Annual Report of the National Nanotechnology Infrastructure Network

March 1, 2005 through Dec 31, 2005

Cooperative Agreement: ECS-0335765

***Participating Institutions**:* Cornell University, Georgia Institute of Technology, Harvard University, Howard University, North Carolina State University (affiliate), Pennsylvania State University, Stanford University, University of California at Santa Barbara, University of Michigan, University of Minnesota, University of New Mexico, University of Texas at Austin, and University of Washington.

NNIN

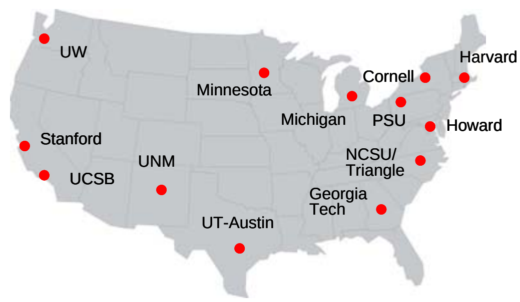
Table of Contents

1.0 Executive Summary

National Nanotechnology Infrastructure Network (NNIN)

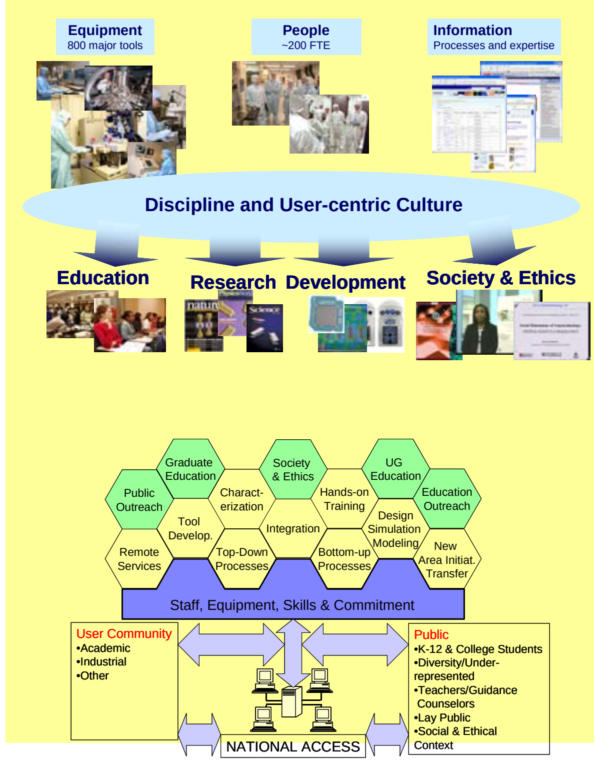
The National Nanotechnology Infrastructure Network (NNIN) provides access to infrastructure within open shared facilities to enable the national science and engineering community to pursue research, education and technology development within all the disciplines that can benefit from nanotechnology. NNIN is now in the second year of its operation. We are a partnership of 13 university-based laboratories, each of whom while serving broader needs provides leadership in specific technical focus areas so that the advanced techniques, instruments, and knowledge can be efficiently utilized. The network also has in place a national and local effort in support of education, public outreach, safety, and a thrust in examining the societal and ethical implications of nanotechnology.

Figure 1: Member institutions of NNIN.



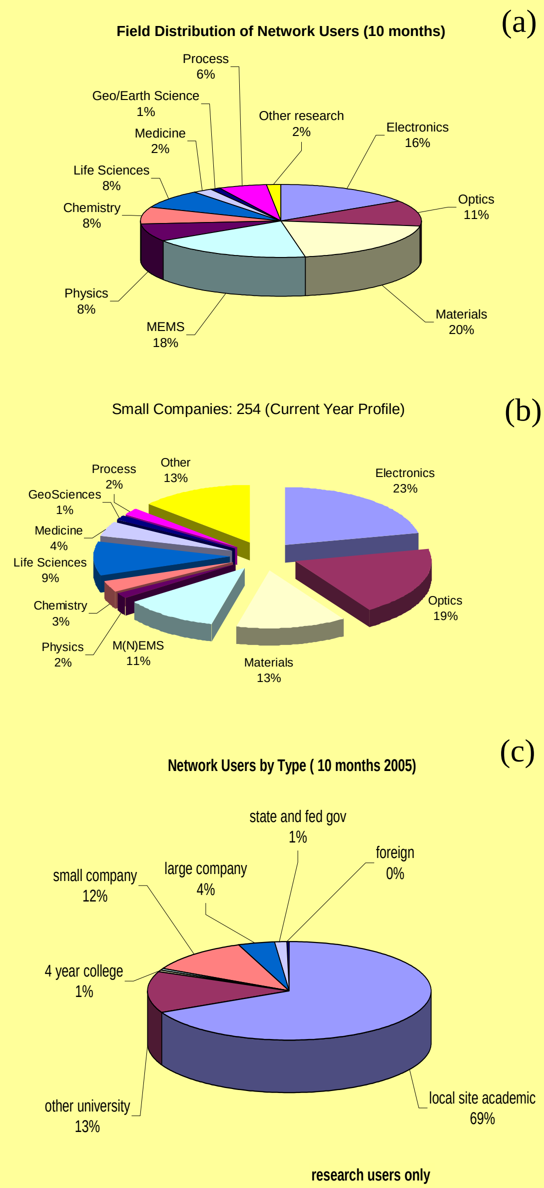
Science, Engineering and Technology Support: The network's current technology scope and activities are summarized in Fig. 2. We make continuous efforts through workshops, and promotion and talks at professional society conferences to inform and to assess needs of new directions developing through the worldwide nanotechnology activities, and to actively develop infrastructure and technical support for these new directions. Supporting hands-on nanoscale research so that graduate researchers, industrial and national laboratory professionals, as well as smaller institutions can build and explore materials, structures, devices, and systems using a combination of bottom-up and self-assembly techniques and top-down fabrication techniques is our central mission.

Figure 2: Network scope and activities**.**



The user support for these tasks is accomplished through rapid technical interchange via user-support staff, arranging the visit to the appropriate facility, and a rapid initiation to the experimental work through training and staff-researcher interactions. NNIN's staff includes PhD level experts that facilitate cross-disciplinary propagation of know-how and NNIN provides remote support for many processes and for characterization where a visit may not be necessary. The key to success in this effort is openness and equal access to all, commitment to service, low costs, and rapid interchange.

Figure 3: a) Discipline breakdown of the 3400 network research users (10 months 2005). b) Distribution of 254 small companies that used the network resources during this time period. c) Distribution of types of research users (academic researchers, company scientists, federal and state lab users, etc. of the network



Network usage for 2005 is 19% above the prior year. NNIN's success in serving the diverse user community is encapsulated in Fig. 3 which shows the breadth of our user community. NNIN facilities are used by an average of 1800 users each month, with an average of 150 new research users trained and accepted into the facilities each month. The network is also employed as a precious resource by more than 250 small companies. One of the key challenges to nanotechnology, as a multi- and inter-disciplinary area where many of the exciting ideas require cross-discipline use of techniques, is finding an efficient way for cross-training. As an infrastructure network, an efficient continuous transfer and cross-fertilization of the knowledge of these techniques and new developments is an important task for us. Our Technical Liaison staff (domain experts) support research at the boundaries of disciplines by day-to-day interactions and hosting site visits, and we organize regular workshops. Examples of areas where this has been very successful include the interface between life-sciences, chemistry, and the major disciplines of engineering. Use of soft-lithography, tools and techniques of biology and chemistry, and connecting them to electronics, optics, and MEMS, and computational modeling in support of research are some examples where the staff provides strong support.

Our web-site (www.nnin.org) is a major link and store-house of information to technical and non-technical community. It provides technical know-how to the national community, provides detailed information of our resources (processes, tools, training media, for users, technical talks, a search engine) and is a web-portal for outreach activity for education and social and ethical discussion. It features a number of links, including recent examples of research made possible through the network. A number of these examples, which have received extensive recognition, came about due to the ability of bringing diverse techniques together through the staff and through focus on user service.

Increasingly, characterization is also an important part of the research since observation of properties and structures at the nanoscale is non-trivial. Thus, various forms of microscopy (cryo-tem, tem, stem, etc.) and preparation of samples, such as through focused-ion beam techniques, are available through the network, alongside traditional and non-traditional synthesis and fabrication tools for integrated processing. We are also placing increasing effort in support of technical usage through remote means. This support activity ranges from critical electron-beam lithography and processing of nanoscale features, providing membrane structures used in a variety of nanoscale experiments, to integrated processing of more complex device and systems.

In order to assure that the network remains dynamic in its support and capabilities and makes judicious use of resources, the network sites have assigned technical focus areas for leadership. These areas correspond to the areas of exceptional strength of the local research and allow us to selectively apply precious financial resources towards maintaining the most advanced capabilities for national community. Cornell and Stanford provide extensive support across disciplines as well as for complex integration projects. For biology and life-sciences, Georgia Tech and U. Washington; for chemistry at nanoscale, Penn-State, Harvard and Texas; for Geosciences, New Mexico and Minnesota; for integrated systems, Michigan; for tool development and manufacturing research support, Texas; for remote use and characterization, Minnesota and New Mexico provide the focus technical area leadership.

Education, Development and Outreach: Education and outreach at the local and national scale is a very key component of the network activities. These activities encompass the needs of public and of the education community. We organize local and national workshops that tie technical areas to research and to practicing knowledge. Our web-site features a number of multi-media offerings related to education and outreach. There include lectures on the practice of nanotechnology, a variety of graduate-level discussions related to specific disciplines – nanomagnetics, e.g., and there are more practical lectures related to mentoring (art of scientific presentation or writing of scientific papers), and also instructional material related to social and ethical considerations.

The network also conducts a very successful REU program and several programs for teachers. During 2005, 81 interns from 66 different institutions across the United States and representing 37 fields of study participated in the program. Sites also have activities focused on local needs, ranging from attracting underrepresented high school students through rewarding experiences, and support for local teaching community – high school, community college and other small colleges. We are also active in workforce development through hands-on practical training. In time, we will have courses and an open text-book available on the web. The workshops conducted by the network during the past year included hands-on three-and-a-half day lectures coupled to fabrication, computation and modeling, movement of ideas and technologies from research to manufacturing, and workshops for small institutions for an immersive laboratory experience.

The network has also extensive international cooperation that takes the form of joint workshops as well as web-based Nanotechnology International Cooperative for knowledge and experience interchange.

Reports on individual NNIN educational activities are available on the web. Nearly 700 attendees participated in our workshops during the year. These events are promoted through mailings and the web.

Societal and Ethical Implications: Integrated into our network activities are activities fostering the awareness of societal and ethical issues for practicing researchers, as well as creation of the archives and collection of data as the nanotechnology area evolves for future studies. These activities are centered at Cornell, Stanford, Washington and Georgia Tech. Discussions and seminars from these activities are available as multi-media presentation from the NNIN web-site.

Research and Development: NNIN is a critical enabler of research and development. Particularly for the 1100 external users of the network, their success would not be possible or would be significantly slowed and expensive. Among the scientific discoveries of note resulting from NNIN's resources include single nuclear spin detection and ultra-sensitive magnetic gradient measurements through special suspended cantilever probes, demonstration of spin-hall effect in semiconductors, a factor of 100 slowing of light in photonic bandgap structures, the first demonstration of electronic tuning of carbon nanotube based oscillators, and non-volatile semiconductor memories at sub-20-nm dimensions. These developments are critical to ultrasensitive atomic and molecular scale detection, and large scale improvements in massive information processing and communications. More than 250 small companies use NNIN, and our facilities have seen many companies grow from exploration and development stage to production and success in the marketplace. These companies are listed along with other user institutions for each site in section 3.6. In addition, large companies, including IBM, Intel, Corning, DuPont and Boeing continue to find the unique tools and knowledge critical to their exploration of future opportunities.

2.0 Introduction- Mission and Operational Principles

2.1 Introduction

NNIN is a network of open university-based laboratories with diverse technical strengths that exists to fulfill the vision of the National Nanotechnology Initiative. The network is an interdisciplinary, multi-faceted and broadly-accessible infrastructure that supports near-term and long-term needs of necessary instrumentation, efficient access to the instrumentation and their use, and conducts activities of broader reach that help establish long-term gains for the society derived from discoveries and inventions from nanoscale science, technology and engineering. The infrastructure provides for the coordinated implementation of large numbers of different types of top-down processing steps together with the complex tasks of synthesis and assembly at the molecular scale. It also supports specialized techniques for characterization at the atomic scale, and supports advanced and robust modeling and simulation tools. The network is a resource center for technology transfer and the sharing of new techniques, and provides a foundation for the education and technical training of new users who will be the leaders in the coming decades. In addition, the network serves to educate the public about the opportunities and challenges of nanotechnology, and promote research in the social sciences so that future developments lead to the greatest possible societal benefits.

Accomplishing the technology-support requires putting the needs of external users as the highest priority. This enables development of openness that enables a broad swath of research of the highest quality, and allows development of efficient means so that a large group can truly leverage the resources. Accommodating large numbers of new users arriving weekly and training them to operate safely and creatively in a shared-facility environment is a critical step of this culture. We have learned how to effectively provide complex technology resources such as e-beam lithography and complicated multi-step integrated processing procedures, how to broaden the reach of knowledge of new nanoscale techniques across disciplinary boundaries, and how to leverage the synergies of a network for the mutual benefit of all users. We continue to improve on our methods as we gain experience, areas expand, and new directions emerge.

Each one of the sites is committed to the vision of open facilities, outstanding service to the external user, comprehensive training and staff support, support of interdisciplinary and emerging areas research, and openness to new materials, techniques, and applications. Our operating principles are:

- 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 independent of interference from other local organizations
- Commitment to no intellectual-property barriers

NNIN is a network of “resource facilities” providing open access to state-of-the-art equipment and expertise. Personnel funded by NNIN are paid to assist others in research. The only research supported directly supported by NNIN is the research and exploration that occurs in the SEI activities (Social and Ethical Implications of Nanotechnology). The nature and scope of research performed within the NNIN facilities is determined by the users and the results of the research belongs to the users.

This is the report of the second year of operation of NNIN. The network began operation on Mar. 1, 2004. Of the thirteen sites of the network, five had been members of the preceding network (National Nanotechnology Users Network) and eight sites are new. The data reported here reflects statistics for 10 months through Dec 31, 2005.

2.2 Mission and Approach

NNIN’s mission is to enable rapid advancements in science, engineering and technology at the nanoscale by efficient access to nanotechnology infrastructure.

As a networked community of university-based facilities that take advantage of the unique research and knowledge strengths of the local community, and by providing an open environment that makes these resources equally accessible to academic, government and industrial users, we provide a low barrier and low cost approach for research, education, and technology development to flourish within all of the many disciplines that can benefit from nanotechnology. Through openly accessible facilities distributed across the country we provide a network that welcomes researchers from established and emerging disciplines with a strong emphasis on accommodating new materials, techniques, and processes.

Qualified technical staff is provided by each of the NNIN sites to serve as a resource for our direct users and to support the broader scientific community through workshops, short courses and web-based instruction. This 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.

The culture of the network is focused on service, and designed for service to outside users. Member sites are committed to equal and open access to projects independent of external or internal origin, and to provide technical leadership in assigned areas. This technical leadership responsibility is coupled to the local technical strengths so that new developments, knowledge and ideas can be made nationally available in a timely manner and so that critical financial resources can be applied efficiently.

Each site is responsible for providing the staff resources sufficient to enable comprehensive training and support for external research projects. Remote-access capabilities coupled with a strong web presence allow NNIN to serve a vast community of researchers beyond the geographic reach of the network. Remote-access projects are treated the same as projects that involve hands-on use of NNIN facilities by external users. 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.

The entire breadth of nanotechnology can not be covered by one facility or by a set of identical facilities. NNIN sites are all different and have different responsibilities within the network, some with responsibilities in traditional areas and others with primary responsibilities in emerging areas such as geosciences and life sciences. Similarly, responsibilities for education and SEI activities are distributed across the network. Figure 4 shows these responsibilities in tabular form. Further discussion of site specializations is given in Section 3.2.

NNIN has also made significant progress in establishing itself as the "national resource" for knowledge and information related to nanoscience and nanotechnology and activities aimed at developing interest and understanding of science in the society. This is accomplished through exhaustive efforts to keep abreast of new research in nanoscale science followed by development of critical network resources required to rapidly exploit these advances. The network plays a vital role in identifying nascent disciplines and interdisciplinary research programs that can make use of nanotechnology. Once identified, NNIN can move quickly to offer our capabilities, and position our training and equipment resources to best meet the needs of these emerging fields.

Network activities are also directed towards encouraging underrepresented groups in the scientific disciplines and in making successful models available on the web through our infrastructure. Our outreach and educational activities are both national in scope (children's magazine, training and technical resources, etc.) and also focused on local needs. With participating universities located strategically in areas with large under-represented communities, e.g., Howard in Washington DC, U. New Mexico in Albuquerque in South West, Georgia Tech in Atlanta, and UCSB in Santa Barbara, we have also in place strong directed programs for local outreach. As these programs develop, the successful efforts will be models for development of nation-wide efforts.

The vision of a nanotechnology future is also critically dependent upon human resources. **Education, human development, and outreach** are thoroughly integrated throughout the network. Our goals are to spread the benefits of nanotechnology to new disciplines, to educate a dynamic workforce in advanced technology, and to become a teaching resource in nanotechnology for people of all ages and educational backgrounds.

2.3 Culture and Commitment

NNIN is a dynamic organization that continues to evolve as it learns best approaches to accomplish its objectives and as new technical areas and needs arise. One constant theme in this evolution has been that effectively working with external users from a variety of disciplines and backgrounds to successfully complete user projects in a short time, at low cost, and with maximum hands-on educational benefit, leads to approaches that provide the largest impact on a national scale with limited resources. We place the needs of external users as the highest priority. This enables development of openness that enables a broad swath of research of the highest quality, and allows development of efficient means so that a large group can truly leverage the resources. Accommodating large numbers of new users arriving weekly and training them to operate safely and creatively in a shared-facility environment is a critical step of this culture. We have learned and continue to fine tune how to effectively provide complex technology resources such as e-beam lithography, new techniques such as those derived from self-assembly, complicated multi-step integrated processing procedures, how to broaden the reach of knowledge of new nanoscale techniques across disciplinary boundaries, and how to leverage the synergies of a network for the mutual benefit of all users. This is an ongoing process that continues to improve on our methods as we gain experience, areas expand, and new directions emerge.

Our mission is broad – in technical areas, in education and outreach activities, and in broader societal activities. The network serves these through a network of university facilities, geographically dispersed across the nation, focusing on needs of new and highly specialized areas, and by providing complementary strengths to efficiently use financial resources. A key element for technical success is the strength of individual sites in contributing to the network's technical and broader goals. Strong technical capabilities based on institutional strengths, and exceptionally diverse ability to contribute to educational, outreach, and societal programs are operating elements of the infrastructure network.

Each one of the NNIN sites is committed to the vision of open facilities, outstanding service to the external user, comprehensive training and staff support, support of interdisciplinary and emerging areas research, and openness to new materials, techniques, and applications. Our operating principles are:

- Open and equal access to all projects independent of origin
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NNIN has a well-developed mechanism for rapidly accommodating users into the laboratory with new users accepted every week. Currently, NNIN trains approximately 1800 new users per year, with a total of over 4000 different users taking advantage of NNIN facilities each year. Safety training is mandated for all users prior to any activity. Each external user project is assigned to a staff mentor who is responsible for the technical support. This is particularly important for new users and for users from outside the domain of electronics. 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.

NNIN'a approach to supporting new developing areas and their needs is to accomplished through exhaustive efforts to keep abreast of new research in nanoscale science and by development of critical network resources required to rapidly exploit these advances. Workshops, presence at conferences, user exchanges, other participatory activities, advise from national advisory board, etc. are all important elements in supporting new areas and needs. The network plays a vital role in identifying nascent disciplines and interdisciplinary research programs that can make use of nanotechnology. Once identified, NNIN can move quickly to offer our capabilities, and position our training and equipment resources to best meet the needs of these emerging fields.

2.4 Specific Practices for User Support

This section describes the NNIN focus on user activities and the mechanisms in place to fulfill that mission.

The facilities of NNIN are resource facilities, i.e. the primary mission of NNIN and NNIN sites is 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. 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. Similarly NNIN does not directly fund user projects from outside users. The user base thus defines the direction of their research in NNIN.

That being said, at most sites there are resident research programs which use the facilities heavily and provide critical knowledge and information. These programs and their associated students provide much of the technology base, process development, and process characterization at each site. A prime tenet of NNIN is, however, that all users are equal and the facility is equally open to all. NNIN sites must take great care to keep the research tasks separate from the user facility tasks so that even researchers from “competing research centers” can have fair access to all site technology. In general, the NNIN facility staff is distinct from any associated research staff. This separation of interests requires considerable effort but it can be done. It is a cornerstone of NNIN operation and distinguishes the NNIN from other organizations.

NNIN sites operate as user facilities, not as research collaboration. Our users come for a short period of time (days, weeks, months) for access to our laboratory facilities without disclosing their intellectual property. They have open access to the instruments, the staff, and the knowledge infrastructure of the “user facility.” The user can use the facility quite independently, having learned the instruments, or can take extensive help offered by the staff. The NNIN staff is available to assist but not to take control of a project. They can even be working in direct competition to local researchers. Access is on an equal basis and the intellectual direction of each project remains with the user.

NNIN facilities are primarily hands-on facilities; users are trained by the staff to become self sufficient. Some processing can be performed remotely (staff working for the user), but this is generally limited to simpler process sequences, i.e. we do not operate as a foundry of complex integration. The execution of a complex multi-step process sequence is a research project of itself, and it must be performed by the user and not by the staff working remotely. 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.

In addition to normal support staff, NNIN has a small set of “Technical Liaisons” or “Domain Experts.” These are senior staff members, typically Ph.D.s, who are scientists and experts in nanotechnology applications to a particular field and who can be non-competitive peers of potential users. They are particularly valuable in establishing the interface to new technical communities, as they have the necessary scientific background, but also have sufficient academic training and standing to converse in the specifics of the potential user's field. They perform an important matching function to new user communities. Even these technical liaisons, while interacting at a higher scientific level, are careful not to take ownership of the user's project. NNIN maintains technical liaisons in the life sciences, in chemical nanotechnology, in geosciences, and in materials characterization. Details on these individuals are available on the NNIN web site.

The access process can be brief, spanning as little as a week or two. It begins when a potential user calls or sends email to an NNIN site or to NNIN management with a brief project outline. A discussion ensues with the site user coordinator to clarify the requirements. Depending on the level of sophistication of the user and the proposed process flow, a subset of the NNIN staff may enter the discussions to work out an acceptable process plan. At any time a project may be referred to an alternative NNIN site which is better suited to the task, and NNIN coordinates efficient conduct of the tasks across sites.

After it is agreed that a project is feasible, a brief proposal, one or two pages, is written to document the agreed upon scope. It is extremely critical by this point that the user expectations are consistent with staff expectations, and that the project is manageable within the resources of NNIN. A brief standard memorandum of understanding is signed between the NNIN facility and the outside institution. This is not a sponsored research contract, merely a purchase of services. If the user is ready and able he/she is assigned the next available slot, which can be as soon as the next week but always less than a month. New users are accepted into the NNIN facilities at least monthly—weekly at some sites. Some of the larger NNIN sites can accommodate 10 new users each week, and through special efforts, more than that during the summer period. Over 1400 new research users were trained and entered NNIN facilities so far in 2005 (10 months).

User projects are accepted without further scientific peer review. All are "reviewed" by the site staff to assure that they are appropriate to the toolset, i.e. that the structural requirements and the proposed materials are compatible with the available processes. But we do not review the scientific merit of the work. Academic users have already secured funding and been reviewed; it would be counter productive for us to institute additional barriers. Commercial users have similarly been vetted by their source of funding. We thus try to be an available resource without impeding the research and development process.

All NNIN facilities have well developed orientation methods to familiarize users at all levels with our expectations for use and safety. Safety and rule compliance is extremely critical in a multi-user facility, and even more so when users come at a variety of skill levels from varied institutions and backgrounds. NNIN staffs are assigned to provide user support for each outside user. Training is provided by staff for all the necessary tools and processes to complete the project, and some level of process integration support is provided. All this training must be delivered efficiently and expediently as the user is resident for a short period of time and needs to keep making progress. NNIN sites are well accomplished at this.

As nanotechnology reaches into new fields and brings new researchers into existing fields, many users have little or no relevant laboratory experience. It is NNIN's task to provide them the necessary support to be successful. Other users may have significant processing experience. They already know what they want to do and they come to NNIN looking only for only equipment access and basic tool instruction. NNIN support mechanisms are flexible enough to handle both of these extremes.

Users may visit for a week or a month or longer. Duration of a few weeks is most typical for first time visits. There are also many users who are permanently resident at the facilities. i.e. technically they work for another institution but they live at the NNIN site and use it everyday. They “reverse commute” to their home institution when necessary. To facilitate the user process some sites provide low cost housing for daily rental. In some areas this is not practical, however. Nonetheless, travel costs are generally small compared to other costs of research.

