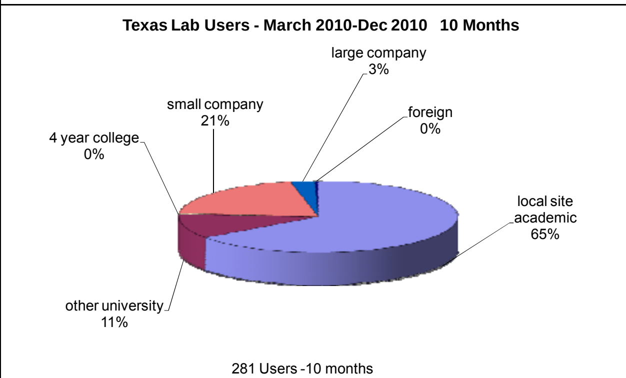
a)Historical Annual Users



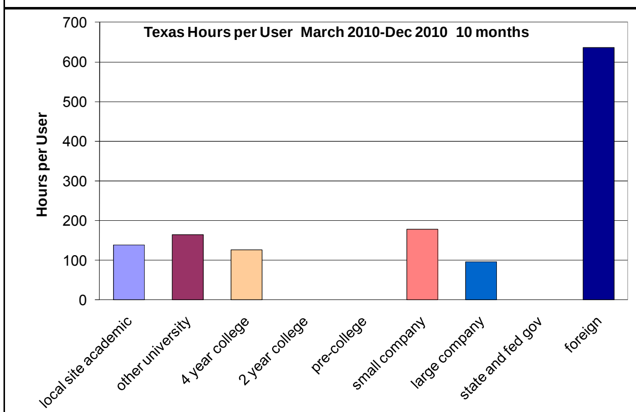

b) Lab Hours by Institution Type




c) User Distribution by Institution Type




d) Average Hours per User( in 10 months)




e)New Users

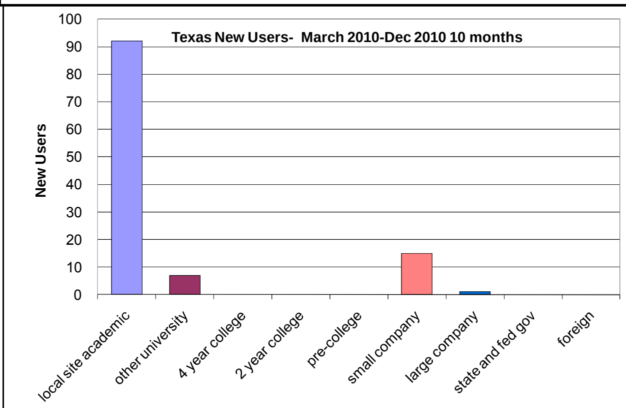



*Figure 125: University of Texas Site Statistics*

### 7.12.6 University of Texas User Institutions (10 Months)

| Academic | Small Companies | Large Companies |
|---|---|---|
| UT El Paso | Applied Nanotech | 3M |
| Texas A&M | Applied Novel Devices | IBM Watson Research Center |
| UTexas MD Anderson Cancer Cen. | Astrowatt | Toppan Global Masks |
| University of Virginia | Atonometrics | Nissan Chemical Industries |
| University of San Antonio | Clean Energy Labs | SVTC Technologies |
| Rice University | Clinasys | |
| Rutgers University | Displaytip | |
| Trinity Univ (San Antonio) | Illumitex | **International** |
| UNC Charlotte | Information Machines .Int. | University of Veracruzana |
| Texas Tech University | Metrosol | Huazong Univ - China |
| UT Houston | Molecular Imprints | CEA-ITER France |
| UT Arlington | Nanomaterials Characterization | Tohoku University |
| University of Illinois at Urbana- | Nanohmics Inc | King Abdullah Univ (KAUST) |
| Columbia University | NanoMedical Systems Inc. | |
| U. Texas Panamerican (UTPA) | NanoNuvo | |
| | Nanoopto | |
| | Quantum Logic Devices | |
| | Saxet Surface Science | |
| | Sheetak | |
| | Silicon Audio | |
| | Stellar Micro Devices | |
| | Xidex | |
| | Trilumina | |
| | SBA Materials | |
| | Heliovolt | |

## 7.13 University of Washington Site Report

### 7.13.1 Overview

The University of Washington NNIN node (UW-NNIN) has primary responsibilities in the areas of biological and life sciences, society and ethics (SEI), and in connecting the network to the aquatic science community. UW-NNIN employs a technical staff of 8 and consists of the Nanotech User Facility (NTUF) and the Washington Technology Center Microfabrication Laboratory. NTUF occupies over 3,000 sq ft of newly renovated laboratory space equipped with tools and facilities targeted towards the investigative needs of nanobio users, and provides complementary e-beam lithography, deposition and soft and photolithography services. The adjacent Microfabrication Laboratory occupies 15,000 sq ft of space and provides access to photolithography, thin-film deposition, plasma and chemical etching, and characterization processes. Over the reporting period, UW-NNIN served ≈ 330 users and enabled the research and development work of 37 companies. The number of large companies served has increased from 4 to 10 and that of external academic institutions served from 4 to 7 over this period.