NNIN facilities are dedicated to user support and user access. This requires a devoted management and staff. Our technical staff is highly knowledgeable but dedicated to research support. This independence from the need for collaboration with a local researcher is key to the success of NNIN facilities in supporting broad national research agenda since a user does not relinquish intellectual control of their project.

Critical to any user facility or network of facilities is modern state-of-the-art equipment. It must also be well characterized and well maintained, and users must be trained and supported in its effective use. A major portion of NNIN support goes to staff as the major NNIN tasks are staff intensive; maintenance of equipment to high up time is staff intensive; user support (training and process assistance) is staff intensive; and process characterization is staff intensive. While some process characterization can be supplied by local users, for the most part, these tasks must fall to the professional staff.

NNIN’s tool set is worth several hundred million dollars and most of it has existed prior to formation of NNIN. Less than 10% of NNIN’s overall budget is spent for capital equipment, a level determined by each site. Most capital equipment is obtained from other sources: university, other research centers, local faculty grants, equipment competitions such as Major Research Instrumentation (MRI), and donations. All of these sources are extremely constrained. The vast majority of equipment available for donation is not suitable for the smaller scale NNIN lab operations. This is particularly the case as manufacturing wafer size increases well beyond the size appropriate to our facilities. And even if appropriate, installation and facilitization costs can be prohibitive. Renewal or the capital resource and its expansion to meet new technology demands remains a critical and continuing issue within NNIN.

Having a large diverse state-of-the-art equipment set is critical to a successful user facility. But a facility can only afford to support a large set of equipment if it has a large set of users, i.e. a critical mass. Complex integration tasks also bring very interdisciplinary knowledge-intensive demands. The critical mass of users enables a large equipment and knowledge base, and is in turn necessary to attract the critical mass of users. NNIN, through its networked operation, makes this easier to achieve and in turn influences the research of a large community of users.

The following sections describe the efforts of the network in support of our mission.

3.0 Research Support Program, Accomplishments and Plans

3.1 Strategic Plan

In April of 2004, NNIN formulated a strategic plan describing our vision, goals and plans in detail and that guides the operation of the network. This strategic plan is included as an appendix in this report.

3.2 Network Sites

The network consists of 12 funded sites and one affiliate. The goal of affiliate membership is to help us evaluate the needs for specific specialized technical capabilities that are unique but whose demand is not well-understood. The affiliate's participation helps us understand the research community's needs, helps foster the area through the network experimental support and the promotion and direction of user support, and helps us determine best ways for the evolution towards the future. Currently the Triangle Lithography Center, a collaboration of North Carolina State University and the University of North Carolina is an affiliate member and provides 193 nm lithography capabilities for patterning at tens to hundreds nm scale.

During the formation of the network, in order to address the broad scope and to provide the most advanced technical capabilities within limited financial means, sites were chosen and assigned specific specializations based on internal research strengths. All sites have responsibilities towards education and outreach activities, with major efforts at Howard University, University of New Mexico, Georgia Institute of Technology, and University of Washington towards under-represented communities. Figure 4 provides a summary view of these responsibilities as viewed from focus areas; here these are described with an institutional view:

- **Cornell:** The Cornell Nanoscale Science and Technology Facility, CNF, along with the facility at Stanford, has the task of providing broad capabilities across biology, chemistry, MEMS, characterization, electronics, materials, and optics, with special focus on complex integration. Leadership of the network SEI activity (Prof. Bruce Lewenstein) resides at Cornell, and Cornell also has responsibility towards nanoscale scientific computation support. Management of the network also resides at Cornell.

- **Stanford:** The Stanford Nanofabrication Facility is broadly responsible for user support across the entire range of nanotechnology, including capabilities in biology, chemistry, MEMS, characterization, electronics, materials, and optics, and complex integration. Stanford is also responsible for providing computation and modeling support and to participate in scholarship activity in social and ethical investigations. The network's health and safety efforts are coordinated from Stanford with Dr. Mary Tang as the network coordinator for these activities.
- **Georgia Tech:** Georgia Tech is responsible for leadership in the Biology and Life Sciences efforts for research and applications of nanotechnology. Georgia Tech also provides expertise in electronics, MEMS, and optics, and participates in SEI activities. In addition, the network's efforts in education and outreach are coordinated from Georgia Tech with Dr. Nancy Healy leading the effort.
- **University of Michigan:** The Michigan Nanofabrication Facility provides technical leadership within the network in integrated systems with particular focus on integration of MEMS, microfluidics in order to create systems for biological sensing and other applications. Michigan also contributes to computation effort of the network.
- **University of Washington:** NNIN services at the University of Washington are provided through the Nanotech User Facility. U. of Washington has specific responsibility for serving the biology, medicine, and life sciences communities in their needs for nanotechnology, participates in the SEI activities and leadership responsibilities for outreach activities.
- **Penn State:** Penn State has specific NNIN leadership in the area of chemical nanotechnology with a particular focus on molecular-scale science, engineering and technology support.

Figure 4: Technical area responsibilities of NNIN sites**.**

	Bio- and Life Sciences	Bio- and Integrated Systems	Chemistry and Molecular Scale Technology	Electronics, Optics, MEMS	Materials and Physical Sciences	Computation	Geosciences	Manufacturing Research Support and Tool Development	Remote Usage and Characterization	Education	Society & Ethics
Cornell	■	■	■	♦	■	♦	■	■	■	♦	♦
Stanford	■	■	■	♦	■	♦	■	■	■	♦	♦
Georgia Tech	♦	■		■		■				♦	■
Washington	♦			■						♦	■
Michigan	■	♦		■		■			■	■	
U.Texas Austin			♦	■				♦		■	
Minnesota				■			♦	■	♦	■	
Penn State			♦	■	■					■	
UCSB				■	♦					■	
Howard				■	■					♦	
New Mexico				■			♦		♦	♦	
Harvard			♦	■	■	♦		■		■	
NCSU				■							

■ Assigned Activities

♦ Special Focus-Network Leadership

- **UCSB:** The laboratory at UCSB has network leadership responsibilities towards support of electronic materials and physics applications of nanotechnology, and to provide outreach support towards underrepresented community in the local community.
- **Texas:** The University of Texas has responsibilities to support chemistry and chemical nanotechnology. U. Texas also has responsibilities for tool development for nanotechnology and through related activities support of manufacturing research.
- **Minnesota:** The Minnesota NNIN Node (MINTEC) consists of the capabilities of three laboratories: the characterization facility, and the particle technology lab and the fabrication facility. Through the former two laboratories, the Minnesota site provides NNIN leadership in remote access characterization and in particles and nanomaterials. Particles, characterization and nanoporous materials are the primary current areas of effort in NNIN towards the Geology community.
- **New Mexico**: Similar to Minnesota, Nanoscience at the University of New Mexico provides expertise in nanomaterials and materials characterization, again with strong interactions with the Geology community. U. of New Mexico also has leadership responsibility in outreach to underrepresented community in the southwest area.
- **Harvard:** The Harvard node is located within the Harvard Center for Nanoscale Systems. Primary responsibilities for Harvard are leadership of the network in chemical nanotechnology, including synthesis and soft lithography, and the network leadership in computational effort in support of nanotechnology. The network computation activities are coordinated from Harvard and are led by Dr. Mike Stopa.
- **Howard**: The facility at Howard supports a variety of specialized materials activities and has major educational and outreach responsibilities towards underrepresented community in the Washington DC area.
- **Triangle National Lithography Center (NCSU/UNC):** The Triangle Lithography Center is an affiliate member of NNIN with the objective of providing access to193 nm deep ultra-violet lithography. They receive no funding from the network for participation but agree to operate the DUV facility on an open basis, consistent with NNIN principles, and NNIN commits to redirect users who can gain from this resource to TNLC.

These assignments remain unchanged from the original proposal. As can be seen from this description, a number of sites participate in each technical and broader outreach activities. The table in Fig. 4 describes these together with the identification of sites that also have leadership responsibilities. Site specific reports are contained in *Appendix A1* describing the progress of the sites towards their objectives.

In most cases, a number of other nanotechnology resources and capabilities exist at each site, outside of the above defined scope. In particular, most sites support a wide range of microscale and nanoscale fabrication technologies, as also some level of characterization that is necessary for rapid execution of research and development objectives. Many of the universities also have additional resources useful for execution of nanoscale science, engineering and technology efforts, but which are outside the NNIN program. These resources can be and, in most cases, are made available to the user community through the NNIN program if their use can help with completing the task. Our goal is to provide service and help the user accomplish tasks with highest level of technical support and rapidly. If a specific sophisticated characterization is necessary in the middle of processing, and the resource is available on campus, we put effort in helping the user take advantage of those capabilities. Alternatively, this may be accomplished by movement of samples to other sites within NNIN where these resources are available, usually remotely. This coordination leverages resources to help accomplish tasks. Sites are encouraged to make a broad range of technologies available on an open basis; in most cases, this includes entire clean room fabrication facilities. It is important, however, to recall the assigned site focus areas when evaluating site performance. This is our primary means to providing best capabilities to the national community in those focus areas by focused use of limited financial resources, and to foster these disciplines through dedicated effort in these focus areas. Sites are expected to allocate resources in accordance with the assigned focus areas and are held specifically accountable for success in those areas, separately from research or educational user numbers in broader areas, or quality of technical accomplishments made possible, or other derived data metrics.

3.3 NNIN Funding

The network is structured as a primary agreement between NSF and Cornell, with subcontracts from Cornell to NNIN participating institutions. At present, Cornell University, as the lead institution, carries the budget for the entire network, $14M per year for 5 years. Of this, the **Cornell University site budget** is $2.5M/yr. An additional $450,000/yr. is retained by the NNIN Network Office at CU for coordinated **network management, outreach, and related activities**. These management funds are administered separate from other CNF/NNIN funds. Integrative network activities, such as advertising and NNIN's national outreach, development of multi-media and national educational resources, certain network REU expenses, web-site creation and maintenance, supplementary costs of integrative workshops, travel costs of affiliate member, annual meeting expenses, travel costs for the Director, and the salary of the NNIN Program Manager (50% FTE) are funded through the management budget. The remaining budget is allocated to the participating network sites according to Table 1.

This report covers primarily the second year of funding; On March 1, 2006, NNIN will enter its third year of operation.

NNIN sites vary considerably in size and scope of effort related to NNIN. Consequently, the level of funding and the resultant expectations vary accordingly. The basis for determining the initial funding allocation for each site was the following:

- 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 is able and committed to undertake with regard to the NNIN education and outreach thrust, the computing and web-infrastructure thrust, and the societal and ethical issues thrust.

Funding varies from $2.5 M to $450,000 per year for the funded members, with one affiliate site receiving no direct funding. The specific technical focus responsibilities of each site are detailed elsewhere. The fund distribution is summarized in Figure 5 and Table 1.

NNIN site funding pays for user support operations, for education activities, and for society and ethics activities at some sites. Within user support activities, NNIN funds primarily pay for staff salaries, particularly for the training staff, project engineering staff, and technical liaisons, all of whom interact most with the outside users. Up to 20% of the NNIN subcontracts may be used for capital equipment purchases. Funds do not generally support normal laboratory operations, i.e. expendables and service contracts, as these are more appropriately served from user fees. In this manner, most of the NNIN funds are directed to those activities which directly support the outside user base, consistent with the objectives of NNIN. With the exception of a small amount of SEI activity, none of the NNIN funds are spent to directly support research or research student salaries.

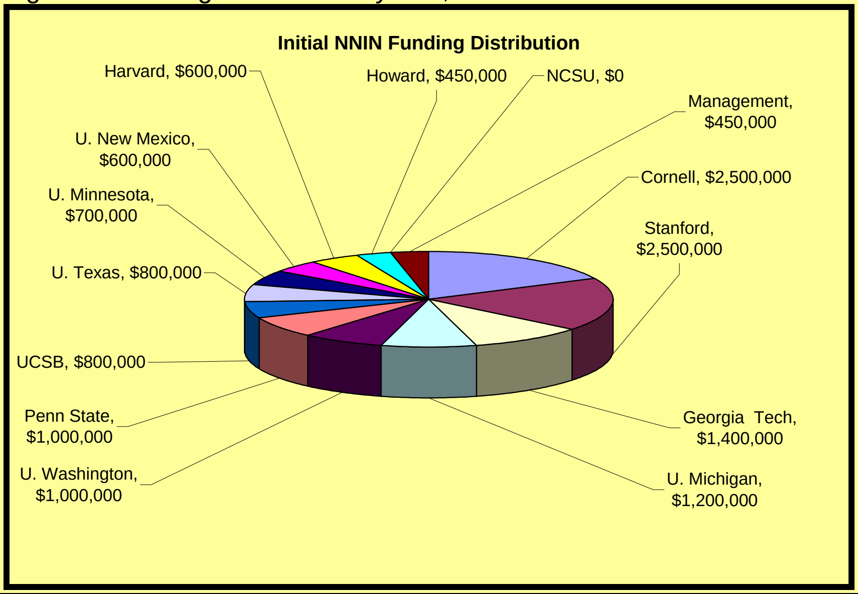
The support of the Network Coordinators (Education:Georgia Tech, Computation: Harvard, SEI: Cornell, and EHS: Stanford) is part of the defined project scope at these sites. The salaries and expenses of these coordinators thus come from the corresponding **site budgets**.

The following supplementary table (Table 1) describes the current site and management budgets by functional category across the network. Included in each cell is the total allocation for the activity, including both direct and associated indirect costs. This breakdown represents budgeted funds. These amounts are consistent with the scope of work assigned to each site in each area.

Table 1: Current Funding by Site and Function.

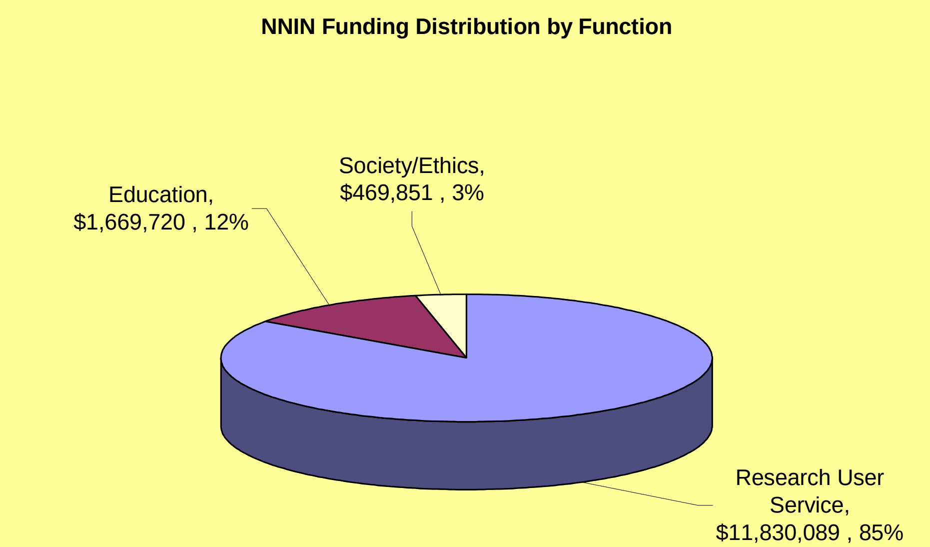
	User Support	Education	Society/Ethics	Total
Cornell Site	$2,212,473	$161,128	$126,399	$2,500,000
Stanford Site	$2,192,469	$173,725	$133,806	$2,500,000
Georgia Tech Site	$1,060,178	$311,181	$28,641	$1,400,000
U. Michigan Site	$1,121,970	$ 78,030	0	$1,200,000
U. Washington Site	$ 743,271	$ 99,084	$157,305	$1,000,000
Penn State Site	$ 880,763	$ 119,237	$0	$1,000,000
UCSB Site	$ 597,886	$202,114	$0	$800,000
U. Texas Site	$ 752,250	$47,750	$0	$800,000
U. Minnesota Site	$646,870	$53,130	$0	$700,000
U. New Mexico Site	$499,868	$100,132	$0	$600,000
Harvard Site	$563,090	$36,910	$0	$600,000
Howard Site	$299,494	$150,506	$0	$450,000
Affiliate: Triangle National Lithography Center (NCSU/UNC)	$0	$0	$0	$0
Network Management & Activities	$259,507	$166,793	$23,700	$450,000
Total by activity	$11,830,089,	$1,699,720	$469,851	$14,000,000

Figure 5: Funding Distribution by Site; $14.0 M total.



As shown in Figure 6, most NNIN support is directed to the laboratory research support activities and principally takes the form of staff salary that supports user services . As shown in Table 2, each site has allocated some support to educational activities and some for Society and Ethics related activities. Approximately 85% of NNIN funds are budgeted for laboratory/research user support, with 13% for education, and 3.4 % for Society/Ethics.

Figure 6: Network Funding by Function



NNIN infrastructure aims to be dynamic and to continually evolve in response to national user needs and to the emergence of exciting new opportunities in nanoscale science, technology and engineering. As a result we expect that in future years there will be reallocation of funds which will depend on shifts in user interests and site performance. The feedback for this occurs through reviews, the advisory board input, the user exchanges, the workshops that are organized to gauge the needs of new areas, and other feedback received from the national community. The quantitative and qualitative productivity of each participating site, the constantly evolving requirements and interests of the national user community and the needs of new and rapidly developing fields determine the evolutionary changes that will occur in the NNIN budget allocations over the lifetime of the infrastructure network. While at present there are no plans to change the number of network sites, this too is a possibility in the future.

Expenditure reports and personnel reports (Dec 31, 2005 snapshot) are provided in *Appendix A4.*

3.4 Performance Metrics

Evaluating performance of a broad and multi-site network is a complex task since it must balance between the nature, character, and the requirements of the activity and its appropriate evaluation. Research user support and educational user support require different resources. 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 research made possible 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, as well as quantitative measures that look at research and educational user service. A list of publications (over 1700) resulting from network efforts during the period through May of 2005 is available in *Appendix A7*. A set of “research nuggets” is also included in *Appendix A6*.

Each site’s technical and other efforts are different and are designed to be complementary in order to make the network an efficient infrastructure. Each site has different activities and different laboratory structures. Each of the NNIN facilities had a large internal user base prior to NNIN which benefits from NNIN but is not the primary target of NNIN support. NNIN’s focus is on supporting external user research and through this approach support the national nanotechnology effort. The transition to a facility focused on outside user needs required changes in personnel and operating procedures, more extensively at some facilities than at others. Furthermore, the level of effort required to support a user performing advanced transmission electron microscopy is quite different from a user using simple fabrication, or a new form of substrate preparation for a chemistry-oriented experiment. And lastly, the level of funding at each site varies significantly. All these factors make direct quantitative comparison of facilities difficult. Prudent management requires, however, that some quantitative metrics be established and kept, and used in context.

As part of the proposal and strategic plan, NNIN sites committed to tracking of use in a variety of categories devoted to research and educational use — lab hours, users, user fees, and new users trained, etc., by both institution type and field— and to a yearly collection of list of publications resulting from research supported by use of the node facility. These data are collected at the sites, and submitted monthly (except publications, surveys, etc., which are collected annually) in summary form to NNIN management. Because of the varied systems already in place, no central database of NNIN users is kept; only summary information is uploaded from each site. Progress towards universal data collection at all sites required considerable effort. Prior to NNIN, some of the facilities had no formal charging scheme, registration scheme, or equipment use tracking scheme. Others already had extensive systems in place but had to be modified to provide consistency with NNIN needs.

We have collected the performance data outlined below for each month since March 2004, the beginning of NNIN. In general, data presented here cover the first year of funding (March 2004-Feb 2005) and 10 months of the second year of funding (March 2005-Dec 2005). These data are reported regularly to NSF.

Five primary quantitative data metrics are collected at each site:

- **Hours:** Hours of equipment or laboratory use during the month. Hours can be viewed monthly or in aggregate over any period.
- **Monthly users:** Number of individuals using the NNIN facilities during the month. Monthly users can be viewed each month, or used to calculate average monthly use. The sum of monthly users over the year, however, is not a useful metric, as repeat users get counted multiple times.
- **Average Monthly Users:** Simply the sum of monthly users divided by 12. Average monthly use gives some information on the busyness of a facility.
- **Cumulative users:** Cumulative users are the number of individuals using the NNIN facilities during the reporting period beginning March 1 each year, to date. This is the cumulative number of unique users — persons repeating month to month are counted only once each year (March-Feb). It is **not** the same as the sum of users each month. At the end of the 12 month period, this metric represents the total number of persons who utilized the resources during the year. It is the most useful of the user metrics, and what is generally referred to when the term “number of users” is used. It is not, however, linear by the month (due to repeat users) and care must be used in comparing use over less than a full year period. Furthermore, we must recognize that different users require different intensity of support. Various forms of advanced microscopy, e.g. transmission may be very intense in staff and sample preparation, or experiments involving integrated processing may be very intense in equipment usage, but still will represent only one user.

Note on counting users:

A facility may have a high number of average monthly users but a relatively lower number of cumulative users, compared to other facilities, if it has the same users month after month, i.e. a set of long term users.

Similarly, a facility may have a relatively higher number of cumulative users with respect to average monthly users if it has different users each month, i.e. a series of short term users.

Both short and long term users are necessary for a successful user program and different technical areas have different profiles of usage.

- **User Fees:** Total user fees collected by the facility in a given period are reported. Fees can be viewed monthly or in aggregate over any period.
- **New Users Trained:** The number of new, first time users trained for facility use is reported. A user is only counted once, the first time a relationship is established. This is a measure of the training burden and impact of staff as well as a measure of the flow of new users into the facility. New users trained is not redundant with the other user counts, and can not be derived from them. Specifically it is **not** the month to month change in cumulative users. New user training is particularly time intensive since it involves safety and equipment usage training.

Each major metric is subdivided and data collected by

- technical field, and
- by institution type.

For tracking purposes, NNIN sites assign each user to one of 12 broad technical fields:

- Electronics (research)
- Optics (research)
- Materials(research)
- MEMs/Mechanical Eng (research)
- Physics (research)
- Chemistry (research)
- Life Sciences (research)
- Medicine (research)
- Geology/Earth Sciences (research)
- Process (research)
- Other research
- Education Lab use

We have separated the educational laboratory use from the research laboratory use as these activities have a very different character and place a different type of burden on the facility resources.

Activity in support of educational use at the local institution is not counted in any of the statistics.

In the future, we will be tracking all educational use separately using the Education Event Manager described later. Admittedly, there are no sharp boundaries between these categories, and due to the interdisciplinary nature of nanotechnology, manyprojects could be placed into at least two different categories. Nonetheless, an attempt is made to classify each project according to its main theme, as a means of examining the interest of users from various fields and the effectiveness of the network in serving them.

In parallel, **for research users only,** the main metric categories are divided by institution type:

- Local site academic
- Other university
- 4 year college
- 2 year college
- Pre-college
- Small company
- Large company
- State and Fed government
- Foreign

Only research users are counted in these categories. Use and users are counted in each of these categories for each of the metrics. While not exhaustive of all the combinations, this set of metrics allows us to profile the user activity at each site and derive a broader picture.

In general, unqualified references to "number of users" are taken to mean cumulative network research users over the course of one year.

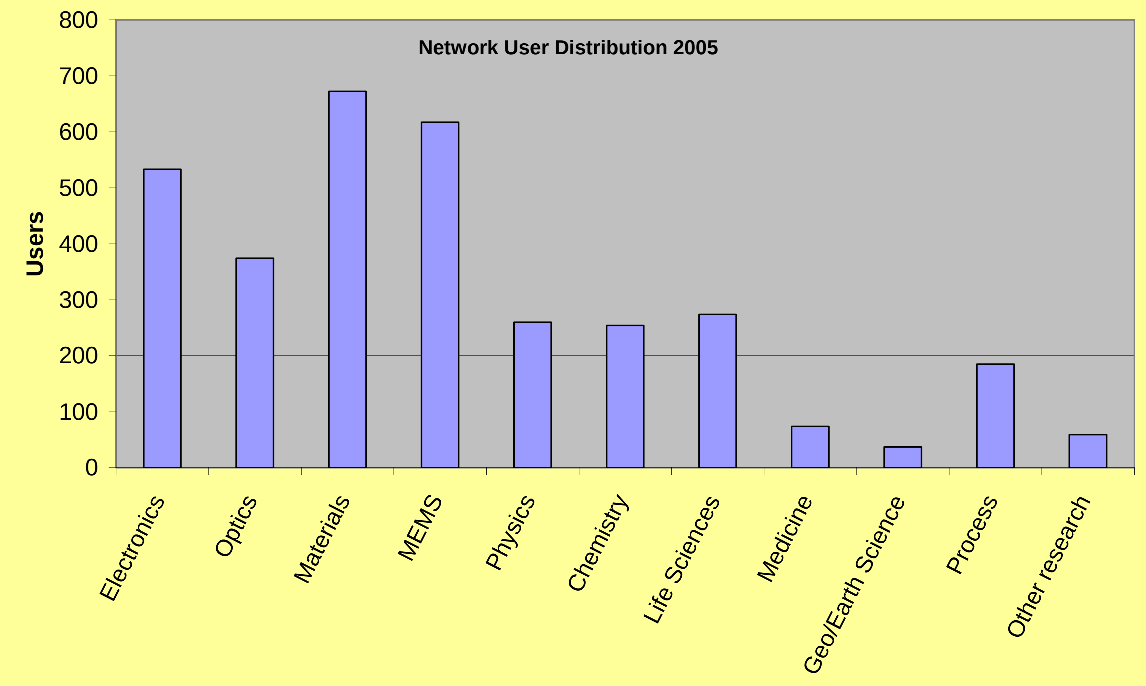
The above data are collected monthly for the NNIN funding year, March-Feb. For purposes of reporting to within the government, the National Nanotechnology Initiative office requests separate statistics on the number of users per government quarter and per government fiscal year. These are collected from sites separately and are reported only as aggregate total research users in those periods. Because of the stagger in periods, the numbers do not agree exactly with the numbers reported here.

3.5 Network Performance Profile

3.5.1 Program Breadth

NNIN's mission in support of experimental nanotechnology is across a broad range, from complex fabricated structures such as MEMS, biosciences, optics and electronics, to synthesized molecular scale structures. Fig. 7 shows the distribution of users by field (10 months, cumulative users) across the network. NNIN users come from a broad range of technical fields. Particularly interesting is the increasing use in GeoScience area, a new direction of effort within NNIN.

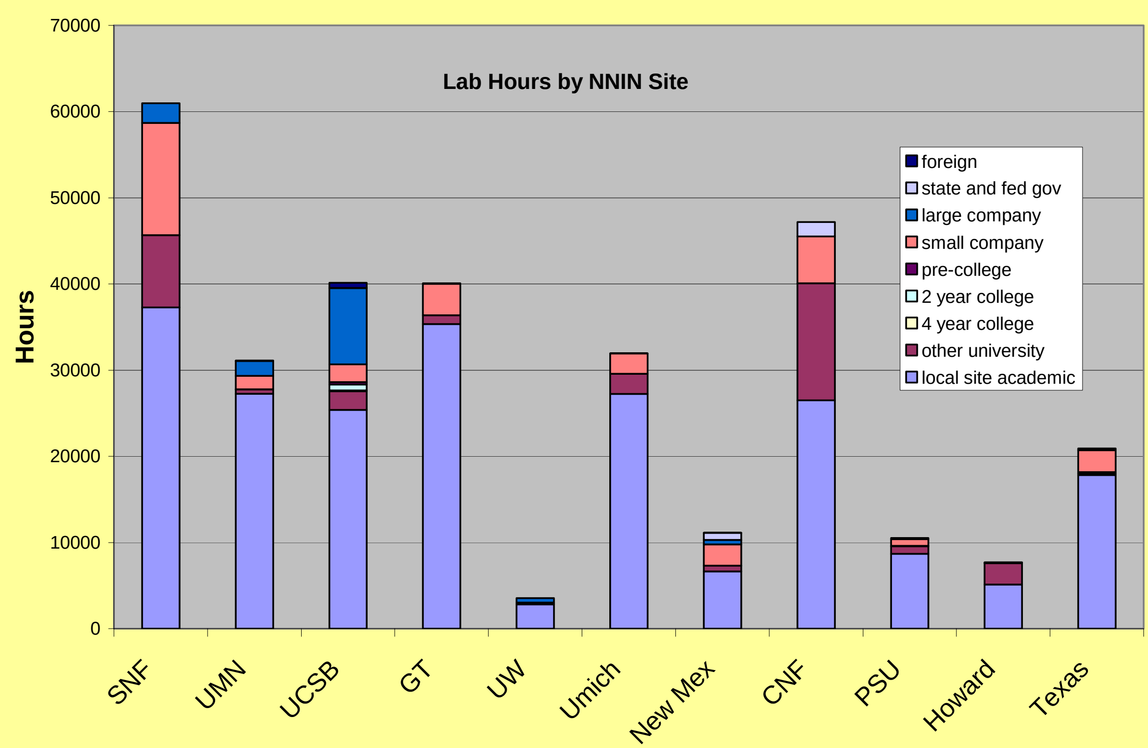
Figure 7: Network User Distribution by Technical Area.



3.5.2 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. Usually, the method of counting clean room time exceeds the direct equipment use time since users spend considerable time characterizing, planning and discussing experiments, a time that may be spent in the clean room but that is not usually reflected in equipment time. 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. However, laboratory hours are an important way to track intensity of laboratory activity at each site and across the network.

Figure 8: User Lab Hours by NNIN Site.

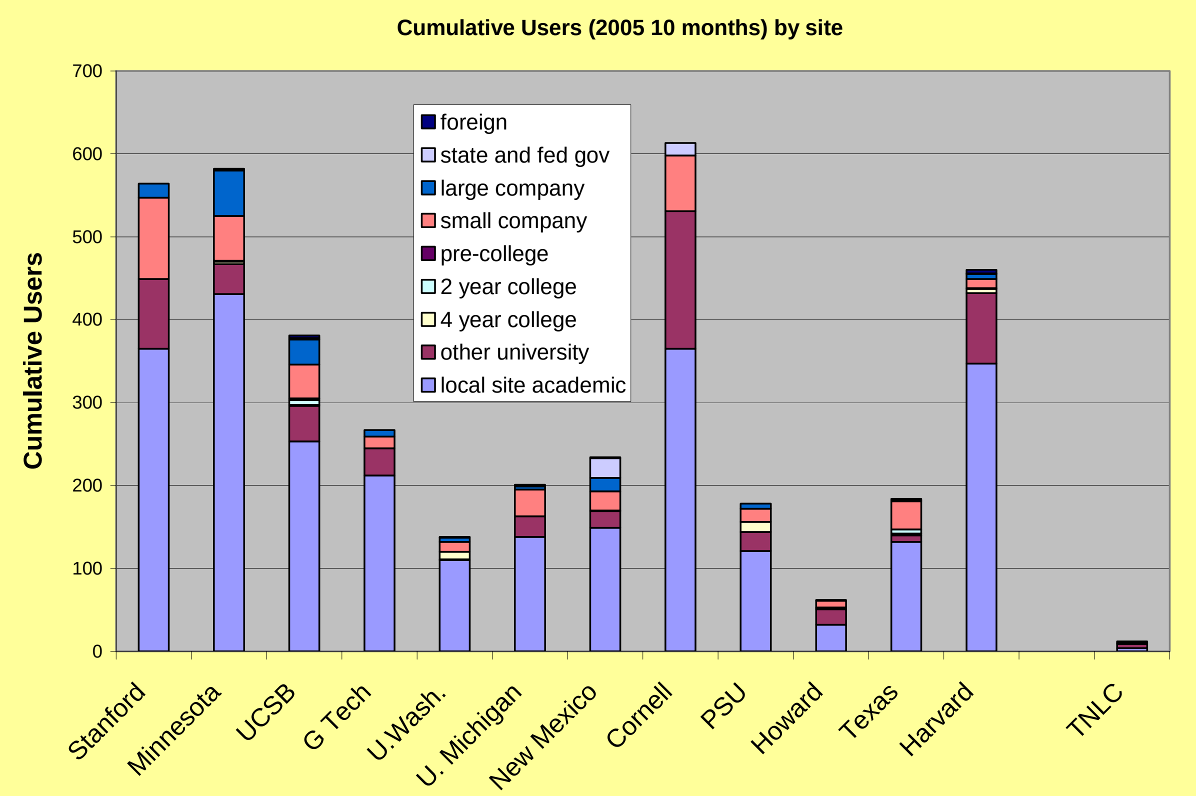


The chart in Figure 8 represents total lab hours during the 10 month period. Size of each NNIN facility varies significantly and each includes different amounts of "associated" facilities. Nonetheless, they reveal information about the size and scope of each laboratory's activities. The activity at all laboratories is dominated by local usage. The local users are a vital foundation 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. These statistics show that Stanford, UCSB and Cornell, three of the older members of the network, have a good balance between internal and external usage, with the former two stronger in industrial support and Cornell in external university support.

3.5.3 Cumulative Annual Users

Cumulative Annual Users is the primary user counting metric employed by NNIN. This is each unique 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 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 may times over the year with a 4 hour threshold for usage. Figure 9 shows the distribution of users across the network by site, with types of users. This figure can also be contrasted with the hours (either laboratory time or equipment time). Cornell and Stanford, the two older NNIN sites, reflect a large and good balance between internal and external users, with U. Minnesota, UCSB, and Harvard showing a significant 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

Figure 9: Cumulative Annual Users at each site.



technical focus responsibility area at the specific site.

As discussed in introduction, NNIN's effort is organized around the theme of serving the external user – a focus we believe leads to the variety of 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. Figure 10 show the distribution of outside users only, i.e. local site users removed for clarity. Nearly all sites continue to make progress towards the objectives. The two major sites of the network, Cornell and Stanford have more than 200 outside users each in the 10 month period, with both academic and industrial users benefiting from the network. In addition, a number of other sites, U. Minnesota, UCSB, and Harvard, two of whom are new members of the network, also have a significant number of external users.

Figure 10: NNIN Outside Users by Site.

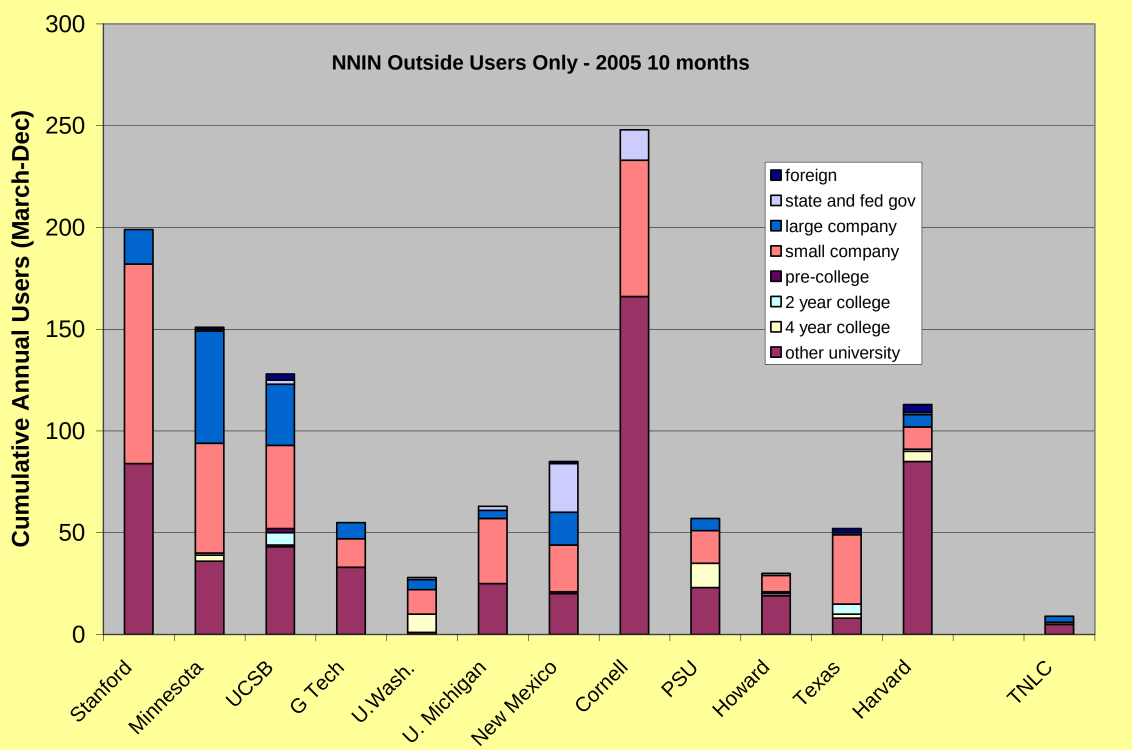
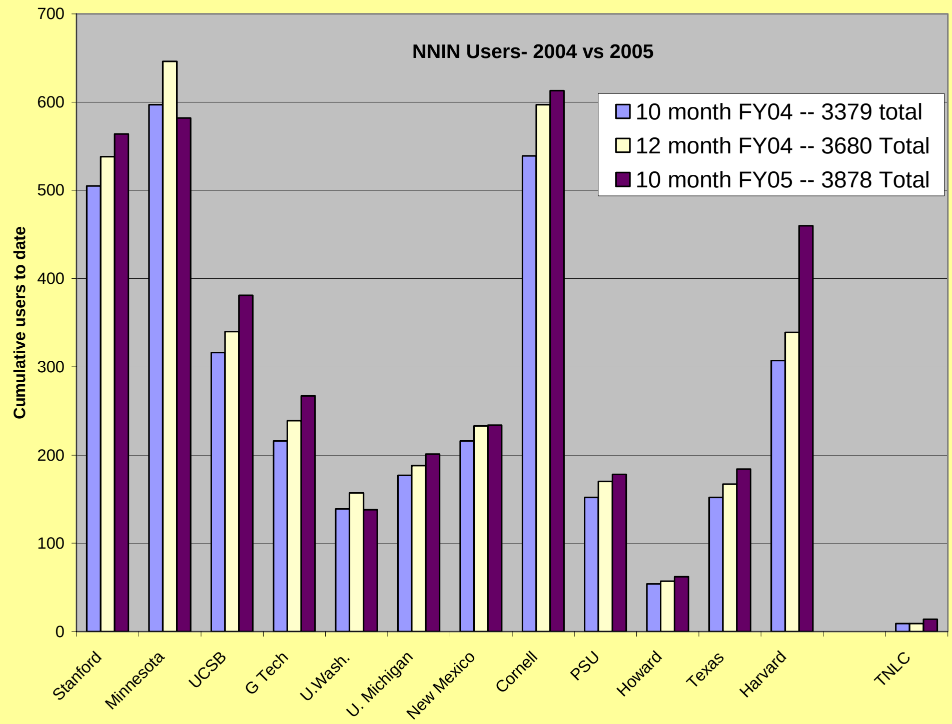


Figure 11: NNIN users by site, 2004 vs 2005 year to date.



Since the network started in 2004, it is important to also view the progress in network usage. The associated chart shows the growth in usage of the network at sites. Nearly all the sites continue to make progress in this objective as shown the two figures, as does the network.

Figure 12. Network wide research usage (cumulative ytd), 2004 vs 2005). 2005 use extrapolates to approximately 4400 users full year.

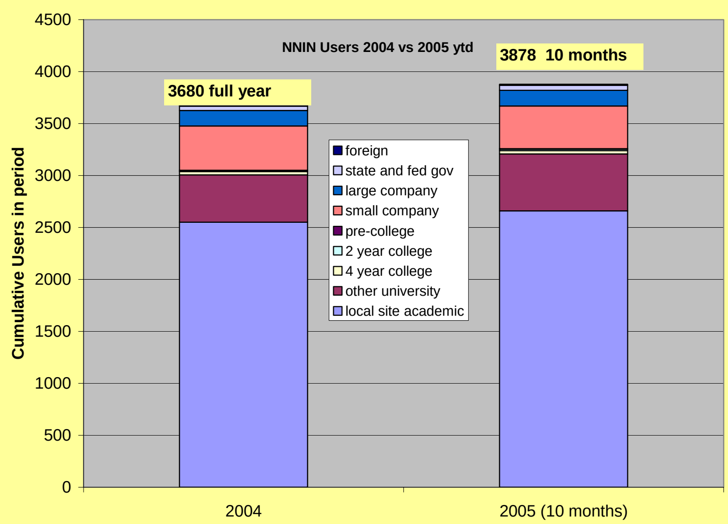


Fig. 12 shows a general increase in network usage across all institution types. Summed across the network and projected to a full year (March 2005-Feb 2006), NNIN usage projects to approximately 4400 research users, an increase of 19% year to year.

3.5.4 User Fees

Lab use fees supplement the NNIN funding at all sites. Fees are charged on a 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 according to federal and university regulations for cost centers. Some of the NNIN site programs are connected through existing, sometimes larger, facilities and programs. As such, no attempt has been made to standardize fees across the network which must remain consistent with local university requirements. NNIN only demands that external academic users receive the same rate as local academic users, and that the NSF funds be organized 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. 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 sources.

User fees provide a mechanism for allocating costs to different activities. The NNIN mission is to make these facilities available openly to 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; examination of total fee recovery yields little new information. One of the tenets of NNIN and a necessary condition for forming the critical mass of users is that use must be affordable, particularly for academic users. An examination of average user cost across the network reveals that this in the case.

Fig. 13: User fee recovery, 2005 10 months.

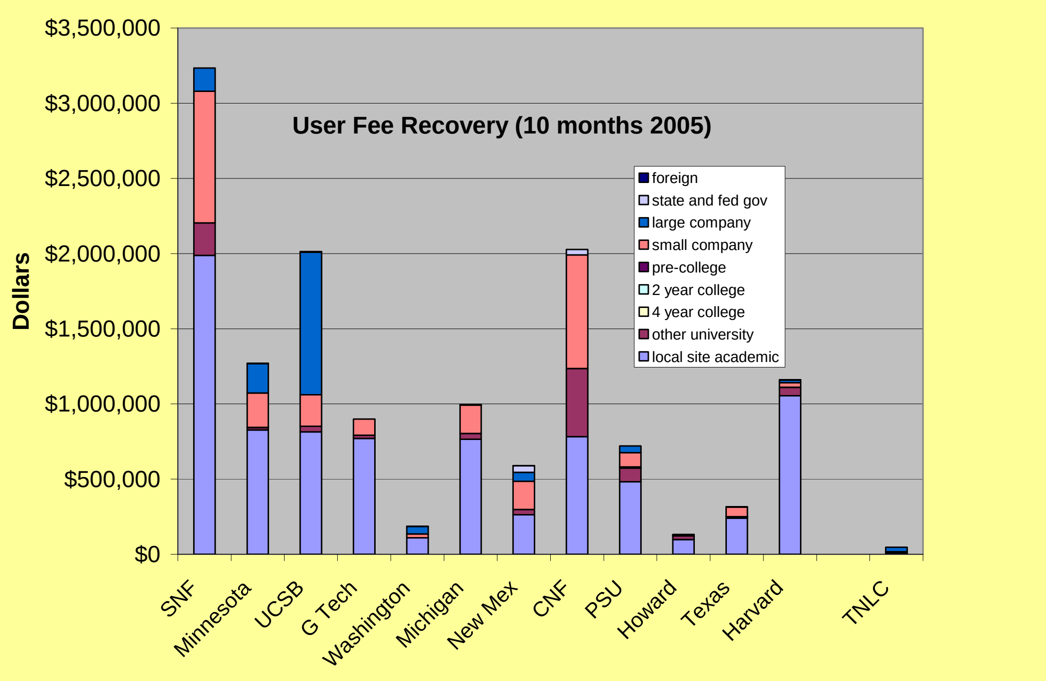


Figure 14: Total network user fees.

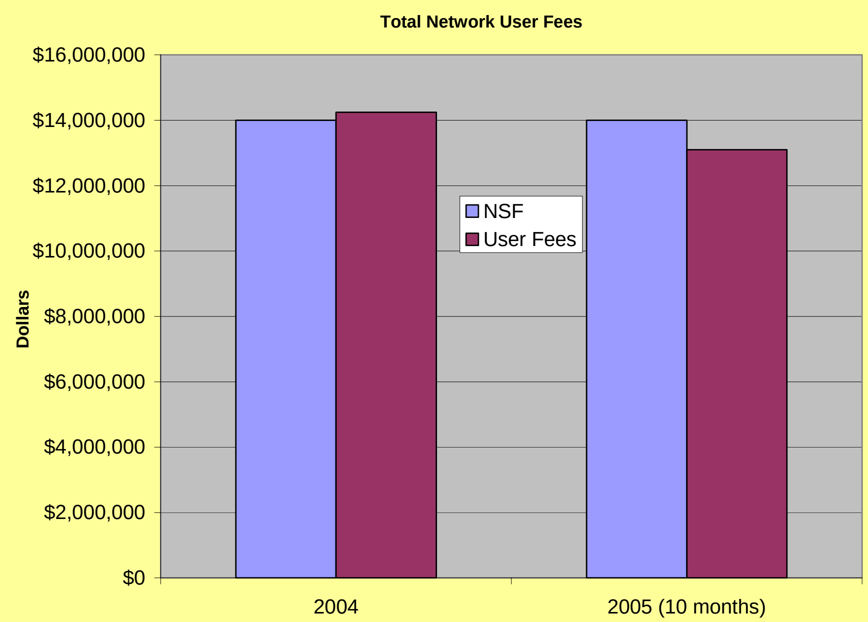
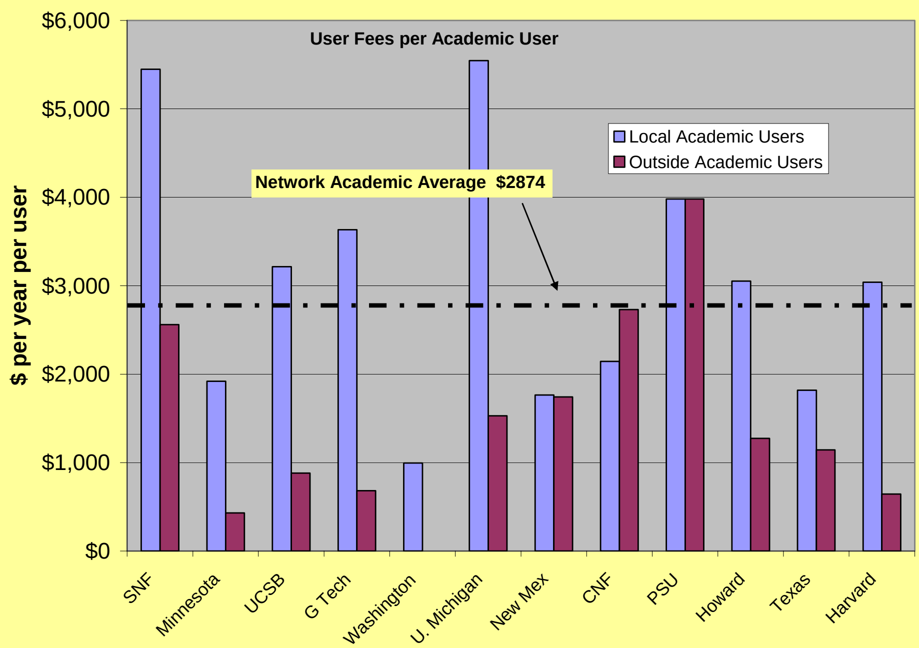


Figure 15: Average academic user fees.



The point of these plots 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. One should thus not conclude that one site's fees are too high or too low from this data. And 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 is $2874 during a full year, quite within the budget of most research grants. In contrast, the average cost for an industrial user is $7613, again with a broad distribution both within sites and across sites, but extremely manageable for the complex resources that the NNIN sites provide.

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.

3.5.5 Average monthly users

Another way to look at use is by average monthly users. Use profiles of different users and different types of users vary significantly. And different sites intersect different groups of users. Whereas cumulative annual users characterizes overall user count, average monthly users reveals more of the general intensity of use on a monthly basis, i.e. how busy is the facility in serving users. Figures 16 and 17 examine average monthly users, both for all users and for outside users only. *Note that on these charts, UCSB data can not be directly compared as their data is reported only quarterly not monthly.*

Figure 16: Average monthly users by site.