### 7.13.2 Aquatic Sciences News

Together with U. Michigan, and with the support of Cornell, Stanford and Georgia Tech, U. Washington has primary responsibility in connecting the network and its users with the aquatic science community. As a follow-up to white papers developed during the "*Nano-Enabled Sensing Microsystems for Geosciences*" workshop held at U. Michigan in February 2010, U. Washington coordinated the submission of two proposals to federal funding agencies. The project entitled "Raman-Based Barcoding for the Identification of Toxic Marine Pathogens and Phytoplankton" involving Vera L. Trainer and Mark S. Strom (West Coast Center for Oceans and Human Health), Mark L. Wells (U. Maine), and Qiuming Yu (U. Washington) was funded by NOAA-OHHI and is under way. Moreover, a collaborative proposal entitled "A Microfabricated Protein-Based Array for Electrochemical Detection of Bioavailable Metals in Aquatic Environments " and involving François Baneyx (U. Washington), Thomas Dichristina (GeorgiaTech), Karen Orcutt (U. Southern Mississippi), Becky Peterson (U. Michigan) and Martial Taillefert (GeorgiaTech) has been submitted to the NSF GEO-OTIC program. A booth staffed by U. Michigan and UW personnel showcased NNIN at the 20010 American Geophysical Union (AGU) Fall Meeting in San Francisco.

### 7.13.3 Research Highlight

***Marco Rolandi*** (UW MSE) has developed the method for the direct writing of germanium nanostructures with the tip of an atomic force microscope (AFM). Germanium writing occurs when the AFM tip traces the desired shape along a biased silicon sample while immersed in an organometallic precursor (diphenylgermane). The high-electric field and the electrons emitted from the tip cause the precursor to locally react and yield germanium nanostructures. This innovative AFM strategy creates sub-30 nm carbon-free germanium nanostructures with desired geometries and placement, as reported in their October 2010 *Advanced Materials* cover story. (Fig. 126a)

*Figure 126 a) Rolandi, etal b) Sniadecki etal c) Dalton etal*

The Platelet Force Project investigates the biomechanics of blood clotting by measuring the contractile forces that platelets generate on arrays of flexible, microfabricated posts. Each post acts as a force transducer because it deflects in proportion to the contractile force that platelets apply at the tip. This novel biomechanical assay developed by ***Sniadecki*** (UW ME) can be used to evaluate hemostasis, thrombosis, and embolization and was described in the April 2010 issue of *Lab on a chip*. (Fig. 126b)

Organic electro-optic (EO) materials have the potential to minimize the size, weight, and power requirements of next-generation computing, telecommunications, and sensing applications through dramatically improved performance and simplified processing compared to existing technologies. The identification of electronic intermolecular electrostatic interactions that can significantly enhance poling-induced order is important to the advancement of the field. In the cover story of the September 23, 2010 issue of the *Journal of Physical Chemistry B*, **Dalton** (UW Chemistry) and coworkers demonstrate both experimentally and theoretically that lattice dimensionality can be defined using the relationship between centrosymmetric order and acentric order, opening the door to the design of superior nano-engineered EO materials. (Fig. 126c)

***Stratos Genomics*** is developing a new method of DNA sequencing that will dramatically reduce time and costs of high throughput DNA sequencing. The technology creates surrogate molecules from DNA targets that comprise a sequential linkage of large reporters. These reporters encode the target DNA sequence information and are measured using nanopore detectors, a silicon-based miniaturized version of Coulter counters. To be commercially feasible it is necessary to reduce the dielectric noise of these nanopores, improve their durability, and develop a wafer-based production scale-up. UW NNIN continues to be the core facility for this project as the 3$^{rd}$ generation of nanopore design begins.Very high signal-to-noise molecular translocations of molecular reporter constructs have been achieved and new concepts for wafer-based production are being explored that utilize E-beam lithography.

### 7.13.4 Equipment, Facility and Staff Highlights

***Equipment*** – Equipment – In 2009, UW-NNIN received $645K of ARRA funds to develop new capabilities and replace aging equipment. In addition to a Heidelberg µPG101 Tabletop Laser Pattern Generator which was made available to users in February 2010, one sputterer and two RTAs have been installed and a RIE is expected to arrive soon. A JEOL e-beam writer, a Woollam ellipsometer and a Bruker XRD system were purchased with internal and external funds and added to the tool inventory over the reporting period.

A *Kurt Lesker Lab 18 sputtering system* was purchased based on its ability to provide standard RF/DC sputtering for at least 4 targets, and the added capabilities of co-sputtering, deposition at temperatures up to 550$^{o}$C, and options for pulsed DC deposition.About 20 users have been trained on the instrument since August 2010. Deposition of common metals (Ti/W, Au, Ni, and Cu) has been demonstrated and dielectric materials deposition is being investigated.(fig 127a)

Two *Allwin21 AW610 rapid thermal annealers* (RTAs) were purchased to allow users to perform implant activations, contact anneals, and oxidation of very thin films. One of the systems will be used for CMOS level cleanliness and the other available for all other needs. The systems were delivered in December 2010, and will be operational before the end of January 2011. (Fig 127b)