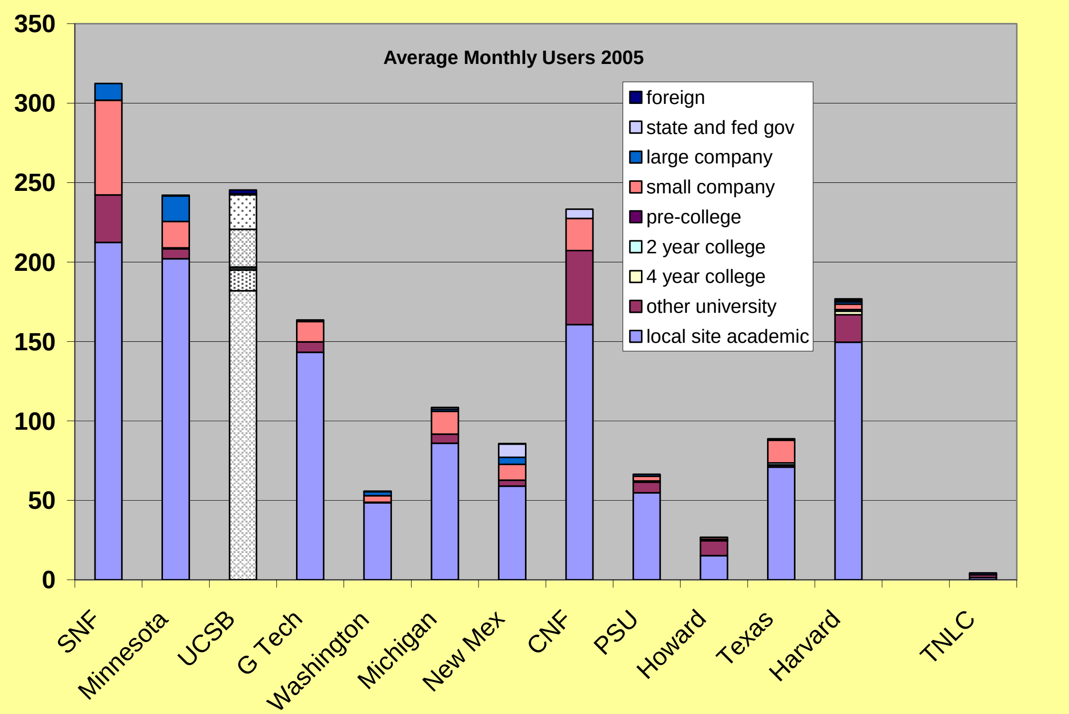
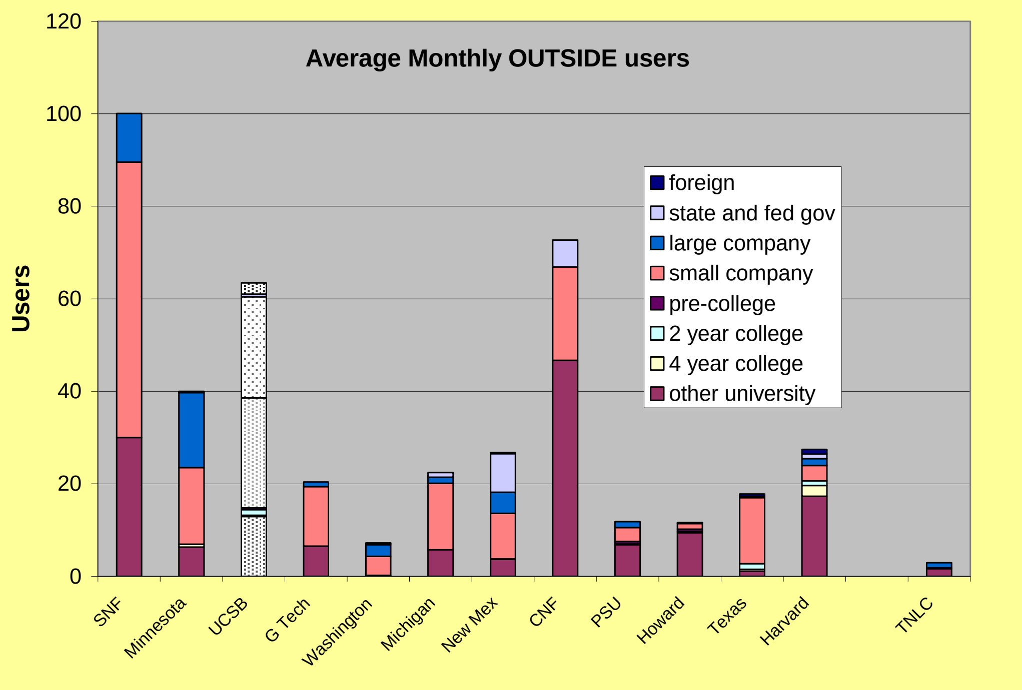


Figure 17: Average monthly outside users by site

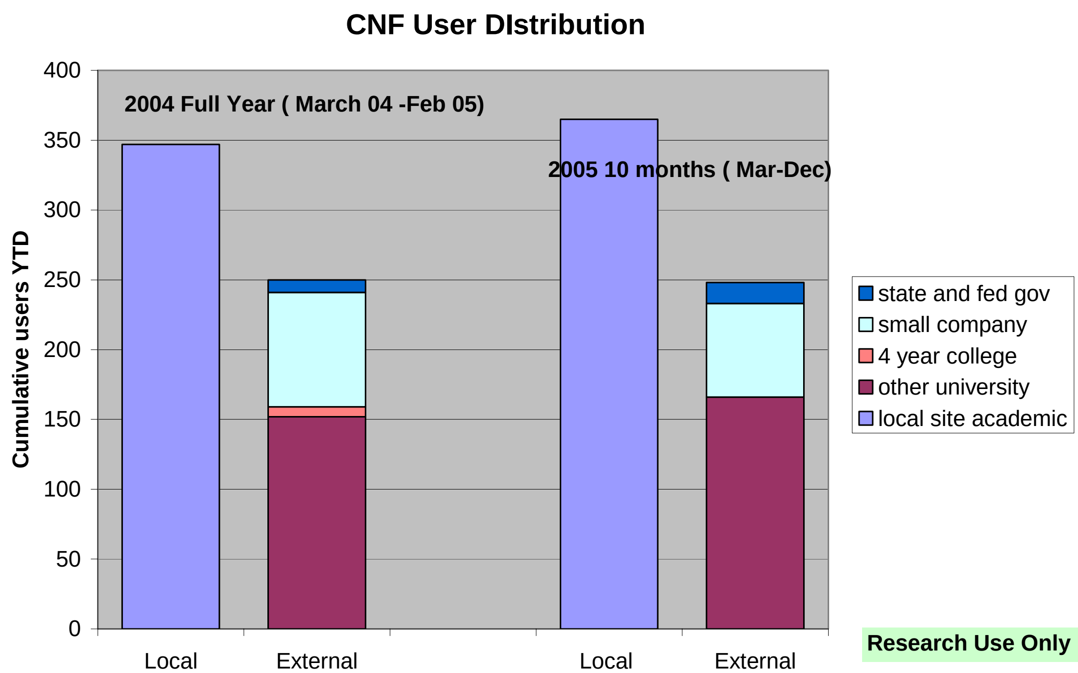


3.6 Site Performance Profiles

This section displays several aspects of individual site performance in a standard format. Included are the distribution of research users by institution type for 2 years, 2) the technical area distribution of each site for 2005, and 3) a list of all user institutions. This is repeated for each site. Sites are presented in the order of their overall funding level. All data in this section is for research users only.

3.6.1 Cornell Site Performance Profile

Figure 18: Cornell site user distribution.



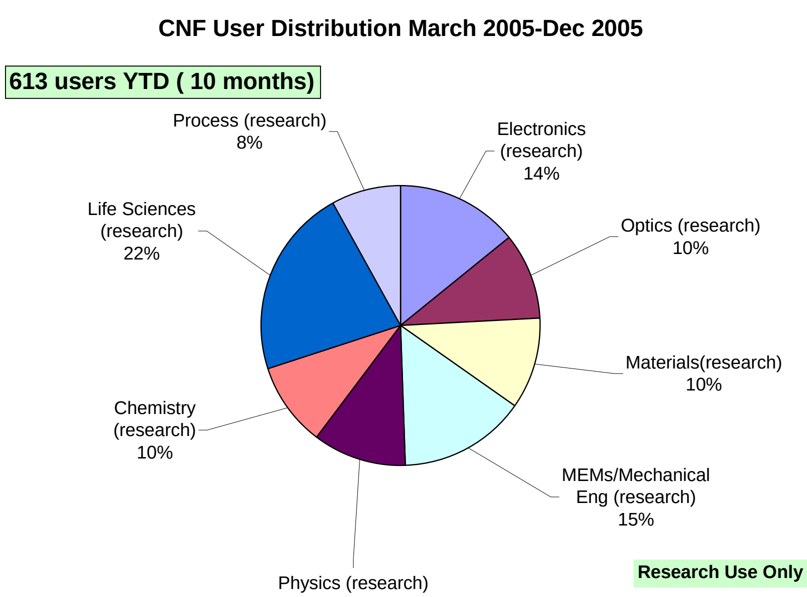


Table 2: Cornell site user institution listing.

NNIN Site: ***Cornell University***

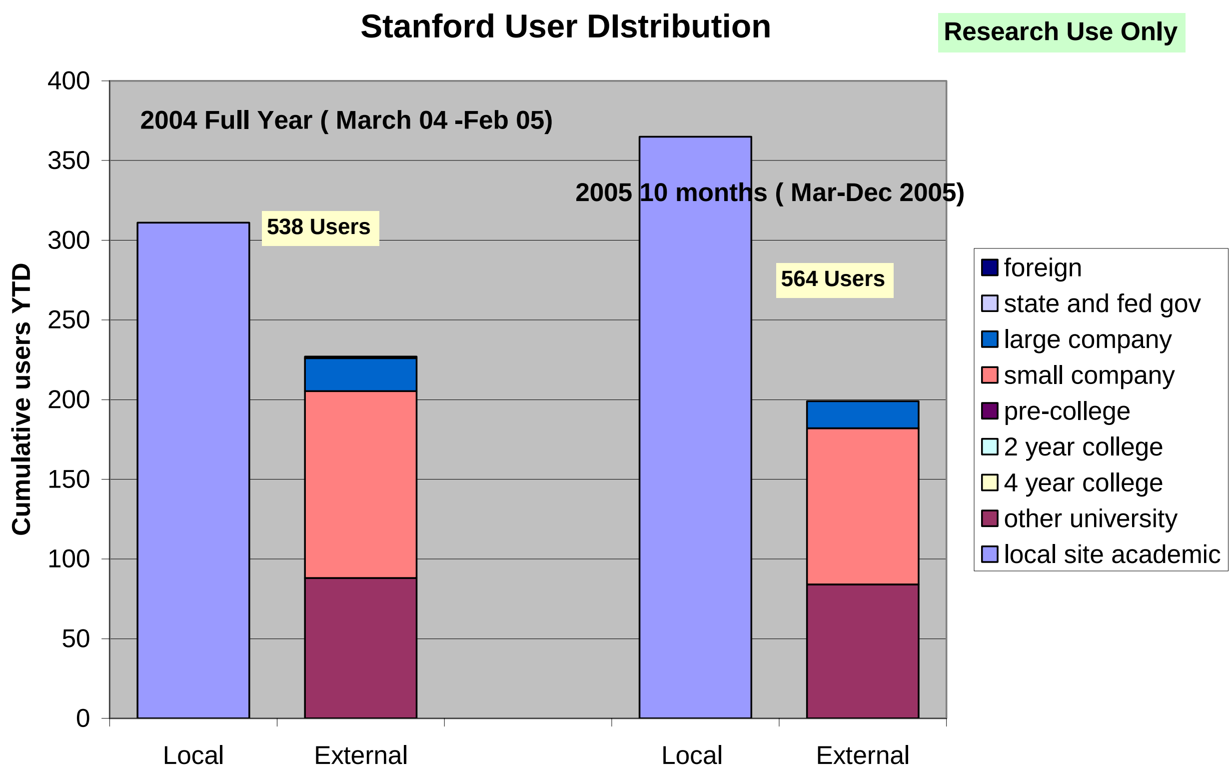
March 2005-Dec 2005 10 months

Outside Academic Institutions	**Companies**	**State and Federal Labs**
Boston College	Advion BioSciences Inc	Air Force Research Laboratory
Brown University	AdvR Inc	Biggs Lab/Wadsworth Ctr.
California Institute of Technology	Agave BioSystems	NASA Ames Research Center
Carnegie Mellon University	Agilent Laboratories	NIST
City College of New York	Air Products & Chemicals, Inc.	NYSDOH Wadsworth Center
Clarkson Universtiy	Apogee Technology Inc.	Oak Ridge National Lab
Clemson University	Battelle	Sandia National Lab
Colgate University	BinOptics Corp	
Columbia University	BioArray Solutions Ltd	
Florida Internationial University	BioVitesse, Inc	
Georgetown University	Boeing Company	
		Outside Academic Institutions-continued
Hamilton College	Calient Optical Components	
Harvard University	Corning Inc	U of IL at U-C
Howard University	DuPont	UC Santa Barbara
Johns Hopkins	EDTEK Inc	UCLA
Lehigh University	EMF Corp.	Univ of Penn. Medical Ctr
MIT	Hospira Corp.	Univ. of California, Berkeley
McGill University	Intel Corporation	Univ. of Michigan
Montana State University	Ion Optics, Inc.	Univ. of Wisconsin-Madison
N.Carolina State Univ.	Kionix Inc	University of Connecticut
New York University	Liquidia Technologies	University of Arkansas
NJIT	Multispectral Imaging, Inc.	University of California
Northwestern University	Nanofluidics Inc	University of Central Florida
Princeton University	Northrop Grumman / CU	University of Connecticut
Purdue University	Nup2 Incorporated	University of Houston
Queen's University at Kingston	Osemi Inc.	University of Montreal
Rensselaer Polytechnic Institute	ProcessTek	University of Pittsburgh
Stevens Institute of Technology	SemiSouth Laboratories	University of Rochester
SUNY Albany	Skyworks Solutions	University of Tennessee
SUNY Binghamton	Transonic Systems Inc	University of Toronto
SUNY Buffalo	Visileo Corp.	University of Washington
SUNY Stony Brook	Wavefront Research, Inc.	U.Texas San Antonio
Syracuse University	Xanoptix Inc.	Weill Cornell Medical School
Texas A&M University	Xerox Wilson Research	Yale University

Cornell has one of the largest user bases, covering a broad spectrum of nanotechnology fields. The CNF user base is particularly strong in outside academic users. With 614 research users in 10 months of FY05 vs. 592 in the prior full year, cumulative users projects to approximately 678 users for the full year, a 13% growth. The average monthly use of 233 users includes 31% outside users on a monthly basis. On a cumulative annual basis, 40% of users are outside users.

3.6.2 Stanford Site Performance Profile

Figure 19: Stanford site user distribution.



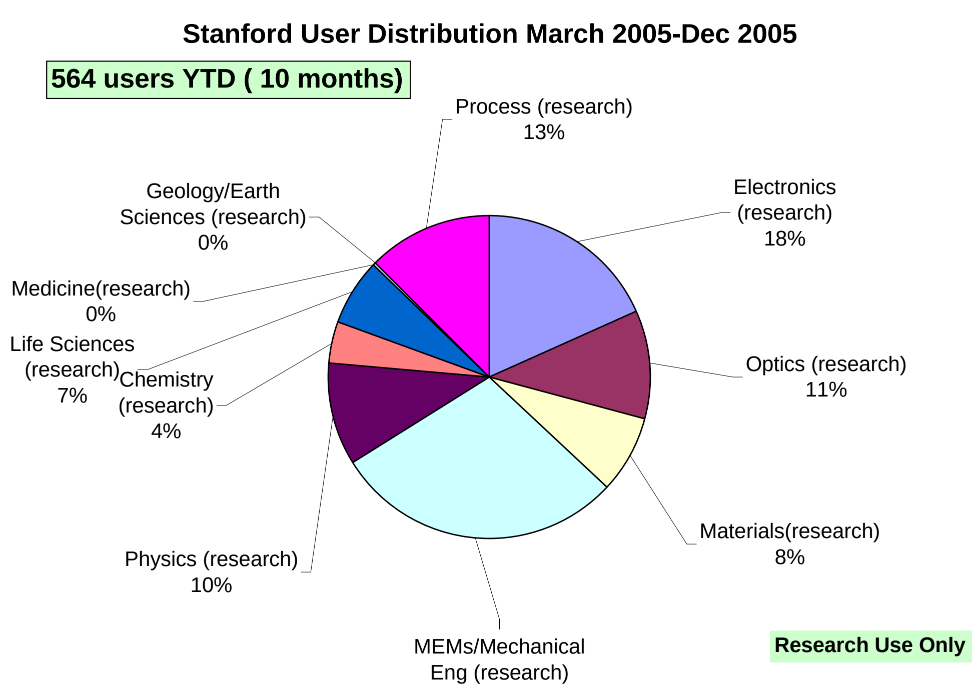


Table 3: Stanford site user distribution.

NNIN Site: ***Stanford***

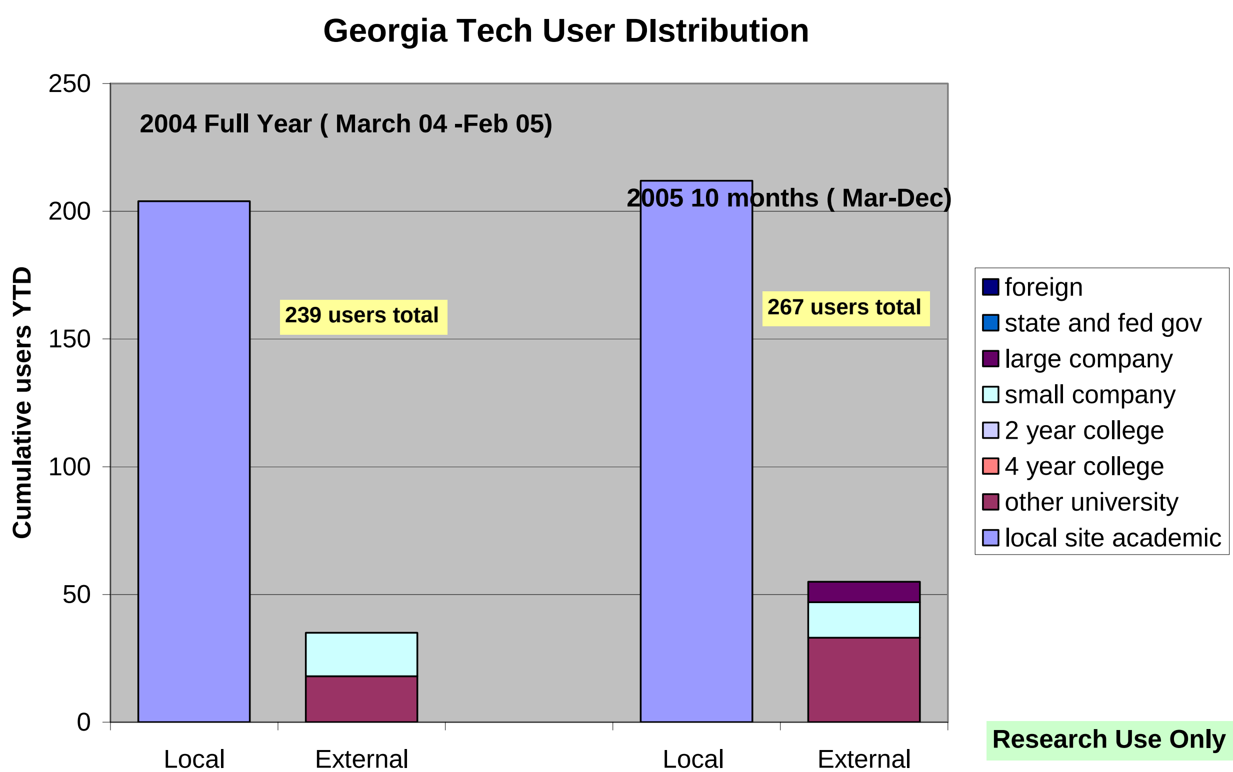
March 2005-Dec 2005 10 months

Outside Academic Institutions	Companies	State and Federal Labs
California Institute of Technology	Acorn Technologies	Lawrence Berkeley Laboratory
Carnegie Mellon University	Active Optical Networks	Lawrence Livermore National Lab
Molecular Biology Consortium	Advanced Nano Systems	
Purdue University	Advanced Nanostructures	
San Francisco State University	ALCES Technology	**Companies Continued**
San Jose Stat University	Alza	Lilliputian Systems
Sunmoon University (Korea)	Analatom	Los Gatos Research
UC Irvine	Anritsu	LV Sensors
UC Santa Cruz	Applied Biosystems	LW Microsystems
UCLA	Applied Materials	Microcess
Univ of Texas at Arlington	Applied Nanostructures	Molecular Devices
University of Florida	Arrayed Fiberoptics	Molecular Nanosystems
University of Glasgow (Scotland)	Atomicity Systems	Nanochip
University of Michigan	BCM	Nanoconduction
University of Nevada, Reno	BioScale	Nanofluidics
University of Southern California	Cambrios	Nanomix
University of Texas, Austin	Capella	Nanostructures
University of Wisconsin	Capital Technology	Nanosys
Yale University	CMT	nLight
	Collinear	Optobionics
	Cymer	Phaseon
Companies Continued	Ecotech	Photon Imaging
JDS Uniphase	Eksigent Technologies	Photonic Power Systems
Keyotee	Finixi	Power Integrations
KLA Tenor	Gemfire	Proteus Biomedical
Koila	General MEMS	RheoSense
Kolo Technologies	Genospectra	RPIC Systems
Kovio	Glide/Write	SBA Materials
Kumetrix	Group4	Seagate Technology
LightConnect	Hewlett-Packard	Siargo
Symyx Technologies	Hitachi	Siimpel
T-Ram	IBM	SiTime
Transfer Devices	Intel	Siverta
Translucent	Invensense	Solus Biosystems
Unity Semiconductor	Iolon	SRI International
Veeco/Digital Instruments		Wavelink
Wave 80 Biosciences		Winged Cat Solutions

Stanford also has a large and diverse user base with a significant number of outside users, with particular strength in outside companies. Like Cornell, Stanford's assigned responsibilities cover the entire breadth of nanotechnology. Cumulative use to date is 554 users, compared to 538 for 12 months in 2004. This extrapolates to approximately 600 for 12 months 2005, a growth of 11% year to year. With an average monthly use of 312 users, 32% of them from outside Stanford, the Stanford lab is quite active, the highest average monthly use in NNIN. On a cumulative annual basis, 40% of users are from outside Stanford.

3.6.3 Georgia Tech Site Performance Profile

Figure 20: Georgia Tech user distribution.



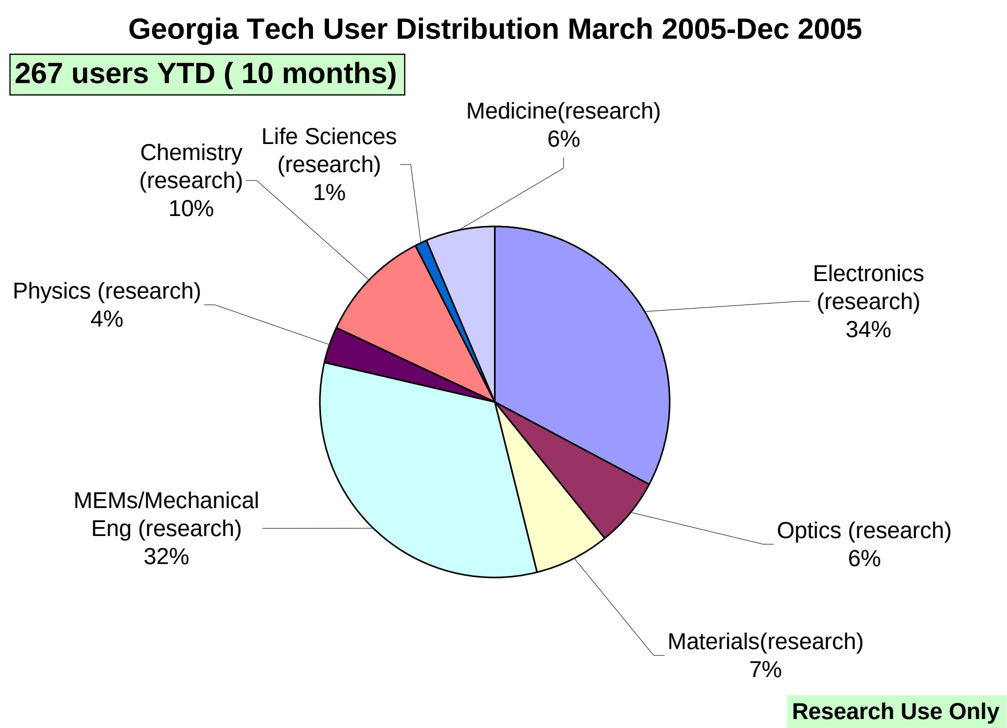


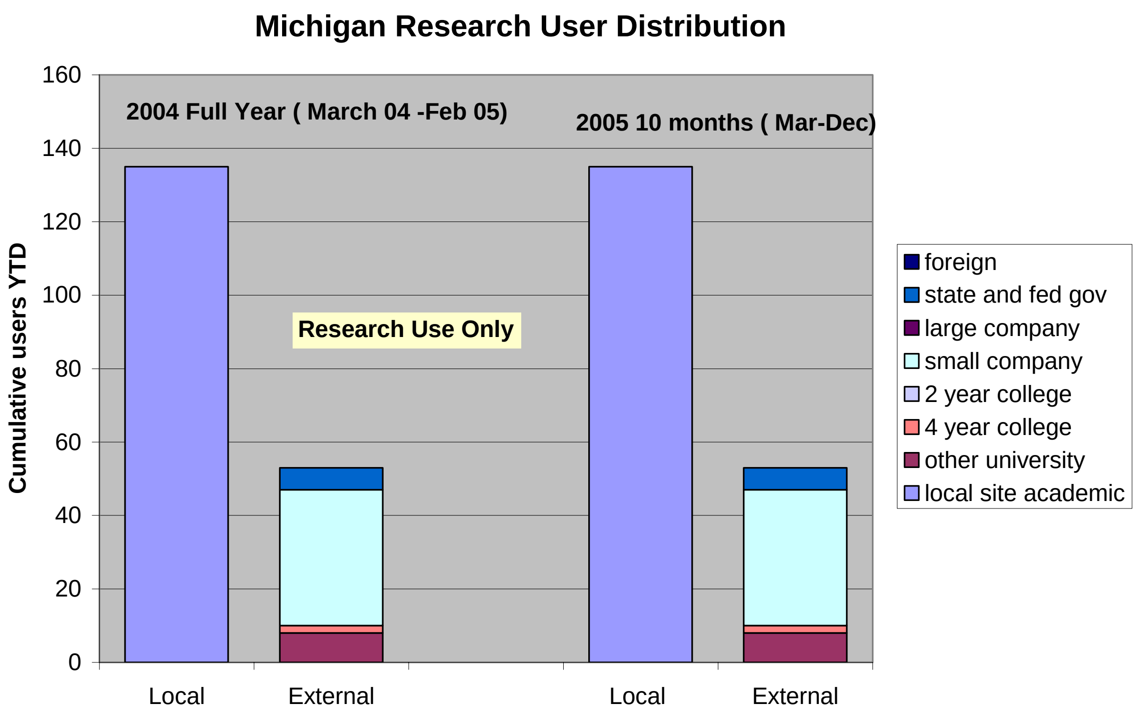
Table 4: Georgia Tech user institution listing.

NNIN Site:	***Georgia Tech***	
March 2005-Dec 2005 10 months		
Outside Academic Institutions	**Companies**	**State and Federal Labs**
Alabama A&M University	Applied Micro-optics	Oak Ridge National Laboratory
Auburn University	Brandywine Optics	
Clark-Atlanta University	CardioMEMS	
Emory University	Diamond Films International	
Florida International University	Icon Interventional Systems	
George Washington University	Micro- and Nano-Technology Consultants	
Georgia State University	ngimat	
Grenoble High Magnetic Field Lab	Novasol	
Louisiana State University	Qcept	
Medical College of Georgia	Sematech	
Tuskegee University	Sharp Labs	
University of Central Florida	STS	
University of Minnesota		
University of Alabama, Birmingham		
University of Basel, Switzerland		
University of Georgia		
University of Pennsylvannia		
University of Tennessee		

The outside user base at Georgia Tech is small but growing significantly. Georgia Tech has made progress in attracting academic institutions and with research successes, the users from these and other institutions should be expected to grow. Georgia Tech has assigned technical responsibilities to the Life Sciences and Medicine communities. With only 5% of its users (12) from these areas however, this responsibility is not yet well represented in the user base. Georgia Tech has recently filled a technical liaison position for life sciences support. Georgia Tech's 267 cumulative users in 10 months projects to approximately 295 for the full year, a growth of 22% over 2004. Georgia Tech had 163 average monthly users in 2005, but with 12% outside users. This high fraction of average users to cumulative users (163/267) is indicative of weighting toward stable long term (local) users. Progress is expected from Georgia Tech in external usage and in its technical area of leadership.

3.6.4 Michigan Site Performance Profile

Figure 21: Michigan site user distribution.



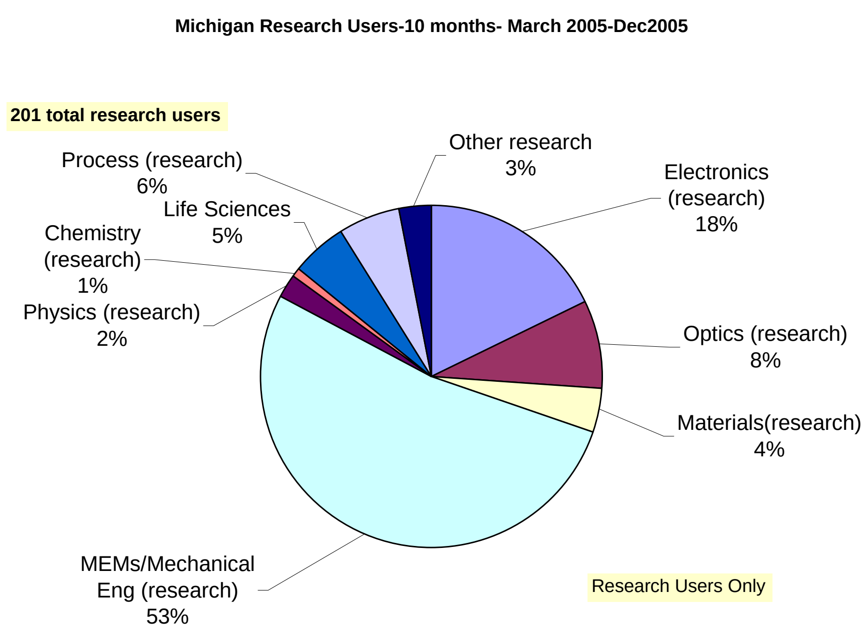


Table 5: Michigan site user institution list.

NNIN Site: *Michigan*

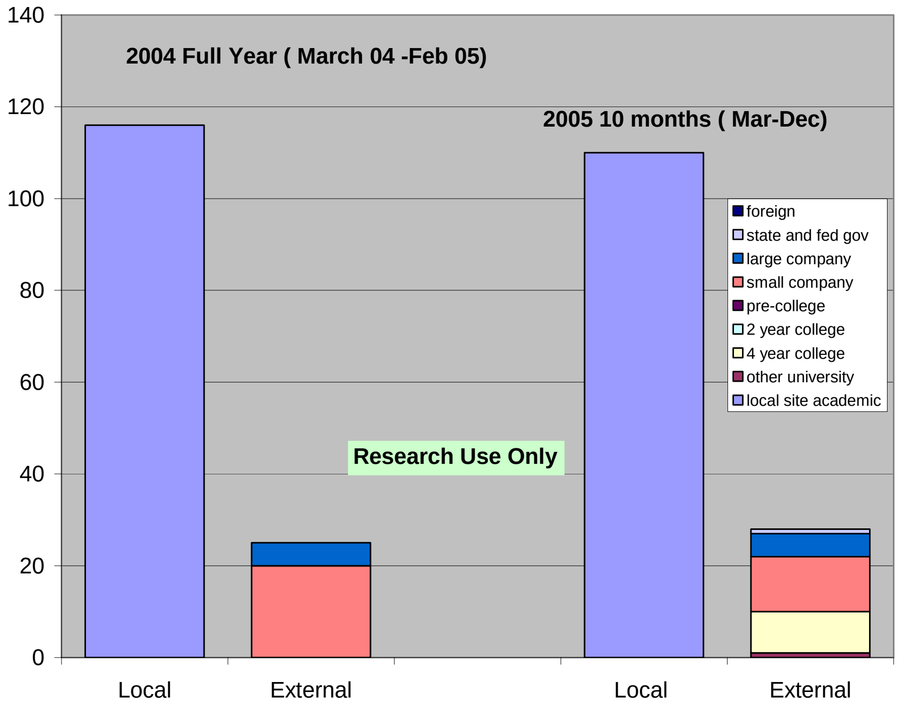
March 2005-Dec 2005   10 months

Outside Academic Institutions	Companies	State and Federal Labs
Michigan State University	Advanced Sensor Technologies, Inc	
Michigan Technological University	Discera	
Northwestern University	EMAG Technologies, Inc.	
Ohio State University	Evigia Systems, Inc.	
Purdue University	Hospira, Inc	
University of New Mexico	IMRA America, Inc.	
Vanderbilt University	Integrated Sensing Systems	
Virginia Polytechnic Institute and State Univ.	K Lab Corp.	
Wayne State University	Midwest MicroDevices	
	Motorola	
	Nanoselect	
	Neuronexus Technologies	
	Picocal	
	Picometrix	
	Sensicore	
	Sonetics Ultrasound, Inc	

Michigan has specific network responsibility for integrated systems – an areas which currently has applications of MEMS and electronics systems connected to life sciences. Within our categorization this most closely maps to MEMS, an area where Michigan has considerable strength representing 51% of its user base. The Michigan outside user base is weighted towards small companies. Michigan is expected to grow its outside user base, particularly academic. The 201 cumulative users year to date projects to approximately 215 users for the full year, compared to 188 last year, an increase of 14%. Average monthly users are 108, with 21% average monthly outside users.

3.6.5 Washington Performance Profile

Figure 22: Washington site user profile.



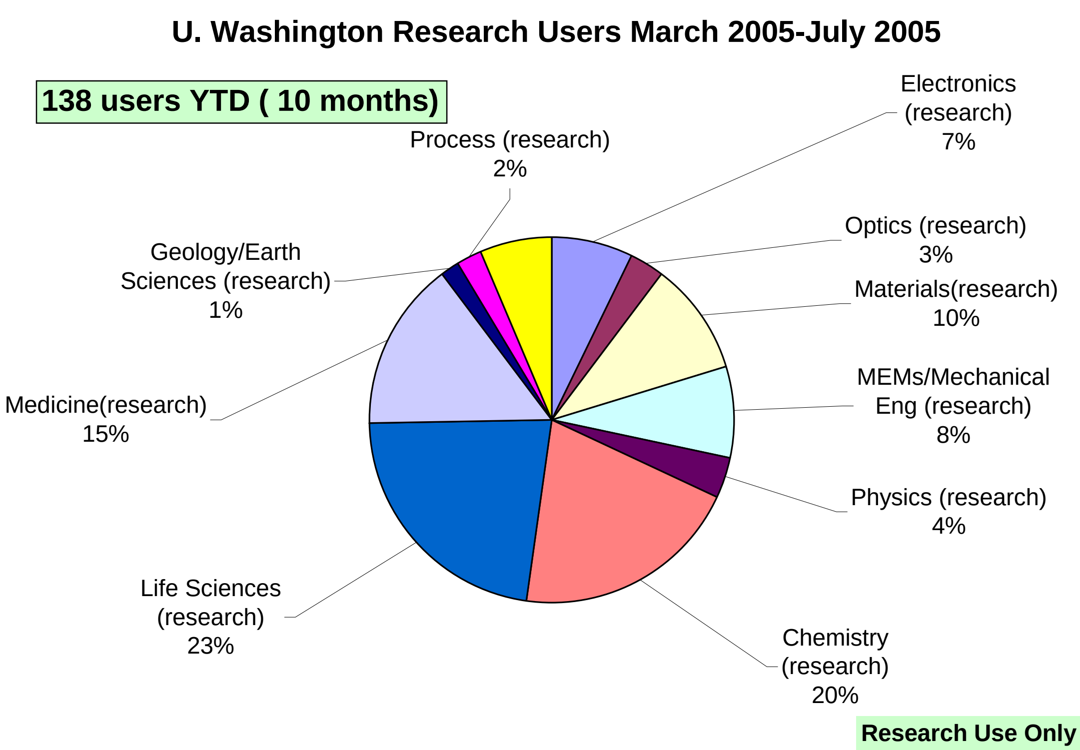


Table 6: Washington site list of user institutions.

NNIN Site: *University of Washington*

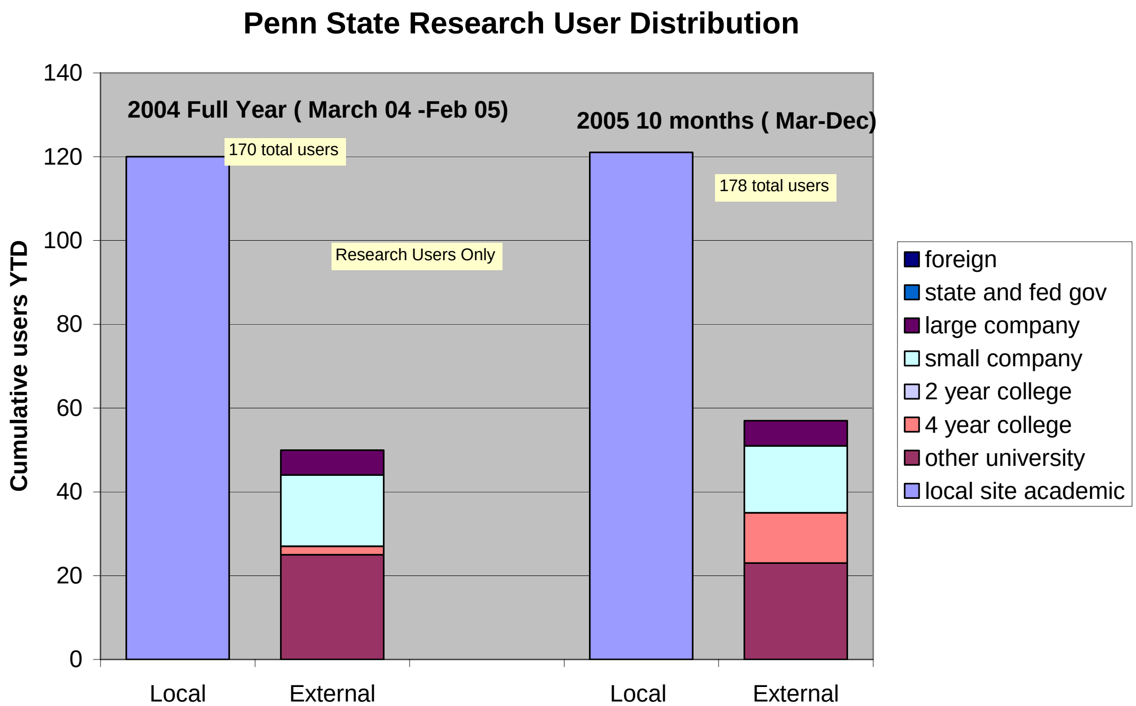
March 2005-Dec 2005 10 months

Outside Academic Institutions	Companies	State and Federal Labs
Bradley University	Intel	Washington Technology Center
North Seattle Community College	Lumera	
Portland State University	Spiration	
Institute for Systems Biology	Neah Power	
Washington State University	Micronics	
	Boston Scientific	
	Phillips Morris	
	Aeorjet	
	Nanomaterials	
	nLight	
	Cardic Dimension	
	Combimatrix	
	CoAptus	
	JanScientific	
	Biomedical strategies	

The University of Washington has network leadership responsibility in support of Life Sciences and Medicine. Thirty eight percent of the user base is from this important area. However, almost all of that is from local U. Washington users. This was the rationale behind U. of Washington's participation in the network, and the external usage needs to evolve to higher numbers from the currently relatively small total user base. Eighty seven percent of the average monthly users of 55 are local. The external user base is 27 for year to date. The current year to date users of 138 projects (projected to approximately 155 for the full year) represents little change in the usage year-to-year.

3.6.6 Penn State Site Performance Profile

Figure 23: Penn State site user profile.



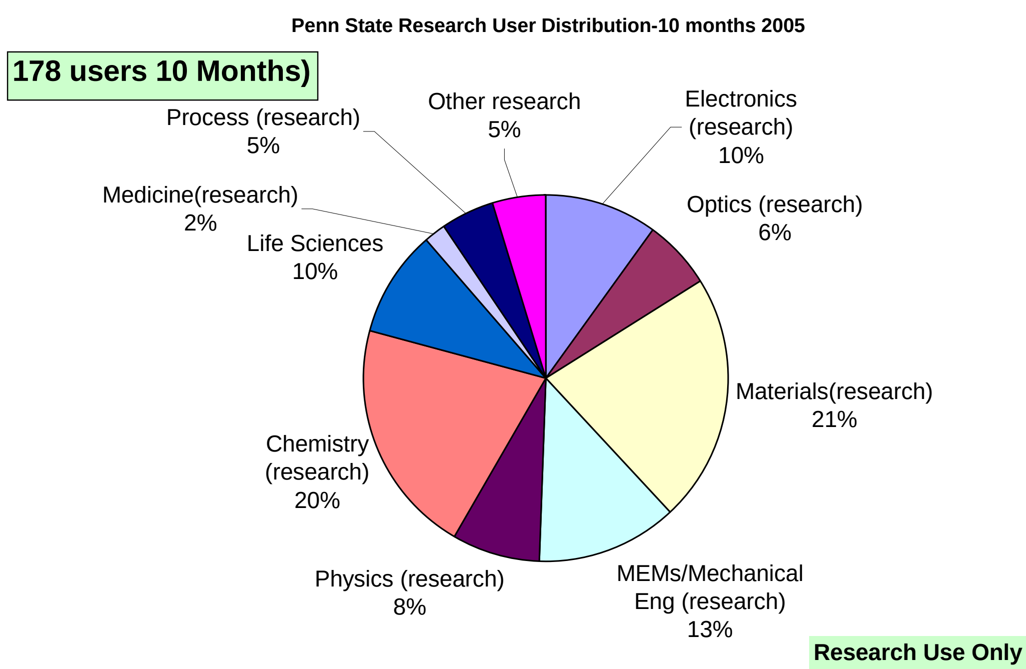


Table 7: Penn State user institution list

NNIN Site: *Penn State University*

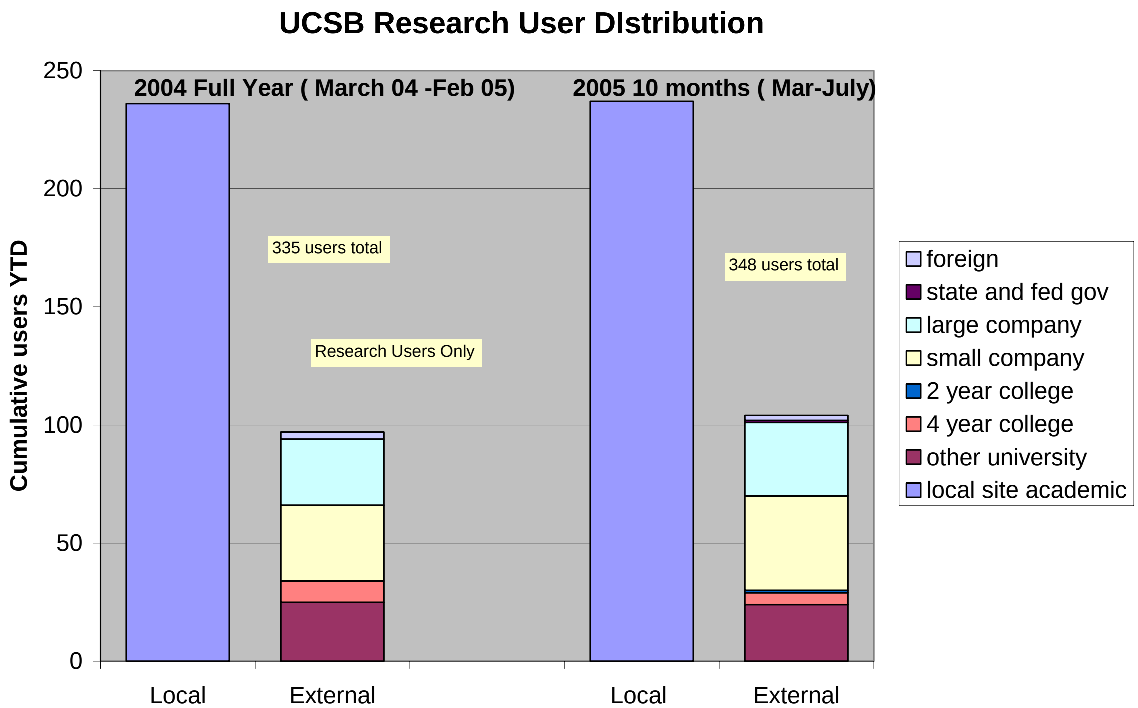
March 2005-Dec 2005 10 months

Outside Academic Institutions	Companies	State and Federal Labs
Purdue University	Spectrum Devices	
Penn State College of Medicine	Solid State Measurements	
University of Maryland	Nanohorizons	
University of Pittsburgh	Membrane Assays	
Drexel University	LCM Technologies	
California Univ of Pennsylvania	TRS Technologies	
University of North Carolina	Applied Research & Photonics	
University of Pennsylvania	IC Mechanics	
Lock Haven University	Bridge Semiconductor	
	Deltronic Crystal Ind	
	J&W Medical	
	Airproducts	
	Dendritic Nanotechnologies	
	Aspex	
	Primaxx	
	Tech Source	
	Verimetra Inc	

Pennsylvania State University has network leadership responsibility in support of chemical nanotechnology and in particular efforts at molecular scale. The site has 178 users in the 10 month period which projects to 199 for the year, and reflects a continuing increase in user population. Of the 66 average monthly users, 82% are from PSU, a significantly high percentage. The number of users in the chemistry-oriented areas (chemistry, materials, and processes) is large reflective of the user base and the area of emphasis. Increase external usage is expected in coming years in this direction of effort, as is the outside academic usage.

3.6.7 UCSB Site Performance Profile

Figure 24: UCSB user profile.



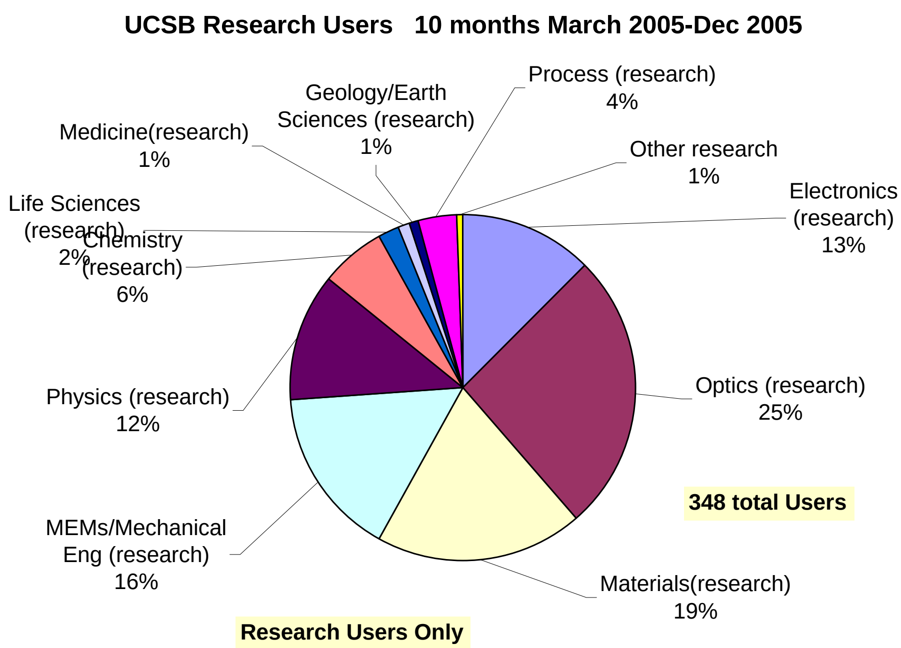


Table 8: UCSB user institution distribution (2005)

NNIN Site: *UCSB*

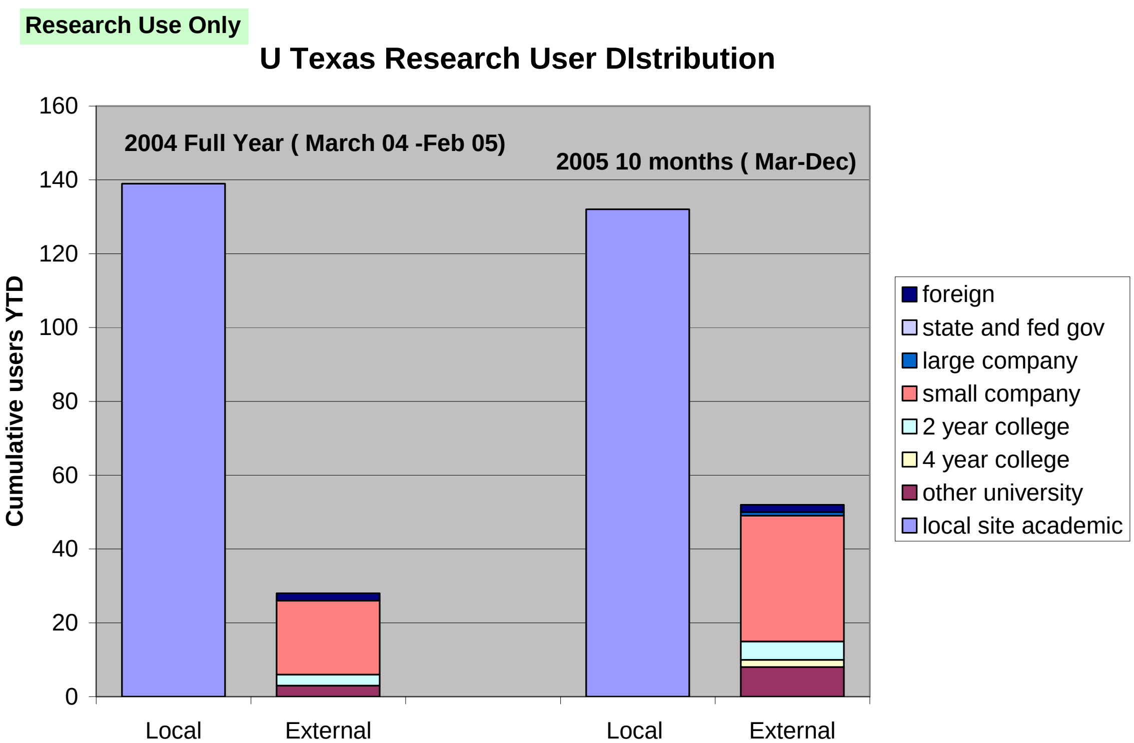
March 2005-Dec 2005 10 months

Outside Academic Institutions	Companies	State and Federal Labs
George Washington University	Advanced Nanostructures	National Inst. Of Standards & Tech
New Mexico State University	AdvR	
Stanford University - Ginzton Laboratory	Aerius Photonics	
UC Berkeley, EECS	Agile Materials & Technologies	
UCLA	Aonex Technologies	
UC, San Diego	Apic Corporation	
University of Pittsburgh	Applied Nanostructures, Inc	
University of Virginia	Atomate Corporation	
University of Nevada, Las Vegas	Collinear Corporation	
	Cree	
	Diode Solutions, Inc.	
	Global Communication Semicond.	
	Innovative Micro Technologies	
	Intel	
	Lockheed Martin, SB Focal Plane	
	Mitsubishi Chem Research	
	Nano and Micro Tech Consultants	
	Nanostrutures, Inc.	
	Photronix	
	PLT	
	Praevium Research	
	Qualcomm MEMS Tech	
	Raytheon Infrared Operations	
	SBA Materials	
	SiVerta	
	Spectrolab	
	TelAztec	
	Veeco Metrology, LLC	

The University of California at Santa Barbara has technical leadership responsibilities towards materials and physical sciences coupled to outreach to local underrepresented community. Of the 245 monthly average users, 74% are for UCSB, and the total usage continues to increase. UCSB's external usage has significant small company participation; the laboratory is making an industrial impact, but the outside academic usage is limited.