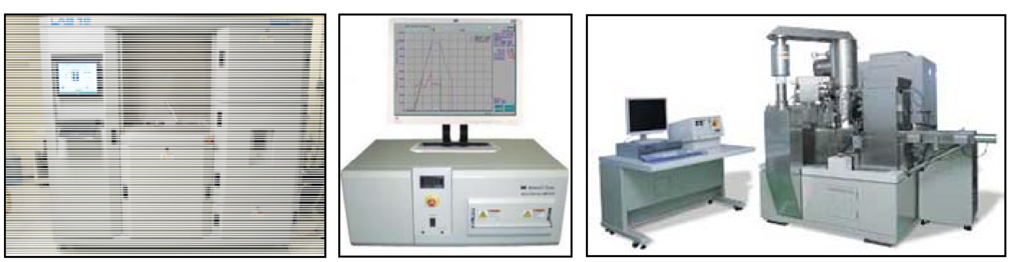


*Figure 127: a) Lab18 Sputtering System, b)RTA , c) JEOL 6300*

An *Advanced Vacuum Vision 320 Mk reactive ion etcher* (RIE) purchased with ARRA funds will replace an aging parallel plate system, allowing for improvements in etch rate and uniformity. Delivery has been delayed until first quarter 2011.

A *JEOL 6300FS e-beam writer* was delivered in May 2010.The system setup and initial tests were completed in July 2010 and the system was made available to users at that time. Currently the system is operated for customers by lab staff with the proper expertise.A training protocol for new users will be developed over the course of 2011.(Fig 127c)

A *Bruker D8 Discover XRD* system was moved to UW-NNIN in September and made available to users in November 2010. (Fig. 128) The tool has a 2D X-ray detector allowing for 2D image processing and 2D diffraction pattern manipulation, an optical laser-video camera system for easy sample alignment, and a high power rotating anode. Phase identification, quantification, texture, stress, high throughput screening, microdiffraction, mapping can be done faster and more easily on this system. About 15 users have been trained on the tool. Finally, a*Woollam M-2000* spectroscopic ellipsometer was received in March 2010 and is now fully utilized in the site research projects.

*Figure 128: Bruker XRD System*

***Facility*** – Construction has been completed for additional class 100 and class 1000 cleanroom spaces for the JEOL 6300FS direct-write e-beam lithography tool.

***Staff*** – Dr. Xiaoxia Gao returned to her native China in December; a search for a replacement EM specialist is under way. Dr. Ethan Allen has accepted a new position and will move to sunny Hawaii in early February.

### 7.13.5 Educational Highlights

Working with the NSF's Portal to the Public program and Pacific Science Center staff, Education Manager Ethan Allen developed a very quick, simple, and accessible demonstration/interactive module that illustrates a change in properties (transparency to iridescence) with change in scale, using clear fingernail polish, water, and black Tyvek®. The activity, *Changing Color by Changing Scal*e, is portable and supported by instructions, explanations, and illustrations, and allows the participants to take away a permanent memento in the form of a nanoscale structure that they have created. About 5,000 of these modules were used and distributed at the U.S. Science and Engineering Festival in Washington, DC. The unit has been included in the NNIN Outreach Demo Guide and can be found on the NNIN website at http://www.nnin.org/doc/NNIN_Outreach_Demo_Guide-11_10.pdf.

In cooperation with the MDITR STC, UW-NNIN continues to develop web-based video-training modules on its tools. These now include a 6-part series on SEM operation, a 2-part series on TEM operation, and a 3-part series on EBL. Videos can be streamed at www.youtube.com/user/UWCNT. Finally, the special REU program for students in North Seattle Community College's Nanotechnology AAS-T degree program continued in 2010 with 4 students working conducting research at NTUF.

### 7.13.6 SEI Highlights

UW-NNIN SEI activities are coordinated by the Center for Workforce Development (CWD). CWD is conducting a research study with nanoscientists & nanoengineers at three NNIN sites (Stanford, Cornell and UW) to examine: (1) career pathways for men and women scientists; (2) perceptions on risks and benefits of nanotechnology; and (3) views on promoting social and ethical awareness in the nanotechnology community. The project involves conducting 30 min to 1h long structured interviews with pre-selected NNIN faculty at each site about their career pathways and their views on nanotechnologies.

Thirty-one interviews have been conducted and the study should be completed by next year. Preliminary findings indicate that:

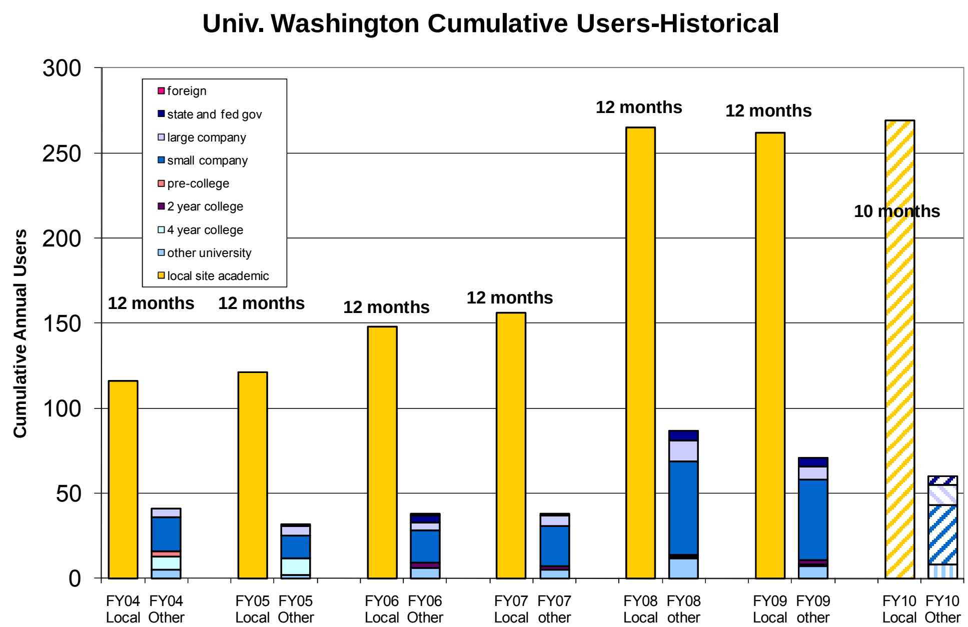
- The interdisciplinary aspect of nano is highly attractive to both men and women working in the field
- At every stage of their careers except graduate school, fewer men than women acknowledge receiving mentoring.Fully 1 in 5 men claim to never have been mentored.Yet, despite this, more men than women claim to be currently acting as mentors.
- Roughly twice as many women as men view their engagement in nanotechnology as secondary, or see nano primarily useful as a tool, rather than being the central focus of their scientific interests.