3.6.8 Texas Performance Profile

Figure 25: Texas site user profile



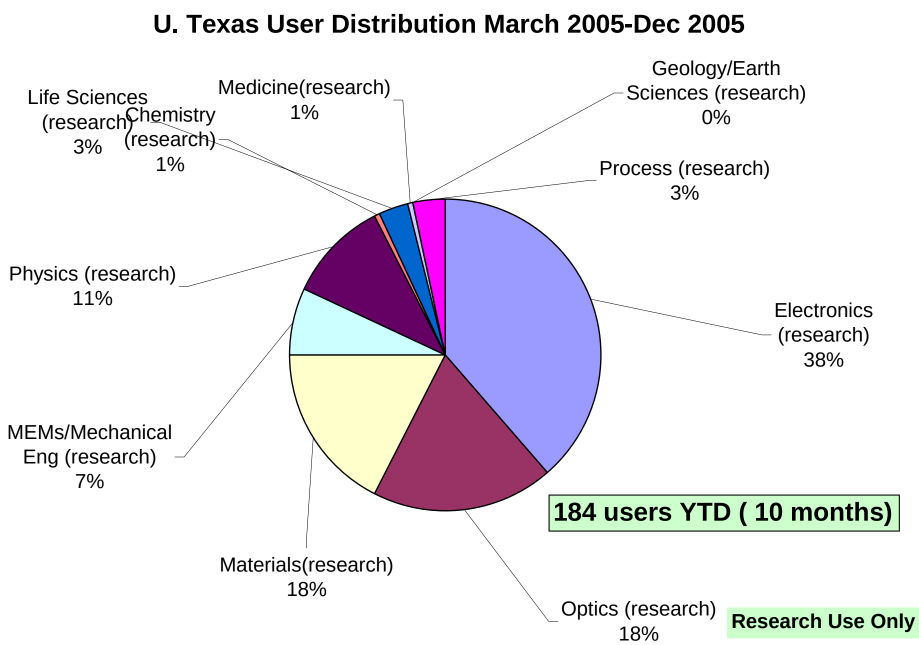


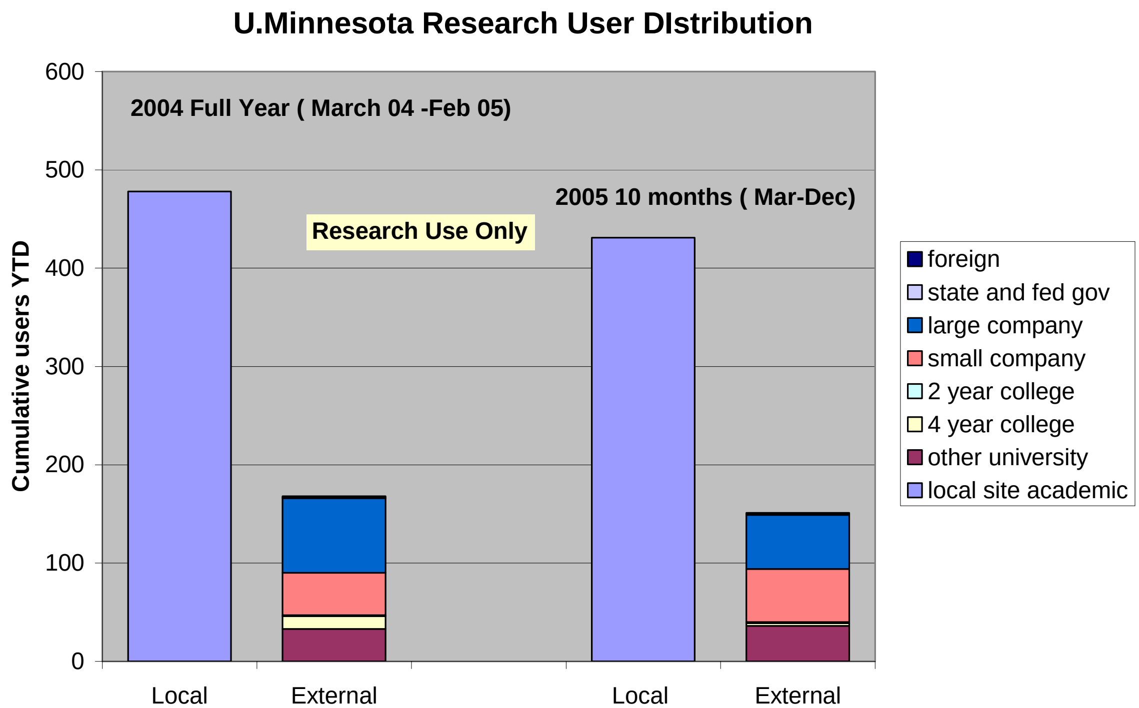
Table 9: Texas user institution list

NNIN Site: March 2005-Dec 2005 10 months	*UT-Austin*	
Outside Academic Institutions	**Companies**	**State and Federal Labs**
Austin Community College	Applied Nanotech, Inc.	
Harvard University	ATDF, Inc.	
UT-Arlington	e-Viz, Inc.	
Texas A&M	Intel Corp.	
University of Illinois at Urbana Champaign	Molecular Imprints	
	Nanocoolers, Inc.	
	Optical Filter Source, LLC	
	Organic ID	
	Quantum Logic Devices	
Other	Saxet Surface Science	
Industrial Technology Research Institute, Taiwan	SBA Materials, Inc.	
	Sematech	
	Systems & Processing Engineering Corp.	
	Stellar Micro Devices	
	Uni-Pixel Displays, Inc.	
	Crossfield Technology	
	Xidex Corporation	

University of Texas at Austin has, within the network leadership responsibility for chemistry-intensive nanotechnology efforts, and in particular through soft lithography oriented efforts support for tool development and processes for manufacturing. UT has 88 average monthly users, ~80% of who are local. The user base is expanding with the outside usage industry-centric. Increase in academic usage, and in particular in the technical area of responsibility is expected in the coming years as UT, new to the network, succeeds with its promotional efforts.

3.6.9 Minnesota Performance Profile

Figure 26. Minnesota user profile.



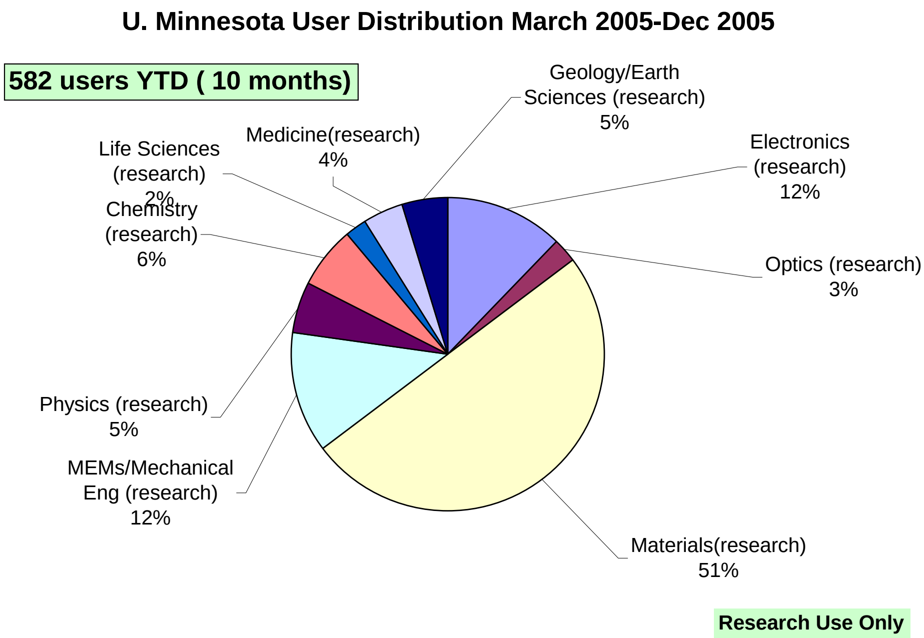


Table 10: Minnesota user institution distribution

NNIN Site: *University of Minnesota*

March 2005-Dec 2005 10 months

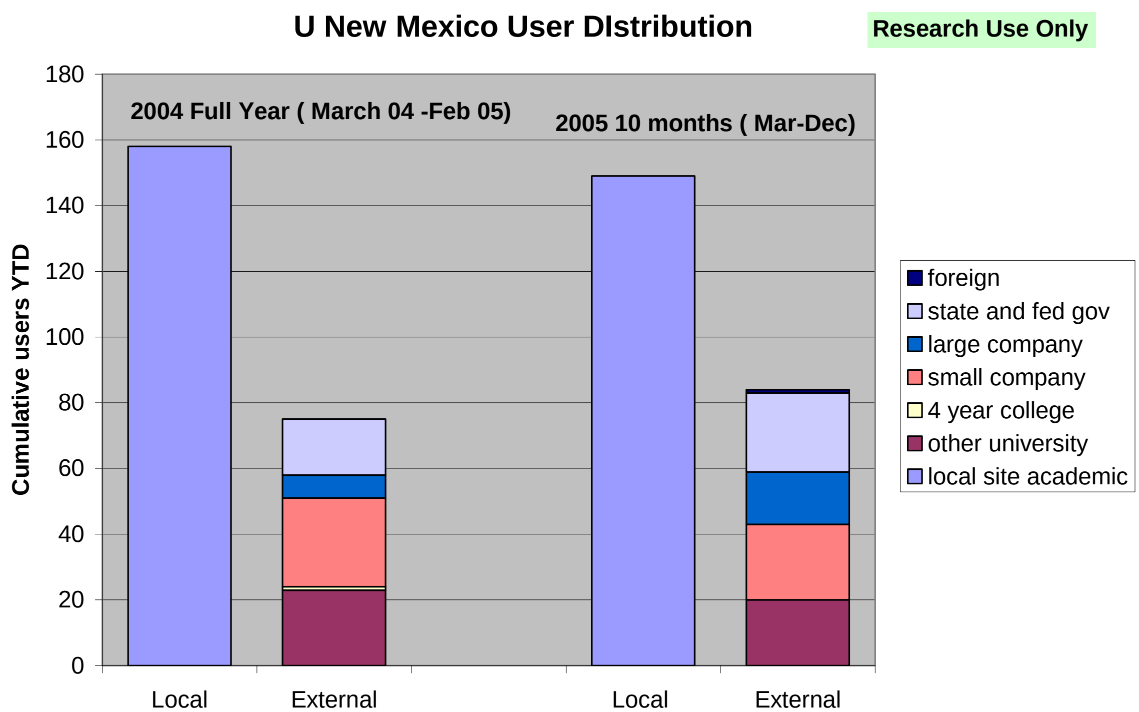
Outside Academic Institutions	Companies	State and Federal Labs
Bethel University	Advanced Bio-Surfaces	Jet Propulsion Laboratory
Brown University	Advanced Research Corporation	Swiss Federal Institute of Technology
Dakota County Technical College	American Medical Systems, Inc.	
Emory University	APA Optics	
George Washington University	Appleton	
Iowa State University	Applied Micro Opitcs, Inc.	
Louisiana State University	Aspen Research Corporation	
Marquette University	ATS Medical, Inc.	
Michigan State University	Aveka, Inc.	
Minnesota State University - Mankato	BF Goodrich	
Southern Illinois University	BH Electronics, Inc.	
Texas A&M	BioForce Nanosciences, Inc.	
University of Arizona	Boston Scientific Corporation	
University of Cincinnati	Cargill, Inc.	
University of Idaho	Chemat Technology, Inc.	
University of Illinois - Champaign Urbana	CHF Solutions, Inc.	
University of Iowa	Cima Nanotech	
University of Missouri - Kansas City	Clear Science, Inc.	
University of MN - Duluth	Colder Products Co.	
University of Nebraska - Lincoln	Crossfire Technologies	
University of St. Thomas	Cymbet Corporation	
University of Texas - Austin	Cypress Semiconductor	
University of Trento	Data Machine Int'l	
University of WI - Eau Claire	Eastman Kodak Company	
University of WI - Madison	Ecolab, Inc.	
Washington State University	Entegris	
Washington University - St. Louis	EnteroMedics, Inc.	
	Envoy Medical	
	Ev3, Inc.	
	GE/Osmonics	
	Gene Segues, Inc.	
	General Mills	
	Glacier Photonics	
	GraftCATH, Inc.	
	Guidant Corporation	
	Hearing Components	
	Honeywell International	
	Hutchinson Technology, Inc.	
	Imation Corp.	
	InnovaLight, Inc.	

Companies Continued
Katun Corporation
Landauer, Inc.
LeSueur, Inc.
Mayo Clinic
Mc Swiggen & Associates
Medtronic, Inc.
MSP Corporation
Multek - Sheldahl
Nanocopoeia, Inc.
NatureWorks LLC
NVE Corporation
Osemi, Inc.
PCB Piezotronics
Phillips Plastics Corp.
PolarFab, LLC
Questar Medical
S. C. Johnson & Son, Inc.
Seagate Technology
Spinnaker Semiconductor
SurModics, Inc.
SVT Associates, Inc.
Tennet Company
Thin Film Technology
TLC Precision Wafer Technology
TSI, Inc.
Valspar Corporations

The University of Minnesota's efforts within the network concentrate on characterization and geosciences, as well as the common tasks for all sites related to physical science and engineering research. U. Minnesota accomplishes this through a collective of three laboratories which is reflected in the higher user base of all the new sites. The usage at U. of Minnesota in Geology (29) and its large usage in materials is reflective of the site's areas of concentration for the network. The node also has significant number of universities and companies utilizing its facilities.

3.6.10 New Mexico Performance Profile

Figure 27: New Mexico site user profile



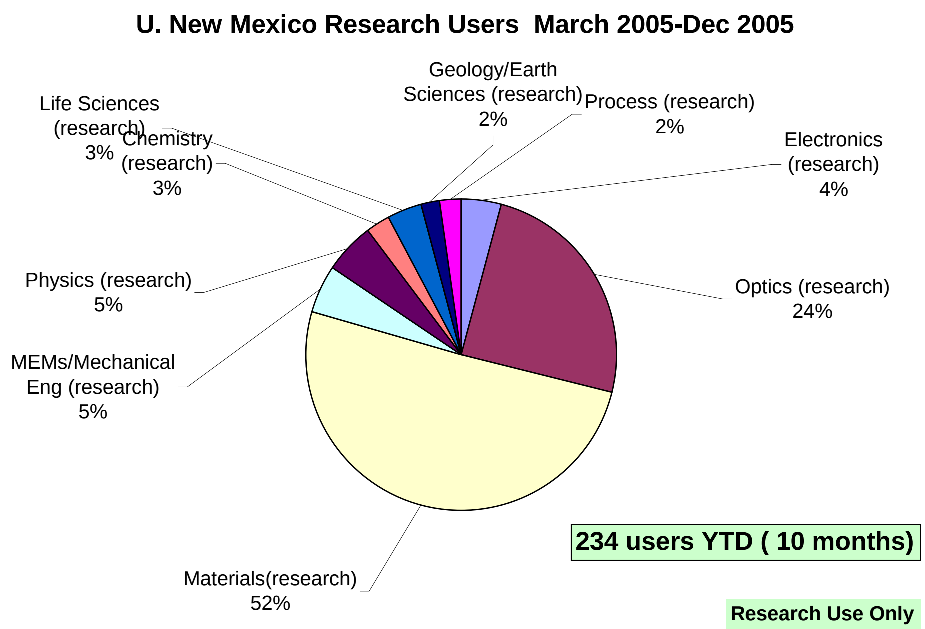


Table 11: New Mexico user institution list

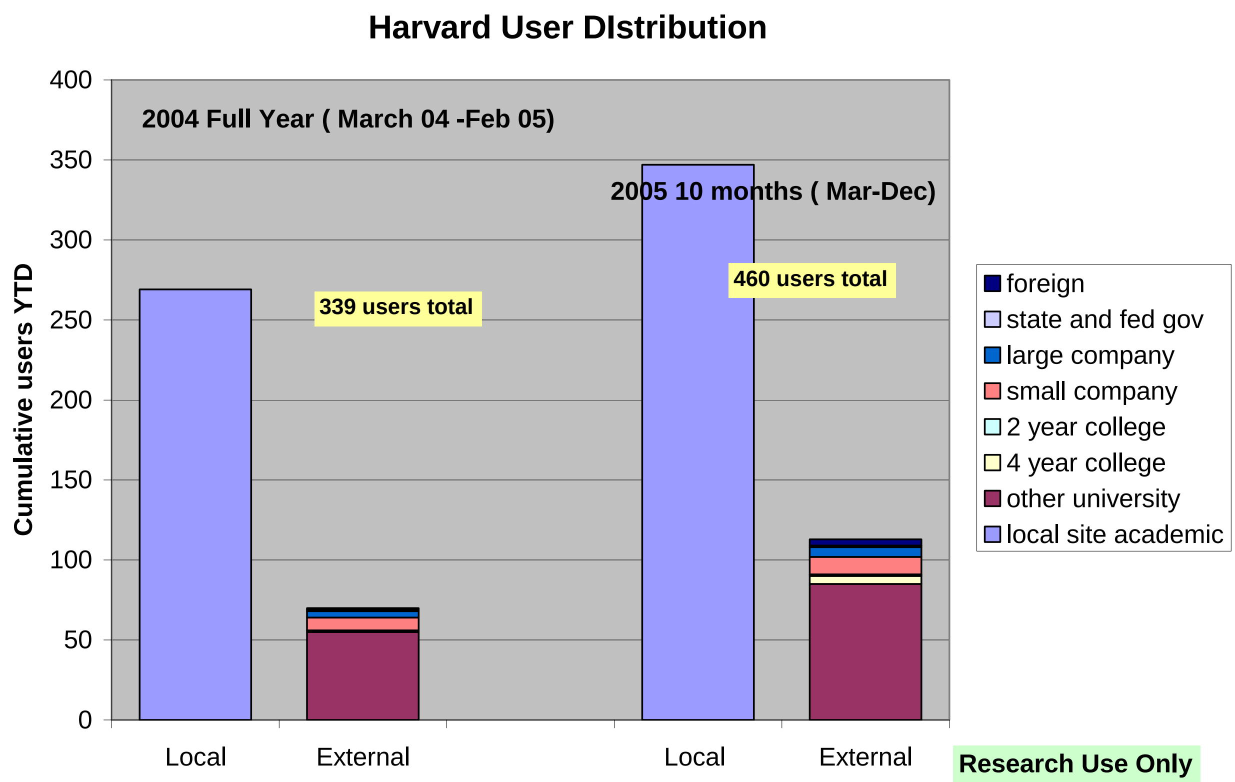
NNIN Site: *New Mexico*
March 2005-Dec 2005 10 months

Outside Academic Institutions	Companies	State and Federal Labs
Georgia State University	Advanced Optical Consultants	AFRL/Sensors Directorate
UMass Lowell	AgilOptics, Inc.	Air Force Institute of Technology
University of Illinois at Chicago	AZ Electronic Materials USA Corp.	Sandia National Laboratory
University of Michigan	CVI Laser, LLC	
University of Texas at El Paso	GE Global Research	
CalTech	Gratings, Inc.	
	Intel Corporation	
	Maxion Technologies, Inc.	
	nLight Photonics	
	Oluma, Inc.	
	OptiComp Corporation	
	qXwave, Inc.	
	Radiant Technologies, Inc.	
	Redondo Optics, Inc.	
	SBA Materials	
	Senspex. Inc.	
	Southwest Sciences, Inc.	
	Uni-Pixel Displays, Inc.	
	Zia Laser	

The University of New Mexico node has responsibilities in characterization, in geosciences, and in outreach to the under-represented community in southwest. About 20 of external users of U. of New Mexico are from outside academic institutions and a significant number of external users are in optics-based companies, an area where a number of companies exist in the local community. The number of geology uses is small and as promotions take hold, a broader increase towards the site's mission is expected.