In addition, CWD received funding from NSF to conduct a workshop on Nano and Gender. Building on CWD's previous work in the recruitment, retention and advancement of women faculty in STEM fields through NSF's ADVANCE Institutional Grants, CWD will develop a focused 1 ½ -day workshop to identify the fundamental research challenges surrounding the participation of women in nanoscience and technology. This workshop will bring together leading national researchers in the social sciences and nanosciences and will provide important information and direction to the NSF on how nanotechnology can benefit from the increased participation of women faculty.

*----End of University of Washington Text Report---*

## 7.13.7 University of Washington Selected Statistics

a)

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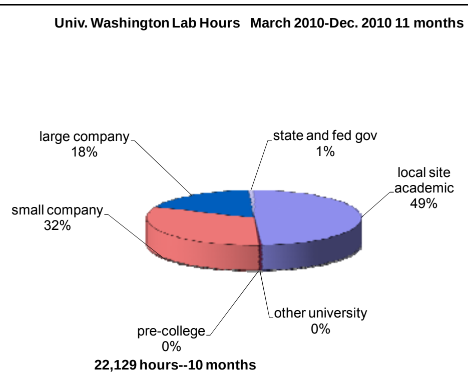


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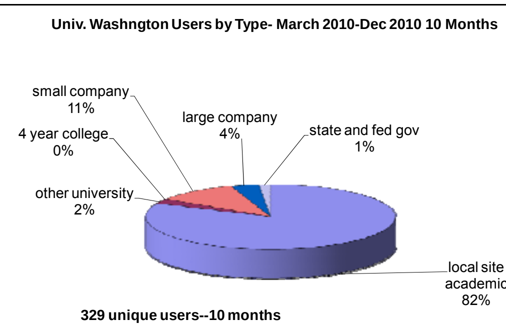


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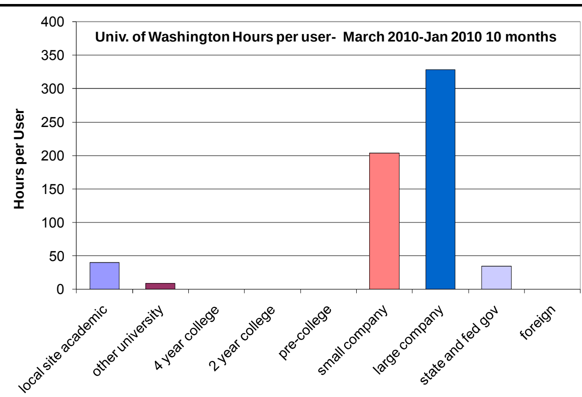


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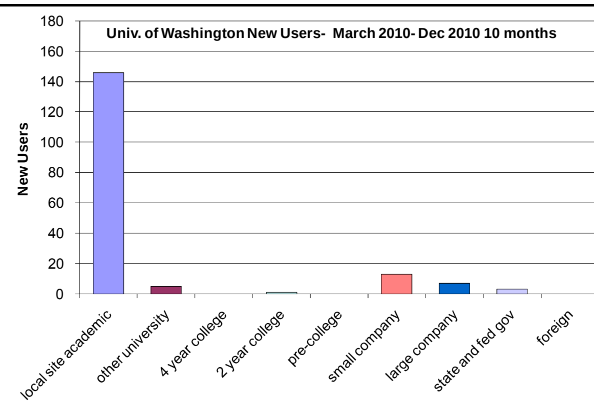



*Figure 129* University of Washington Selected Statistics

### 7.13.8 Univ. of Washington User Institutions

| Academic | Small Companies | Large Companies |
|---|---|---|
| Bradley University | Blue View Tech. | PCB Piezotronics |
| North Seattle CC | Cascade Microtech | Google |
| Oregon State University | Energ2 | Aerojet |
| Portland State University | EOSpace | Quest Integrated |
| Seattle University | EOTron | Microsoft |
| Western Washington Univ. | Healionics Corp | Honeywell |
| University of Virginia | Impinj | ThermoFisher |
| | Ionographics | HP Labs |
| | GigOptix | Sharp Labs of America |
| | Marina Biotech | |
| | MicroGreen Polymers, Inc | |
| | Microvision | |
| | NanoICE | |
| | New Light Industries | **State and Federal** |
| | RJC Enterprises | Lawrence Berkeley National Lab |
| | Silicon Designs | Pacific Northwest National Lab |
| | Spiration | Fred Hutchinson Cancer Center |
| | Stratos Biosystems | |
| | TargetedGrowth | |
| | Triakis | **Other** |
| | VisionGate | Arctic Medical Foundation (nonprofit) |
| | IMAT Inc. | |
| | Intellectual Ventures Lab | |
| | Revalesio Corp | |
| | Lab/Cor Materials LLC | |
| | Radiabeam Technologies | |
| | Modumetal | |

## 7.14 Washington University in St. Louis Site Report

### 7.14.1 Overview

The Nano Research Facility (NRF), a new NNIN node at Washington University in St. Louis, completed the second-year operation. Specifically, we facilitated our full operation in the newly established class 100/1000/10,000 clean rooms (2,150 sqft with a total capital investment of $8.6M from the University) and developed a set of unconventional top-down approaches, Near-Field Lithography and Nanoskiving, to fabricate nanostructures; we continuously expanded our unique capabilities in the synthesis of functional nanomaterials and included 10-140 nm magnetic nanoparticles to our portfolios for potential applications in drug delivery and magnetic resonance imaging (MRI); we developed a standard procedure for the characterization of nanomaterial that includes i) UV-Vis measurement of unique optical properties, ii) dynamic light scattering measurement of size distribution and zeta potential, iii) ICP-MS/OES analysis of particle concentration, and iv) biological sample prep and EM analysis of morphology; we developed an in vitro approach to evaluate the toxicity of silver nanomaterials by monitoring the growth of yeast cells in the presence of silver nanoparticles with different sizes, shapes, and surface charges; and we started to build NRF Bio-imaging Lab in the Engineering School's new complex Brauer Hall (850 sqft) and we will install an Olympus Integrated two-photon/confocal/photoacoustic microscopy system in the summer of 2011 – the first integrated system in the nation that was funded through a collaboration of NRF and Professor Lihong Wang of Biomedical Engineering at Washington University (PI, NIH-1S10 RR028864-01, $1,198,524).

As a new node in the NNIN community, NRF is growing as we continuously strive to identify specific needs from the research community, develop distinctive technical capabilities, enhance comprehensive training programs, and make profound impacts in areas of nanotechnology at the intersection of public health and environment. To promote NNIN to the research community in Missouri, we sponsored the 2nd annual Missouri NanoFrontiers Symposium – A Gateway to Economic Development. More than 150 scientists from across Missouri met at Washington University in St. Louis to learn about the latest advances in nanotechnology and opportunities for commercializing them. Chancellor Mark S. Wrighton of Washington University, Vice-chancellor Robert Duncan of the University of Missouri-Columbia, and Chancellor Thomas F. George of the University of Missouri-St. Louis welcomed participants to the symposium. Professor Zhong Lin Wang at the Georgia Institute of Technology delivered the first keynote – "Self-Powered Nanosensors for Medical Science, Environmental Monitoring and Personal Electronics". Missouri Senator Christopher S. "Kit" Bond delivered the second address and discussed the role of nanotechnology ventures to Missouri's economic development.

The NNIN serves as a catalyst to change the education landscape at Washington University. By leveraging NRF by large, we received an NSF-supported Nanotechnology for Undergraduate Education (NUE) grant award to create a Minor in Nanotechnology for all undergraduate students across the Washington University campus. This new program will provide an excellent opportunity to build an interdisciplinary education and research program in nanotechnology for undergraduate students with a focus on the following components: i) learning that exposes students to a multifaceted, integrated approach to learning about the fundamentals and new developments in nanotechnology, as well as its environmental and societal impacts; ii) training that offers students research experience in the NRF – a site of the NSF-supported NNIN and in the laboratories of participating faculty for exploration of research tools and discovery in the frontiers of nanotechnology; and iii) engaging that connects the students with community and society to impart and promote a basic conceptual understanding of nanotechnology in high school students and teachers.

## 7.14.2 Research Project Highlights

### Highlight 1: Understanding the Implication of Nanotechnology

As Nanotechnology advances from research to commercialization rapidly, we should act to address the potential risks associated with the interactions of nanoparticles with tissues, cells, organelles, and functional bio-molecular structures as these small particles enter plants and human bodies. Specifically, it is keen to identify the relationship between unique physiochemical properties of nanostructures and their corresponding in-vitro and in-vivo responses upon uptake. NRF has the unique capabilities to make nanomaterials with controls in shape, size, and surface morphology. We have provided silver nanostructures – cubes, wires, plates, and rods – to two external user groups: i) Uday Burman and J. C. Tarafdar at the Central Arid Zone Research Institute (India) – the team was investigating the effects of size and shape on nanoparticle uptake by pumpkin and watermelon plants and assess toxicological symptoms (See figure 130). This study will help to provide better understanding on the transport and fate of nanoparticles in an ecological system; ii) Saber Hussain's group at the Air Force Research Lab (Dayton OH) – the team was developing a systematic and reliable method to evaluate the toxicity of nanoparticles with well-controlled parameters. This research will provide insight on how cells respond to specific nanoparticle parameters, and ultimately, seek guidance for designing safe nanomaterials for various applications.