3.6.11 Harvard Performance Profile

Figure 28: Harvard site user profile



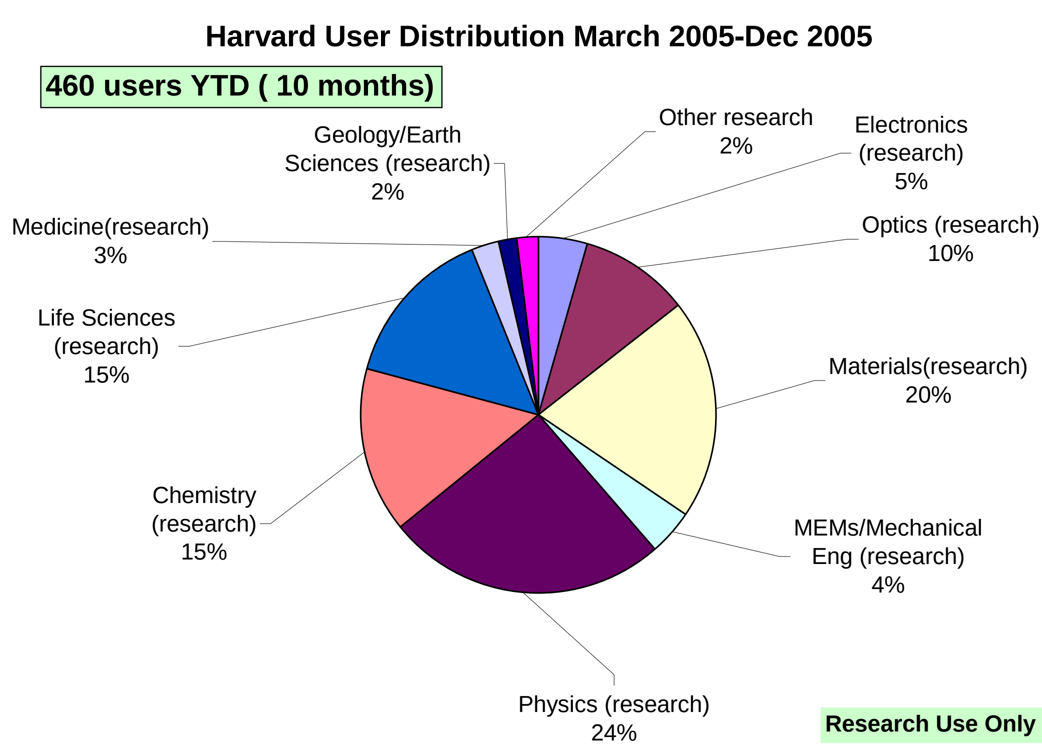


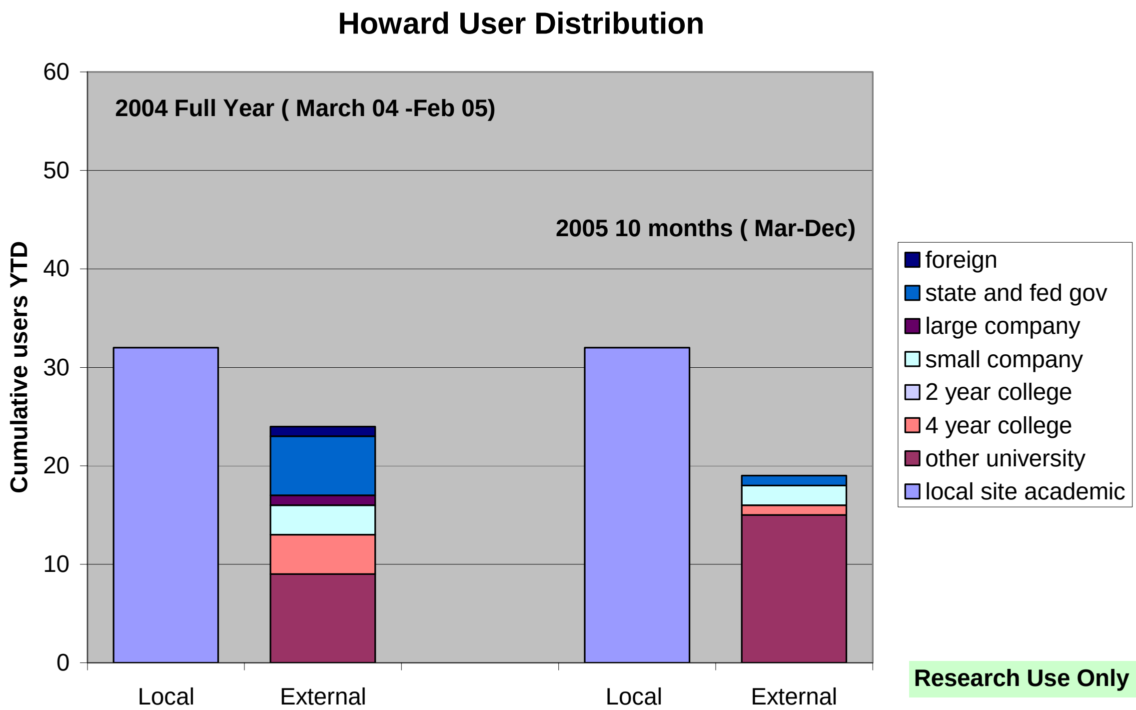
Table 12: Harvard user institution list

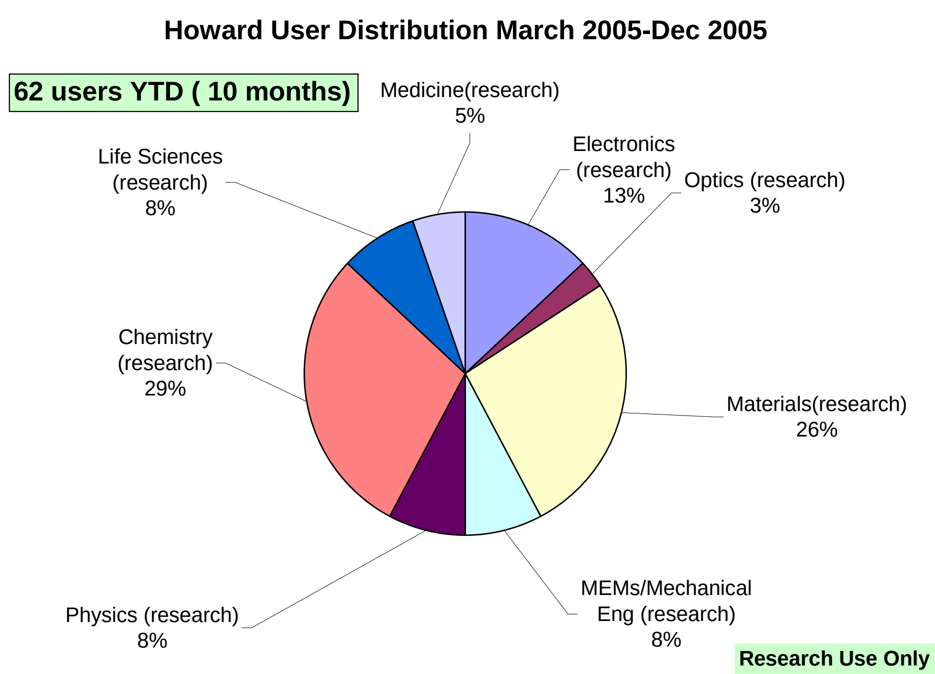
NNIN Site:	*Center for Nanoscale Systems (CNS)-Harvard*	
March 2005-Dec 2005 10 months		
Outside Academic Institutions	**Companies**	**State and Federal Labs**
Arizona State University	Bayer Healthcare - Diagnostics Division	New York State Department of Health - Wadsworth Center
Boston University	Cambridge NanoTech, Inc.	
Bowdoin College	CTS, Inc.	
Brandeis University	Delta F Corporation	
Bristol Community College	General Electric Global Research Center	
Colorado State University	Hyperion Catalysis	
Cooper Union	National Semiconductor Corporation	
Dartmouth College	Optical Tape Systems, Inc.	
Dickinson College	Osram Sylvania, Inc.	
Elon University	PLEX LLC	
Georgetown	RainDance Technologies	
Harding University	ZS Genetics, Inc.	
Ludwig Maximillians University - Munchen (Germany)	ARC Seibersdorf Research GmbH (Austria)	
Massachusetts Institute of Technology - MIT	Beth Israel Deaconess Medical Center	
North Carolina A&T University	Draper Laboratory	
Northeastern University	Historic New England	
Santa Clara University	Lahey Clinic Medical Center	
Stanford University	Massachusetts General Hospital	
State University of New York - Stoney Brook	RIKEN (Japan)	
Swarthmore University	Shriners Hospital	
Technion (Israel)		
University of Illinois, Urbana-Champaign		
University of Maryland, College Park		
University of Massachusetts, Lowell		
University of Massachusetts, Medical School		
University of Miami		
University of Missouri, Rolla		
University of New Hampshire		
Vanderbilt University		
Worcester Polytechnic Institute		
Yale University		

Harvard University has a large academic usage and has made large strides in building the external user community. Harvard has also started significant effort towards becoming a source for soft-lithography, consistent with its area responsibility in chemical nanotechnology. Harvard also coordinates NNIN's computation effort.

3.6.12 Howard Performance Profile

Figure 29: Howard site user distribution



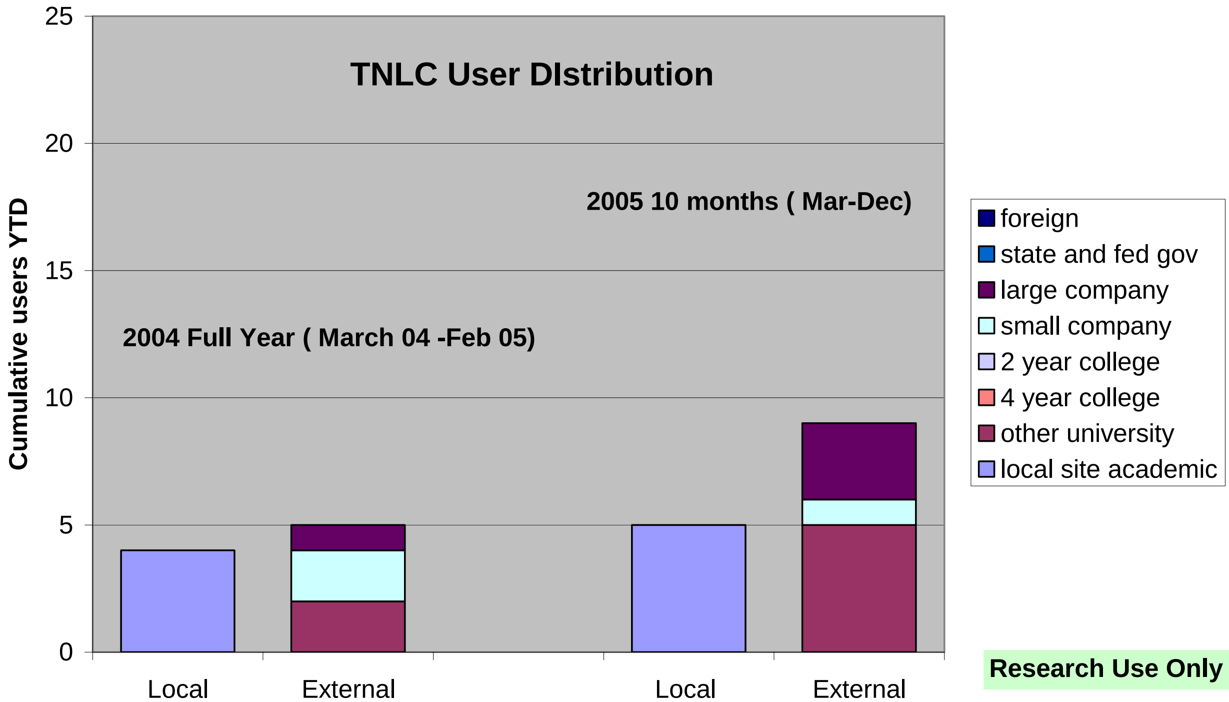


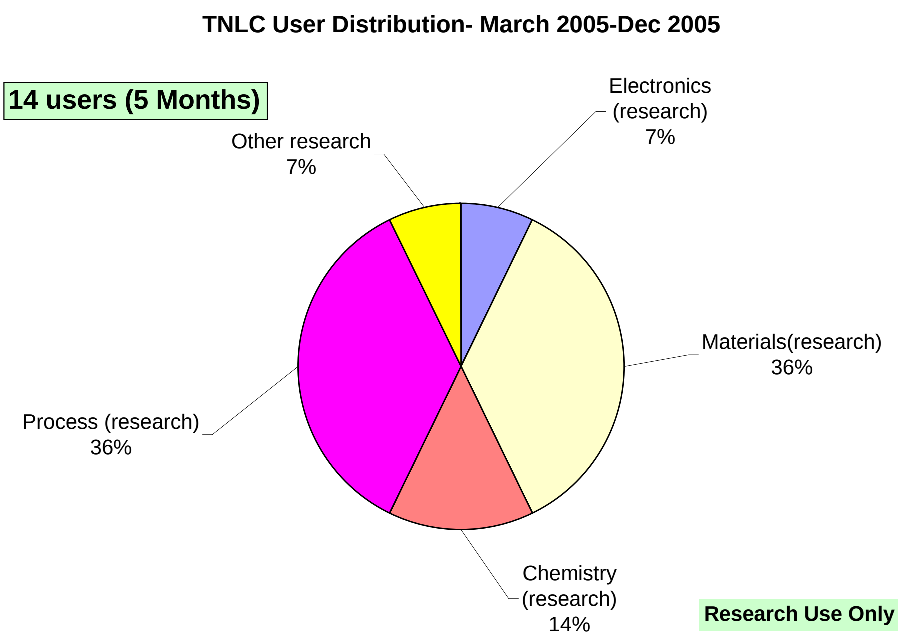
No list of institutions was provided

Howard University has broad materials oriented efforts and leads the network’s effort in under-represented outreach in the District of Columbia community. The distribution of users is broad, a fair fraction of which is external, and from academia. Howard’s external usage may potentially decline, and extra effort may be needed.

3.6.13 NCSU/TNLC Performance Profile

Figure 30: TNLC user profile





The Triangle National Lithography Center at NCSU is an affiliate of NNIN. It receives no funding from NNIN. The focus of the effort is in 193 nm lithography, a technique that provides reproducible capabilities for patterning in the tens to 100’s of nm length scale with high throughput. Currently, there are less than 15 users.

4.0 Education and Human Resources

4.1 Objectives and Program

The NNIN Education Program supports educational outreach and activities in nanotechnology. Our goals are both local and national in scope with efforts spanning the spectrum of K-gray, i.e. school aged children, academy and adult professionals and the community. Education and outreach components of the NNIN include network-wide programs to address needs at the national scale and more specific efforts for communities that are local to network sites. Here, we provide updates of our accomplishments and current programs at the local and national level.

The NNIN has the following specific goals for its network-based education program:

- Expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering;
- Help educate teachers and guidance counselors about the discipline of experimental sciences, provide additional teaching tools, and enhance their enthusiasm for having students pursue careers in science;
- Create and distribute educational materials for children, college students, technical professionals, teachers and the general population, as well as improve the understanding of and involvement with science, technology, engineering and mathematics;
- Focus these efforts on population segments having disproportionately low employment and education in sciences, including women, disadvantaged minorities, and the economically disadvantaged.

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

- Developing and distributing activities to encourage K-12 students to enter science and engineering fields;
- Developing resources to inform the public about nanotechnology;
- 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 and guidance counselors.

To attain each of the NNIN's education objectives, a variety of innovative activities have been defined and developed. The network coordination for these activities occurs at Georgia Tech. Different sites are also responsible for specific components of our education programs. In addition, the NNIN education coordinators have established a communications network which allows us to refine our work plans, establish short and long-range plans, and ensure continuous communication and collaboration among the sites. Summarized below in Figure 31 are some of the specific programs for education and human resources and the lead institutions:

Figure 31 Education activity responsibilities	
Activity	**Lead Site**
Web-based open textbook on nanotechnology	University of Minnesota
Instructional modules for K-12 teachers	Georgia Institute of Technology
Tools for web-based education and outreach	Stanford University
Research Experience for Undergraduates	Network-wide activity coordinated by Cornell University
Research Experience for Teachers	Georgia Institute of Technology and University of California Santa Barbara
Workforce Development	Pennsylvania State University
On-line science magazine for grades 3-8	Cornell University
Videos and public service announcements for K-12	Howard University
Guidance Counselor outreach on educational and career opportunities	University of Washington
Nano camps for middle and high school students	Pennsylvania State University
Inclusion of underrepresented populations	University of New Mexico

The challenges of any large-scale activity center on coordination and communication. The coordination of the NNIN education efforts is undertaken by the education coordinator, Dr. Nancy Healy, who is located at Georgia Tech. Since the last annual review she has completed visits to all of the sites, except for the affiliate site at TNLC. These visits have resulted in the refinement of collaboration among the educational outreach activities at each site, focusing of these activities, and establishment of direct lines of communication between the main education office and the sites.

At the last review we noted, "The current challenge is to develop these activities into a cohesive framework, establish a useful communication system, continue the momentum of the activities, and present the educational activities as useful links on the NNIN website." To achieve these goals, the education coordinators held their first joint meeting in April 2005 at CalTech. This meeting was held prior to the *NSF's Research Centers Educators Network* (NRCEN) annual meeting which the NNIN education coordinators also attended and became members of the organization. From this first NNIN Education Coordinators meeting, we established a meeting schedule which includes two "face to face" meetings per year and two teleconferences per year. Additional meetings have occurred in October 2005 at Howard University (in conjunction with the *NSF K-12 & Informal Nanoscale Science and Engineering Education Workshop*, and February 2006 at the University of Texas during the NSF's NNIN Annual Review. Teleconferences of working subgroups have occurred throughout the year as well as continuous communication through e-mail and NNIN's Structured Response System (web tool).

Another of the challenge that any large network faces is coordination of effort between sites and exploitation of network synergies. We view this however, as an important role that we can play in enhancing, for a variety of audiences, knowledge of this fast growing field. We believe that we are uniquely positioned to gather activities, resources, programs, etc. that have been developed at other sites (NNIN, NSEC, MRSEC, etc.) and adopt and adapt them for use by the NNIN and distribute these across the network and nation. This is one of the goals of the NNIN in that we will leverage our network experience and resources to implement programs on a national scale. Towards this goal we have been gathering materials from within the network and from other national initiatives. For example, several sites are using the “NanoProducts” activity developed at Penn State for use in middle and high school activities. Georgia Tech has been using in its high school outreach programs activities developed by SRI’s *Nanosense* project.

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. Straight counting of participants or users can be very misleading as they can range from large group tours to intensive laboratory workshops. The NNIN education coordinator and program manager worked with NNIN web developers to implement a system for tracking events and recording participation by categories, the Educational Event Manager (EEM) which is detailed under the web tools section of the *Annual Report*. This tracking system for education efforts has recently been implemented and will be used by each site for all educational events to provide quantitative data on our efforts.

4.2 Scope of Effort and Impact: National and Local

NNIN has both local and national (i.e. site specific and network wide) educational programs. Each site has a history and a set of local expertise in educational activities. These efforts were incorporated into NNIN as the network was formed, taking advantage of the uniqueness of each site. Some of these activities have been sufficiently strong or had sufficient broad support that they have been expanded to national (network wide) activities taking advantage of synergy between sites and the increased visibility possible with a network program. Some site activities will grow to national activities; others will remain as successful specialized site activities. This will be an ongoing process.

Figure 32: Network and Site Activities

	Site Specific Activities	Network wide Activities
Local Scope	**Local Activities – Site Specific**	**Network Activities w/ Local Scope**
	Facility tours Community days Open house Seminars/Public lectures	User support and training Diversity K-12 education Summer camps, after school/ weekend programs, on and off site programs
National Scope	**Site Activities w/ National Scope**	**Network Activities w/ National Scope**
	Workshops Technical Training Teacher Training Research Experience for Teachers (initial) Curriculum Development (initial) K-12 Instructional materials	National Conferences & Meetings Research Experience for Undergraduates RET NNIN Web site User support Diversity Open Textbook nanooze

Similarly, educational activities can have either localized or broader national impact or range. The quad chart in Figure 32 shows the categories of current NNIN education activities

As activities develop they may move from one category to another. In particular, successful activities within quadrant III (site activities with National Scope) are prime candidates for new Network wide programs (quadrant IV). In this way we can take advantage of network strengths when appropriate, but let site specific activities flourish with the local environment.

4.3 NNIN REU Program

The premier NNIN network-wide education program is the NNIN Research Experience for Undergraduates Program (REU) program. The NNIN has developed, operated, and managed a large highly successful REU program in Nanotechnology evolving from prior efforts of NNUN. In 2004 and 2005, 72 and 81 students respectively participated across 12 NNIN sites using a combination of NSF REU funds and site funds. Between NNIN and NNUN, we have 9 years experience running this highly successful program with over 470 participants to date. 2006 will mark the 10th year of this program. This program is operated as a uniform program across the 12 participating sites with extensive interaction across the network.

Program Applicants

Our program draws top quality participants from a diverse applicant pool, with an emphasis on women and minorities, and by students from non-research (non Ph.D-granting) institutions. Due to the size and visibility of our program, we have been successful in this effort resulting in a high quality diverse applicant pool. Our program remains a popular choice among students with 500 applications received in 2005 for 81 possible positions. A measure of the NNIN REU appeal is that 31% of participants applied only to the NNIN REU program, with an additional 15 % applying to only one other REU program indicating a high degree of commitment to nanotechnology and to our program.

We remain committed to providing research opportunities to students who have the most to gain from the NNIN REU experience—67% of the 2005 participants had not participated in a prior summer research experience. Below is the demographic make-up of applicants and participants and their type of home institution for 2005. Prior years show a similar distribution. Women and minorities are well represented in the applicant pool but more importantly at an even higher level in the participant group.

Table 13: REU Demographics, Participant and Applicant

	2005 REU Program Demographics				
	Applicants	Applicant Pool (%)	Participants	Applicant Success Rate	Participation (%)
Overall	500		81	16%	
Gender					
Women	148	30%	33	22%	41%
Men	352	70%	48	14%	59%
Race/Ethnicity					
Minorities	74	15%	19	26%	23%
Non-minorities	426	85%	62	15%	77%
Institution Type**					
Ph.D. Level	343	69%	49	14%	60%
Master's Level	82	16%	17	21%	35%
Bacc. Level	63	13%	13	21%	16%
Assoc. Level	12	2%	1	8%	2%

**Carnegie Ratings: The Carnegie Foundation ratings of high education institutions are used as the measure of institutional diversity. Some Ph.D. institutions may not offer advanced degrees in the sciences and engineering.

The Program

Our eighty one participants in 2005 were located at 12 of the NNIN sites and conducted research across several disciplines within nanoscale science and engineering. They came from 60 difference undergraduate institutions. The program offers a focused 10 week research experience in one of the NNIN labs, working closely with either an academic research group or an NNIN staff member. To assure a successful project in a short time period, considerable care is taken, both at the network level and the site level, to assure that projects are appropriate and that the appropriate mentoring and advice is available from the PIs and graduate student mentors. Not all good research projects make good REU projects, and not all research groups are equipped to provide the support necessary for a successful project. Care must be taken to craft an interesting project that can be accomplished in 10 weeks with some obstacles but not too many. Nonetheless there is an adequate supply of appropriate projects and project leaders at each site.

To enhance the spirit of community across the network, we offered webcast seminars to the participants. These seminars can be viewed at http://www nnin.org/nnin_multimedia.html. The NNIN REU program culminates in the NNIN REU Convocation which is a “mini” scientific conference for the interns. The 2005 convocation was held August 11-12 at Stanford University. At the convocation, each student presents their research results to their fellow NNIN REU participants and to staff and faculty who also attend. For many of our students, this is their first scientific presentation and their first scientific conference. We also simultaneously webcast these presentations. This allows family, friends, and faculty and graduate student mentors from the sites to view the convocation. The on-site peer interaction at the convocation among all the NNIN students is considered by the participants to be a highlight of the program and the interaction and the broader exposure are extremely important in making career decisions.

Results

Student research from our 2005 program has led to several publications that are currently in preparation with their faculty advisor. Examples include

- Investigation of Line-Edge Roughness in Immersion Lithography, will be submitted to the Journal of Vacuum Science and Technology—Prof. Steve Brueck, David Light, Univ. New Mexico.
- A Study of Sintering-proof Nanoscale Magnets: Silica-coated FePt Nanocrystals, will be submitted to the Journal of Applied Physics—Prof. Brian Korgel, Jose Pelaez, Univ. of Texas Austin.
- Focused Ion Beam Fabrication of Supended Pt Electrodes with an Interelectrode Spacing of less than 10 nm, accepted at the Electron, Ion, and Photon Beams and Nanotechnology Conference, Michael Guillorn and Josh Montague, CNF

> “Let me preface this by saying that I almost never fill out surveys. But my experience with the NNUN program at UCSB has left a lasting impression on my life and career. Let's keep the program going…”
>
> —Thomas Michael Graziano
> 2002 intern at UCSB

All students write a research report which we publish in the *NNIN REU Research Accomplishments*. We also post this online at http:// www.nnin.org/nnin_2005reu.html. The *NNIN REU Research Accomplishments* will be available at the annual meeting.

External Evaluation

Each year we contract with an external evaluator to assess the impact of the REU Convocation and provide feedback on the overall program. In 2005, Dr. Joyce Harris, Professor Emeritus of DeAnza College, served as the evaluator of the convocation. The evaluation focused on three primary areas: 1) quality of the student presentations, 2) personal impact of the NNIN REU program and convocation on the participants, and 3) quality of the NNIN REU program and convocation. In her summary, Dr. Harris stated, “The NNIN REU program is a mature, well-constructed program that has been fine-tuned over the years to provide a powerful and excellent research experience for undergraduates in the field of nanotechnology.” Her interviews with the students regarding the convocation indicated, “The vast majority of the students were very enthusiastic about the participation in the convocation. When asked what they liked about the convocation, they mentioned the opportunity to present their research, to network with other students, and to see another research facility/graduate school.”

Participant Evaluation

Results from project evaluation indicate highly positive research experiences for our participants. The spring 2005 survey of 2004 participants indicated a highly positive influence of the program on the students’ interest in graduate education in STEM, and in particular, nanotechnology. The program was highly rated by summer 2005 participants. Of 77 responses to a post-program survey, 62 gave the program an average rating (36 questions) of above 4 on a scale of 1–5 (5 being the best). Below is a table highlighting several questions from our annual survey of participants:

Table 14:	
NNIN REU Program Survey Questions (subset)	**Average Score** **Scale 1 to 5**
How well did the program help you understand the research process?	4.5
How well did the program help you understand the variety in interdisciplinary research?	4.4
How well did the program offer to you a substantial independent research project which had a strong intellectual focus?	4.1
Were you able to plan, execute, and complete a research project using the necessary equipment and facilities?	4.2
How well did you receive sufficient scientific interactions with a faculty member or senior staff at your site?	4.4
How well did the program assist you in learning to use advanced equipment and processes in nanotechnology?	4.1
How well did the program assist you in making future educational and career choices?	4.3
How likely is it that when you return to you home campus that you will share your experience with fellow students and faculty?	4.7
Do you consider participation in this program as a positive influence on your future educational and/ or career choices?	4.7
How do you rate the overall quality of the program?	4.5

Longitudinal Evaluation

During the past year, we began a longitudinal study of our REU participants. Long-term assessments of outcomes and experiences are necessary for a comprehensive project evaluation. Measuring the impact of our program on career choices is challenging because it plays out over the course of 10 years after the REU experience. Most programs can generate only anecdotal data on a small sample size. Because of its size and long history, the NNIN/NNUN program has had the opportunity to generate statistically meaningful, long-term outcome data on its participants. Finding students after 5 or 10 years is somewhat challenging but we have been moderately successful by taking advantage of the internet in the process.