*Figure 130:* Pumpkin plant after Ag nanoparticle uptake.

### Highlight 2: Discovering the Niche of Nanomaterials

Nanomaterials exhibit unique properties when the dimensions of materials shrink down to nanoscale. In additional to providing services on making nanomaterials via both top-down and bottom-up approaches, NRF has gauged technical expertise to support users for their exploration of unique properties and applications of nanomaterials: i) NRF provided palladium and silver nanocrystals to Scott Mao's group at the University of Pittsburg. This group was working on a pioneering work to understand the deformation mechanisms of nanomaterials with experimental approaches, and ultimately, validate their results with the corresponding theoretical work. ii) Jingyue Liu's group at the University of Missouri – St. Louis was investigating the size dependence on the catalytic performance of palladium nanocrystals for carbon monoxide oxidation in collaborations with Younan Xia at Washington University (see Figure 131). This team used the NRF's TEM and ICP-MS extensively to characterize morphology and concentration of nanocrystals, respectively. These measurements provide critical data in support of their proposed mechanisms. iii) NRF provided silver nanomaterials to Cate Ducati at the University of Cambridge (UK).This group was mapping surface plasmons of these silver nanostructures with in electron energy loss spectroscopy, an approach to provide understanding on how morphology and crystallinity of silver affect photonic properties at the nanoscale.

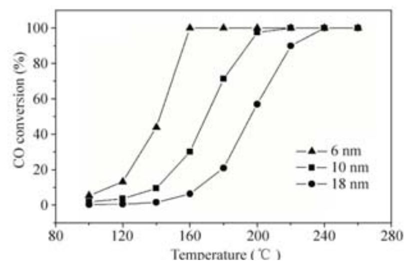



*Figure 131:* Size-dependent CO conversion as a function of temperature for Pd nanocubes.
*cubes*

### Highlight 3: Engaging Environmental Research at Washington University

NRF has cultivated an open and shared research environment to provide expertise in microscopy imaging, elemental analysis and device fabrication. Multiple user groups at Washington University were performing environmental research across disciplines that cover the spectrum from aquatic chemistry, mineral science to environmental sensing: *i)* Daniel Giammar's group at Energy Environmental and Chemical Engineering was investigating uraninite dissolution as a function of important water chemistry parameters – a critical aspect for the success of environmental remediation strategies. *ii)* Jeffrey Catalano's group at Earth and Planetary Science was studying the fate of trace elements and contaminants in aquatic system that was mainly controlled by adsorption onto mineral surfaces. *iii)* Srikanth Singamaneni's group at Mechanical Engineering and Materials Science was fabricating novel surface-enhanced Raman spectroscopy (SERS) substrates based on common filter paper decorated with gold nanorods for environmental sensing. *iv)* Lan Yang's group at Electrical System Engineering was working on a portable optical device that provides real-time, in-situ detection and measurement of single nanoparticles and pathogens for environmental monitoring, clinical diagnostics, pharmaceutical studies, and homeland security applications.

Highlight 4: Delivering Genes to Microorganisms

Gene delivery refers to a process that introduces foreign DNA into host cells to facilitate gene therapy to treat disease. Two research groups, Professors Yinjie Tang and Daren Chen, in the Department of Energy Environmental and Chemical Engineering at Washington University have developed a novel technique for delivering genes to microorganisms via electrospray of gold nanoparticles (see Figure 132). During an electrospray process, a mixture of pET30a-GFP plasmid and gold nanoparticles is deposited on a thin layer of non-competent Escherichia coli cells. The team used the NRF's electron microscopy facility extensively to monitor the morphological changes of plasmids and cellular membranes after an electrospray process with gold nanoparticles. This method has the potential to work universally for different genetic materials in both prokaryotic and eukaryotic cells.

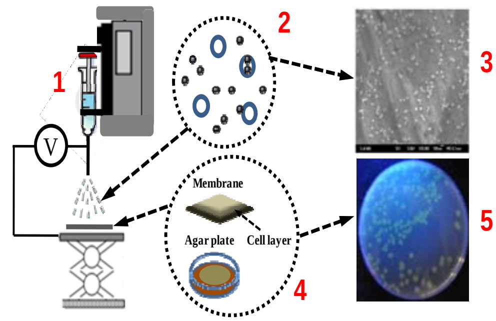



*Figure 132:* Electrospray for gene transformation.

## 7.13.3 Equipment and Operation

In 2010, NRF has installed the following tools:

- **Leica EM UC7 Ultra-microtome** has extended applications for biologists to examine details of cellular or tissue ultra-structures with optical or electron microscopy. (Owned by Professor Younan Xia at Washington University)
- **EMS 850 Critical Point Dryer** is useful to preserve delicate biological structures, such as cell walls, in the drying process prior to SEM imaging. (Supported by the NSF-NNIN 2010)
- **Oxford PlasmaLab 100 ICP-RIE System** provides the capability to etch a variety of materials with vertical profiles. (Supported by the NSF-MRI 2009)
- **TSI 2D & 3D Particle Image Velocimetry (PIV)** can collect instantaneous information on velocity and spatial distribution of particles in air or liquid flow. (Supported by NSF-NNIN-ARRA 2009)

In 2010, NRF has developed the following new capabilities:

- **Magnetic Nanomaterials:** NRF has demonstrated the capabilities to produce monodispersed magnetite nanoparticles with an ability to maneuver the size from 8 nm to 120 nm precisely (see

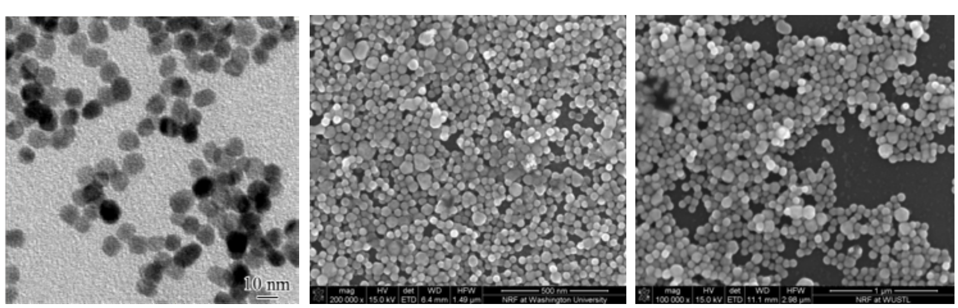



*Figure 133:* TEM and SEM images of magnetite nanoparticles with different sizes:8, 80, and 120 nm.

Figure 133).

- **Unconventional Top-down Approaches to Nanofabrication:** NRF has developed routine procedures for performing near-field lithography (NFL) and nanoskiving. NFL is not limited by optical diffraction and it has the ability to define nanostructures with complex patterns (see Figure 134). Nanoskiving is a simple and convenient procedure for generating arrays of nanostructures with cross-sectional dimensions in the 30-nm regime (see Figure 135).

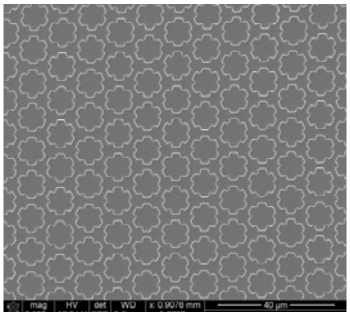


*Figure 134*: Photoresist patterns generated with near-field lithography.

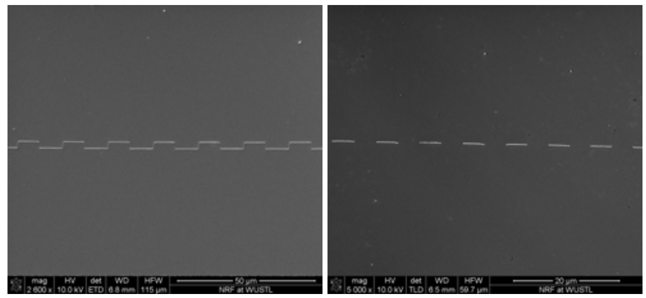


*Figure 135:* Gold patterns with different geometries fabricated with nanoskiving.

- **Toxicity Evaluation:** NRF has started to work towards establishing our own toxicity core. Specifically, we have developed standard procedures for screening toxicity of nanoparticles using a yeast cell model system.In a typical process, Saccharomyces cerevisiae yeast cells are grown in the presence of silver nanoparticles at different concentrations, whose growth curves could reflect any inhibition effect from silver nanoparticles. The uptake of nanoparticles by cells has been examined by transmission electron microscopy and inductively-coupled plasma mass spectrometry, while their dispersion state was monitored by dynamic light scattering. Evidently, we observed a strong dependence of toxicity on particle size, shape, surface group and species in surrounding environment to the cells (see Figure 136).We started to explore methods for controlling the toxicity of nanoparticles.

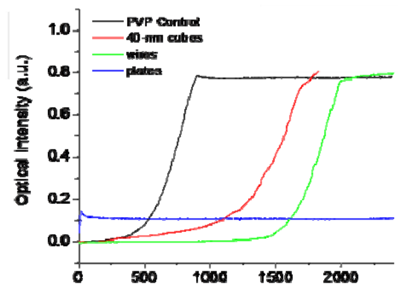



*Figure 136:* Growth curves of yeast cells in the presence of silver nanoparticles with different shapes at the same concentration.

## 7.14.4 Staff

NRF added one staff member, Kate Nelson with master degree in Environmental Engineering, joining the NRF taskforce team to provide her expertise in ICM-MS/OES systems.

## 7.14.5 Education and Other Activities

NRF is developing the Personalized Nanotechnology Laboratory (300 level course) with an ultimate goal to create a dynamic teaching lab environment with emphasis on hands-on experience for undergraduates. Upon successful completion of the Nanotechnology Laboratory course students will earn 3 credit units toward the Minor in Nanotechnology. NRF will also award a credential for all undergraduate students who register for the course regardless of their intention to pursue the Minor. This credential can serve as a reference for students to explore research internship opportunities in academic institutions.

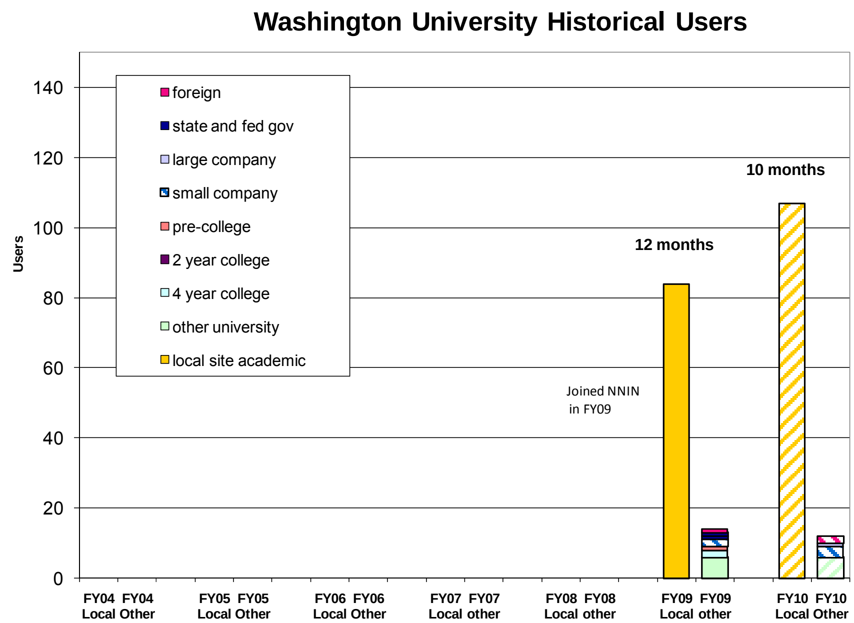
NRF is working closely with Cornell University to develop social ethnical issue training modules. We hosted an event – “Implementation and Impact: A Workshop on the SEI Training at NNIN Laboratories” on October 15th, 2010 on the Washington University campus.

NRF participated in Nanodays at the St. Louis Science Center.

*---End of Washington University at St. Louis Text Site Report--*

## 7.14.6 Washington University at St. Louis Selected Site Statistics

a)

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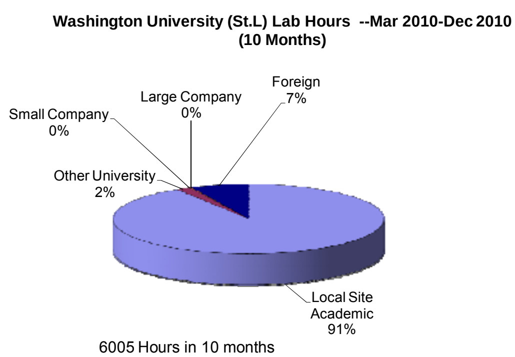


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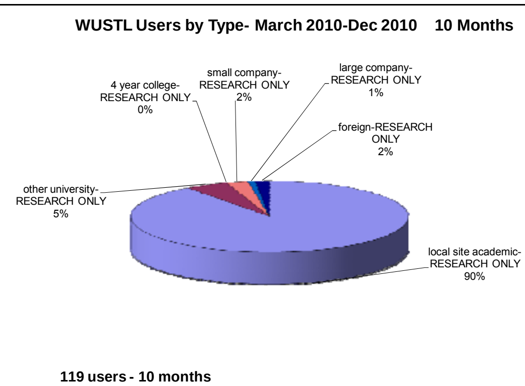


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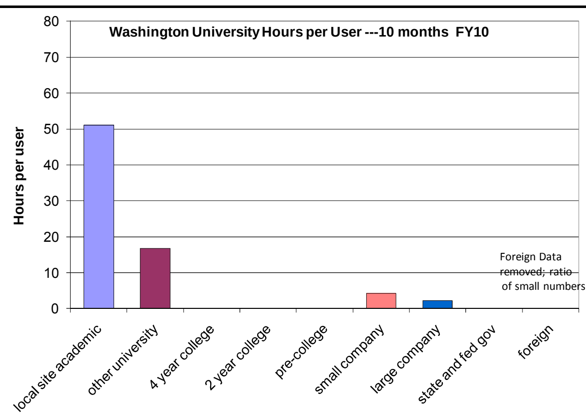


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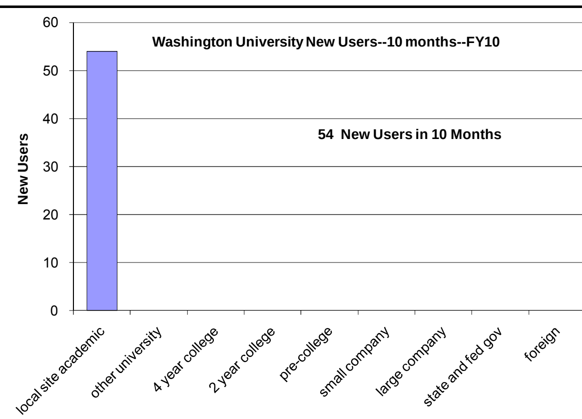


*Figure 137*: Washington University Selected Site Statistics

## 7.14.7 Washington University at St. Louis User Institutions

| Outside US. Academic | Small Companies | Large Companies |
|---|---|---|
| Massachusetts Institute of Technology | Actium BioSystems | Covidien/Mallinckrodt |
| New York University | Dynalabs | |
| University of California, Riverside | Pulse Therapeutics, Inc. | **State and Federal** |
| University of Pittsburg | | Air Force Research Lab |
| Northwestern University | | |
| | | **International** |
| | | Ben Gurion University |
| | | Central Arid Zone Research Institute (India) |

# Appendix 1:  NNIN Network and Site Directors and Coordinators

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## University of Washington
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End of NNIN Annual Report