> "The program helped guide me on the path to a career in science and technology. I currently work for a cutting edge technology company working in high throughput experimentation and combinatorial science and chemistry. The company does work in microfluidic devices and in a broad sense does include nanotechnology. The REU experience helped get me a job in the summer of 2004 at Micron technologies working in the fabrication of masks used to manufacture microelectronic devices. The experience also helped me get my job at Symyx and gave me the experience in scientific techniques and experimentation. I have also established life long contacts with people I met during the REU experience including professors, former/current graduate students, and friends."
>
> —Michael Isaac Reichman
> 2003 intern at UC Santa Barbara
> Currently Systems Engineer at Symyx Technologies

Our initial analysis this year investigated the impact of our program on the career paths of the 84 participants in our program from 1997 and 1998—the first two years of the "networked" NNUN REU program. *To date we have contacted 33 of the 84 with the following results: 46% completed or are still working on a Ph.D.; 39% continued their education with a master's degree; and 6% terminated their education with a B.S. degree. Career paths of these students are: 88% are involved in a science and technology career; 46% of them are in nanotechnology. In addition, 60% of participants (years 1997-1998) stated that their opinion of their REU experience remained unchanged, but 40% said that time had increased their value of the REU experience.* We will be continuing this longitudinal study to track more recent participants in our program. We believe that such efforts will provide information specifically on the impact of our program and REU programs in general.

Plans for Summer 2006

Despite our prior success, for 2006 we no longer have NSF REU funding for this program. We will, however, continue this valuable program during the summer of 2006 using site funds (NNIN and other sources) supporting approximately 60 students while looking for alternate long term funding. We view this as an important nanotechnology human resources program, extraordinarily successful with a strong and long history, and an effort that is truly unique. This year's REU application process is as overwhelmingly subscribed as in past years.

4.4 Development of Materials for Training and Education

A variety of training and development activities have been implemented or are under development across the network. NNIN can have national impact on education via development activities that occur at individual sites as well as through network coordinated activities. Both are part of the NNIN program. Training and development include activities that focus on undergraduate and graduate students, teachers (professional development), and workforce training as well as K-12 educational materials include:

Open Textbook

The Open Textbook is a web-based textbook for nanotechnology to be used at the upper undergraduate and beginning graduate student level. The University of Minnesota, under the direction of Dr. Steve Campbell, is the lead site for this project. The writing assignments for the chapters have been finalized as seen in Figure 33. In addition, the format for each section has been developed and approved by the site directors. Chapter 7, *Growth of Nanoparticles, Tubes, Wires, Belts, etc*. is expected to be completed during this academic year. Authors for the chapter sections come from a variety of institutions and underscore the collaborative effort for this endeavor. Writing assignments are being shared by researchers from University of Minnesota, Cornell University, Notre Dame, RPI, University of Hawaii, and Brookhaven National Lab.

Figure 33: Open Textbook assignments

Open Text Assignments

		Corn	Stan	Mich	Geor	Wash	PSU	UCSB	UMN	UNM	UTA	Hv	How
	Preface								L				
	Introduction												
1	Atoms, Molecules and Molecular States												L
2	Biochemistry Fundamentals					L							
3	Solids, Energy Bands, Optical Processes									L			
4	Charge Transport and Quantum Confinement	L											
	Techniques for Nanotechnology												
5	Advanced Lithography (Double length)				L						L	P	
6	Self Assembly						P			P		L	
7	Growth of nanoparticles, tubes, wires, belts, etc.	P							L	P			
	Nano Materials and Devices												
8	Applications of Carbon Nanostructures	P	L		P								
9	Nanoelectronics	L	P					P	P		P		
10	Optical and Magnetic Nanodevices				P			L	P				
11	Molecular Devices		P				L	P				P	
12	Nano-Bio: Systems	P		L	P	P							
13	NMEMS		L	P			P						

L = Lead; P= Participant

NNIN_05 NSF.ppt – August, 2005

Nanoleap/McREL

Stanford University in collaboration with Mid-continent Research for Education and Learning (McREL) and Aspen Associates has an NSF NIMD project titled *The Nanoleap NIMD Project* (http://www.mcrel.org/nanoleap-review/index.asp). It is developing two high school curriculum modules that address nanoscale science, technology, engineering, and mathematics (STEM) as well as accompanying resources and professional development for educators to facilitate implementation of the modules. The following have been developed this year for the curricula being created: Essential Understandings (or “big ideas” in nanoscience), Alignment to Standards, and Student Objectives.

Stanford’s (SNF) focus is on developing two different two- to three-week modules for use in a physical science course and in a chemistry course. The development team has written detailed outlines of each module, which have been reviewed by the NNIN SNF team. In addition, 15 master teachers have been selected to participate in the design process. Stanford is now soliciting other NNIN sites to help with this project through content review and/or remote access to equipment. SNF hopes to use the remote user tools being developed at other NNIN sites (such as remote SEMs, microscopes and cleanroom cams) in this program, either for teacher development or for classroom demos, or both. Several NNIN sites have agreed to work with this project. NNIN partially funds this curriculum development program along with the NSF NIMD contract through McREL. It will benefit NNIN’s efforts in K-12 curriculum development and teacher training, as well as in developing the network’s remote access capabilities and tools.

Other Material Development

Course development at the post-secondary level is occurring at numerous NNIN sites. One example is the effort at Penn State. Penn State is developing, piloting, and refining hands-on nanotechnology learning activities that will be used in secondary and undergraduate classrooms across Pennsylvania. Equipment for these activities is being bought by participating institutions or being accessed remotely through the internet to Penn State equipment. Penn State also provides training to faculty members at institutions in the use of this equipment and performance of the experiments.

Penn State staff members continue to teach, three times per year, the six courses (18 credits) that comprise the nanofabrication capstone semester to associate and baccalaureate candidates across Pennsylvania. These courses continuously evolve in close consultation with industry to address and incorporate new product and process technologies that are constantly being developed by industry. Since the inception of the NNIN, 135 students from the various partner institutions have completed the nanofabrication capstone semester.

Penn State produced a series of Nanotechnology Education Modules in 2005. These video modules are intended to be used by institutions that need introductory and orientation course work materials and focus on what nanotechnology is, the impact it has on today’s world of industrial products and services, on how nanotechnology influences multiple scientific disciplines, on how current advancements in nanotechnology will be influencing our lives in the future, and on highlighting career and educational opportunities available through the NMT Partnership. These modules are available for viewing at http://www.cneu.psu.edu/edTools.html.

The October coordinators meeting also resulted in the development of a plan for dissemination of our K-12 education materials. First on the work plan was to design a set of templates for the NNIN education activities and this has been developed. This set features a student version and a teacher version. We believe that all of our educational materials must have a common format and meet high review standards before dissemination on the NNIN education portal. This will require formatting, review, field testing, and revision. Dr. Monica Plisch of Cornell and Dr. Christine Morrow of Colorado State University have agreed to serve as reviewers of NNIN materials. We are in the process of seeking other reviewers. Our next step is to begin the review process of materials already developed by the NNIN sites.

The next meeting of the NNIN Education Coordinators will occur at the University of Texas in conjunction with the NNIN annual review. At that meeting, we will review the work plan developed in October, determine progress, and timelines for various aspects of our projects.

4.5 Education and Workforce Workshops

Several sites are active in providing or developing teacher workshops on nanotechnology. Penn State offers three-day professional development workshops for secondary and post-secondary educators at the Penn State Nanofabrication Facility. Since the inception of the NNIN, 135 educators have attended these workshops. The workshops include lectures on the fundamentals of nanotechnology and nanofabrication, combined with laboratory experiments in the clean room where these fundamentals are practiced.

The site is presently developing nanotechnology learning enrichment tools (kits) to be utilized in secondary and undergraduate classrooms. The Nanotechnology in the Secondary Classroom Workshop held November 14-16, 2005, in partnership with the Penn State Science Education Department, was successful in bringing to 17 secondary educators information on how the field and tools of nanotechnology can enhance secondary level experiments and experiences in the classroom. Remote tool access was demonstrated and schools were invited to utilize this remote tool access capability for their classroom use. Each participant was provided introductory activities and materials to take back to his or her classroom to pilot and to provide feedback. NNIN will use this feedback to increase the effectiveness of these materials before dissemination to other sites and the web.

The University of Washington site is working closely with North Seattle Community College on the implementation and refinement of its newly state-approved 2-year nano AAS-T degree program. As well as serving on NSCC nanotechnology advisory board, allied CNT-NSCC collaborations focused on an NSF NUE grant (not funded) and on a broad collaborative NSF ATE grant proposal (awaiting decision). UW also helped to coordinate the regional proposal for a substantial U.S. Dept. of Labor Workforce Development proposal (WIRED) and ensured the inclusion of nanotechnology in the proposed activities.

A workshop was held at the Michigan Nanofabrication Facility on January 19th, 2006 for approximately 15 K-12 teachers and principals. The workshop included a brief overview of micro and nano technology, hands-on activities in the clean room, and a discussion of non-clean room activities (both onsite and in the classroom) that can be used to introduce students to nanotechnology. UCSB is also developing a set of nanotechnology courses that will be used be teachers to earn California professional development credits. TNLC/NCSU hosted the “Emerging Science and Technologies” short course on nanotechnology for 20 high school teachers. Teachers spent half the course in lectures and half the course in the cleanroom.

The University of Washington and Georgia Tech have developed nanotechnology graduate student organizations. UW’s Nanoscience and Nanotechnology Student Association (NaNSA) held seminars by researchers from across the country as well as by student members. The students also provide outreach to regional K-12 classrooms. Georgia Tech’s Nano@Tech has over 100 members (Georgia Tech and Emory) who meet monthly for seminars, lab tours, and networking. The students are developing an equipment list to be shared among the members to assist graduate students in locating equipment for research. A subgroup of Nano@Tech called Nano@Partners was formed and provides support for K-12 outreach and public speaking. Members of this group had their first training workshop on educational materials on January 24, 2006.

UCSB has developed the Technician Internships in NanoTechnology (TINT) which brings 4 foreign (Germany & Vietnam) undergraduate students each year to the UCSB nanofabrication facility for a 6-month apprenticeship. This site also recruited seven students from Ventura College (a non-research institution) for participation in a free, week-long Nanofabrication Short Course. The students spent 1 hour in lecture and 6 hours in the lab every day for the course duration.

Cornell conducted a three day hands-on workshop (spring 2005) for 12 undergraduate students from Clarkson University. The primary goal of this workshop was to give students from a college without a nano-facility the opportunity to experience nanofabrication first hand in a laboratory. This workshop was coupled to a course at Clarkson. The students fabricated the structures at Cornell and followed it with measurements at Clarkson. Evaluations indicated that the workshop served as a very viable supplement to classroom-based education in nanotechnology. This appears to be a viable model which would allow colleges without facilities to incorporate lab experiences into undergraduate courses.

4.6 Technology Workshops

NNIN sites host workshops for graduate students, faculty, technicians, and industry personnel on a wide variety of topics. These are an important part of the research education mission of NNIN and tie together the user program and the education program.

In 2005, CNF developed a new lecture and lab based workshop called ***Technology and Characterization at the Nanoscale*** (TCN). This three day course featured lectures in the morning and demonstration activities within the CNF clean room in the afternoon, and covered all the fundamental nanofabrication technologies. This course was offered twice, in June 2005 and January 2006, to a total of over 100 participants. This course will be repeated at least annually and has been extremely well-received.

Cornell also held a workshop in October on computational nanotechnology, ***Modeling the Nanoscale World***, to kick off its NNIN computing effort. The workshop included over 40 participants from around the world and provided a large boost in usage of the CNF computational facilities. A follow on workshop at CU will be held in fall 2006, and a companion workshop on nanotechnology computational science will be held at Harvard in May 2006.

Successful NNIN industrial users often need to transition from laboratory development activities within NNIN to manufacturing activities elsewhere. There are a number of paths that can be taken but this transition can be challenging. Stanford held a successful workshop in October, ***Nanotechnology: from Prototype to Product***, to provide insight in this important area.

These are but a few of the many technology workshops held across the network. A more complete list of technical (research) workshops in the past year is given below. These workshops are open to all: NNIN users, potential NNIN users, and non-users alike.

Table 15			
NNIN Research/Technology Workshops			
Micro and Nanofabrication	University of Michigan	July 2006	1 day
Modeling the Nanoscale world	Cornell	October 2005	3 days
TCN	Cornell	June 2005	3 days
TCN	Cornell	Jan. 2006	3 days
Nanoboot camp (in association with ASME)	Howard	July 2005	5 days
Nanoscale Science and Technology	U. Washington	Sept 2005	3 days
Nanotechnoloy: From Prototype to Product	Stanford	October 2005	1 day
Imprint lithography	Texas	Nov. 2005	1 day
Nanotechnology Fabrication Introduction	Georgia Tech	July 2005	3 days
Intl. Conf. on Nanotechnology Occupational Health and Safety , in conjunction with NIOSH	U. Minnesota	Oct 2005	4 days
Nanoscale Processes in Earth and Planetary Sciences	U. New Mexico	Jan 2006	4 days
Environmental Health and Safety in Nanotechnology	Stanford and Cornell at Georgia Tech	Dec 2004	1 day

A full slate of workshops is planned for 2006. Current information is always available on the NNIN web site.

4.7 Integration of Research and Education

Two of our most prominent programs for the integration of research and education are the REU and RET (Research Experience for Teachers) programs. The REU program has been described above. During summer 2005, Georgia Tech, Stanford University, and the University of Washington supported two teachers each for research experiences in separate programs at their facilities.

Stanford leveraged resources and joined with others on campus and Industry Initiatives in Science and Math Education (IISME) to create the Stanford Summer Program for High School Science Teachers. IISME is a local nonprofit organization that places science and math teachers in summer internships. SNF/NNIN supported two teachers in the program who concentrated on nanotechnology projects working with SNF faculty and staff. One teacher worked on creating a sensor for diabetes patients who lose sensation in their fingers that could be used to determine the force at which the patients had feeling. The other teacher worked on a project characterizing a nanoimprint tool. Both created an education transfer plan (ETP) describing how they will bring their experience back to their classrooms.

Georgia Tech's program is similar to Stanford's in that the NNIN sponsors teachers in the Georgia Intern-Fellowship for Teachers program (GIFT) which is a collaborative effort designed and run by Georgia Tech's Center for Education Integrating Science, Mathematics, and Computing. The two teachers spent seven weeks working with a faculty mentor and staff on cleanroom research. Their research established growth and characterization methods for plasma enhanced chemical vapor deposition. The teachers developed an implementation plan on how they would incorporate their experiences into their classrooms.

The University of Washington provides a two week summer program and during summer 2005 supported two high school teachers who learned about assorted aspects of nanotechnology and developed classroom materials. Material from the 2004 participant has been developed, field-tested, and sent to the NNIN Education Office for further evaluation and formatting. The 2004 participant is working with NNIN to use these materials as the basis for a collaborative two-day intensive teacher workshop on nanotechnology in summer 2006. The 2005 RET participants have recently developed a classroom module featuring a discrepant event around magnetic nanoparticles which is ready for field-testing and refinement. The teacher-developed materials from all three sites will undergo review, field testing, and refinement before placement on our web site.

In September 2005, five NNIN sites (Georgia Tech, UCSB, Penn State, Harvard, and Howard) collaborated in the submission of a proposal to NSF for an NNIN RET program in Nanotechnology. The proposal has been recommended for funding. The NNIN RET program will begin at these five sites in summer 2006, leveraging prior site specific experience into a coherent NNIN program.

4.8 User Training Materials

There is considerable synergy between NNIN sites on training materials, There are many similar instruments at different NNIN sites and while exact safety protocols may vary there is still considerable overlap. Training materials developed at NNIN sites are shared via the NNIN web site with other NNIN sites and with users around the world. The contents of the original CNF Laboratory Usage and Safety Manual, for example, can be found in use in many laboratories around the world. NNIN has developed copyright policies to assure that its information is fairly shared.

4.9 Informal Science Education

While many of these programs are being developed at the local level, it is the intent to leverage this rich array of resources into programs across the network and thus have a national impact. Outreach and knowledge transfer include informing various groups and initiatives of the NNIN programs and activities, public outreach, and K-12 programs. All sites conduct tours of their facilities for school groups and other visitors in addition to more substantial educational activities that may include facility tours.

A variety of local outreach activities have occurred that include K-12 field trips to facilities, visits to schools and community colleges, summer camps, mentoring, workshops, and demonstrations. In order to provide these activities, the NNIN sites have had to develop hands-on activities, demonstrations, and presentations on nanotechnology. These resources are being compiled for distribution across the network via our web site.

Hands-on summer, weekend, or after-school camps/programs to engage students in nanotechnology have been offered by Penn State, UCSB, Georgia Tech, University of Washington, University of Minnesota, Howard University, and NC State University. These camps/programs focus on high school students and have a variety of formats (2 days to one week) and content (chip camps, introduction to nano, biomedical, etc.). Approximately 350 students were served by these programs in 2005. The University of Michigan site assisted the ERC at that institution in providing cleanroom activities during the ERC's summer programs. Approximately 100 underrepresented students participated.

The University of Texas uses NNIN funds to provide activities and events for UT's "Young Scientist." They provided these hands-on events to 156 primarily Hispanic sixth grade students from low socio-economic backgrounds. The program focuses on assisting these students in gaining admission to the math and science magnet program at an Austin middle school. NNIN assisted the program by providing support for the summer science camp, teacher training, parent meetings. UT is also sharing with the NNIN its *Big Ideas about Little Things Program* (http://z.cs.utexas.edu/users/s2s/utopia/cogito/projectGenerated.php?s2scodename=bialt1) which was developed under a NIRT award and targets elementary to middle school students. This education kit is currently being replicated at the Georgia Tech site and then will be disseminated throughout the network.

UCSB has collaborated with Mathematics, Engineering, Science Achievement (MESA) to provide six nanotechnology workshops at its annual campus-wide event which reaches about 825 middle and high school students. The program was in collaboration with UCSB's materials research labs and the California Nanosystems Institute. The site also funded four students in the Apprentice Researchers Program which is an REU-type program for high school students. NNIN at UCSB provided a project for and mentored a high school student, which resulted in the design of a portable device that could be used to teach photolithography in high schools. The write-up for this lab and the teacher's preparatory notes are in preparation for review, field testing, and network distribution. UCSB also hosted 6 students for a weekend "chip camp" which is being prepared for the same network dissemination process.

The NNIN site at the University of Washington is working with Seattle's Science Fiction Museum to provide general introduction presentations on nanotechnology to school groups that visit the museum. To date, they have been able to reach approximately 100 fifth and sixth grade students with this program.

Howard University has developed the Nano-Express which is a mobile nano laboratory that transports nano experiments and demonstrations to area schools and teacher conferences. Undergraduate students from the National Society of Black Engineers will serve as volunteers to run Nano-Express programs. The University has also developed a new Middle School of Mathematics and Science. The NNIN site is providing a four week nanotechnology program for 150 students which will be a combination of lectures and experiments.

The University of Michigan has developed two programs for middle and high school students: Microfabrication Technology Experiences and Microelectronics and Nanotechnology Experiences. A total of 105 students participated in several cleanroom activities. Students were introduced to micro and nano fabrication technology through hands-on experiences.

Georgia Tech has had numerous school groups visit its site for hands-on activities in conjunction with lab tours. Groups have come from elementary, middle, and high schools and have spent from two hours to two days at the site. One visit involved 350 eight graders, who visited 15 research labs on campus. The lectures, demos, experiments, and tours were supported by over 70 volunteers. The site is now working with the education coordinator in the School of Electrical and Computer Engineering to support the K-12 outreach activities that each program offers.

4.10 Materials and Information for Informal Science Activities

As noted above, the NNIN education coordinators have devised a work plan that is more focused and allows for the development of NNIN national educational models. Georgia Tech and Penn State have taken the lead with support from UCSB in developing models for summer nano camps for middle and high school students. These camps run in duration from one, three, and five days. The model programs have been developed and have been reviewed by the three sites. These are currently waiting for the next revision to be completed. The idea is to provide activities and resources that will allow sites to offer camps that range from simple (general intro to nano) to more advanced camps (such as chip camps) at both school levels. Anyone interested in developing a nano camp would be able to pick and choose from a host of activities, videos, and lecture topics to form a camp that would suit the needs and abilities of their target audience. Listed below is a preliminary list of materials that we plan to include:

- Nanoproducts – PSU
- Memory Wire – GT and/or Wisconsin MRSEC
- AFM – Wisconsin MRSEC and Cornell NSEC have probe activities
    - Asylum Research has great image cards that require 3-day glasses
- General lecture on tools of nanotechnology This would be followed with AFM activity, and/or PSU activities. Remote use of an SEM/AFM?
- Career game – PSU
- Nanometer height conversion
- UT's pixel activity with digital camera and photo printer
- Photolithography, etching, and metal deposition – U. of Michigan
    - Students get a personalized wafer
- LEGO model of photolithography process - U. of Michigan
- Liquid Nitrogen experiments - U. of Michigan
- Materials Properties – PSU
- Deposition/Profilometer – PSU
- Photolithography/Etch –PSU
- AFM/SEM - PSU
- Questor game – PSU has source for ordering
- Other possible resources:
    - Wisconsin MRSEC has several activities
    - Materials World at Northwestern
    - NBTC at Cornell's one hour microfluidics activityl
    - NSEC at Cornell's several materials activities
    - *Nanosense* developed by SRI

4.11 Education Program Plans

At the coordinator's meeting in October we devised a work plan that continues improvement in focus and that allows for the development of NNIN national educational models. One project is the development of teacher workshops model that will be used by NNIN sites and also placed on the NNIN education portal with appropriate materials support and resources. The lead sites for this project are Penn State and Georgia Tech with additional support from the University of Washington. We have developed draft models for one day, three day, and five day professional development workshops for teachers. This model also lists the possible lab activities and lecture topics. The plan is that the model would provide a menu of topics and activities that sites could then pick and choose from. All supporting materials will be compiled so that anyone choosing to host one of these workshops would have a "one-stop shopping" place to access materials. The models are in review by the three lead sites and materials and resources are being compiled. Once reviewed, the models will be distributed across the network with the request for input on additional activities and lecture topics. Possible laboratory activities being practiced for possible inclusion:

- Video presentation (ex. Silicon Run Series)
- Tour/Lab Orientation
- Other Research Lab Tours
- NANO PACE Group Activity
- Atomic Force Microscopy
- Lithography and Etching
- Deposition and Characterization
- Optical Metrology and Scanning Electron Microscopy
- Computer Simulations
- Camp Activities (see Camp Agendas)
- Secondary Classroom Activities/Demonstrations/Labs

Lecture Topics:

- The World of Nanotechnology/What is Nanotechnology
- The Historical Perspective of Nanotechnology
- Ethics in Science and Technology
- Education Programs and Details (PSU-NMT)
- Nanotechnology in the Secondary Classroom
- Nanoscale Characterization and Metrology
- Lithography and Deposition Techniques
- Etch Techniques
- Nanoparticle Synthesis/Quantum Dots
- Micro-Electrical-Mechanical-Systems (MEMS) and NEMS
- Bottom-Up Nanofabrication/Nano-Bio
- Nanoelectronics
- Optics (UNM)

- Photonics (UNM)

A second component of the NNIN work plan is to develop middle school instructional units. The lead sites for this program are UCSB, University of Washington, and Howard. The action plan for "Bringing Nanoscale Science to Middle Schools" has been developed and includes the goals, quality control, process for development, and timeline.

The Education Activities Development Committee has been formed in response to ongoing requests from teachers and administrators for middle school level nanoscale science and technology educational materials. The goals are:

(i) Solicit potentially appropriate materials from NNIN members
(ii) Evaluate the materials for appropriate content and developmental levels
(iii) If needed, adjust the materials to a middle school level
(iv) Index the materials to the appropriate NSES, and place such materials into common classroom-useable formats

The timetable for development is:

Action Plan & Timeline

Theme	Year	Month	Goal
Assemble	2006	Feb	Solicit nanotechnology activities From NNIN Sites
		April	Collate initial set of activities from sites
		Dec	Initial set of activities formatted into templates Pilot/beta test activities in nanocamps, workshops, & classrooms
Test & Evaluate	2007	Jun	Activities correlated with NSES Publish nanotechnology activities on NNIN website in draft form Publish activity assessment form for classroom use feedback
		Dec	Teachers/classrooms selected for testing & external evaluation; Activity testing begins
Publish	2008	Jun	Publish activities refined based on assessment feedback
		Dec	Publish assessed & refined activities in a workbook

The Open Textbook will continue with the solicitation of authors for the proposed sections and the development of the text materials. Once chapter 7 is completed, testing of the material on-line and revisions will occur.

5.0 Marketing and Promoting NNIN Capabilities and Results

5.1 Outreach at Research and Technology Conferences

Supporting the expansion of nanotechnology into new fields is a critical part of the NNIN mission. In parallel, NNIN sites need to assure that the existing nanotechnology community is aware of the nanotechnology support capabilities of the network. Exhibiting at research conferences is one way in which NNIN reaches to these communities. With the explosion in the number of nanotechnology conferences, NNIN must limit itself to the major scientific conferences, with care to cover the breadth of technical areas encompassed by NNIN.

Since March 2005, NNIN has participated in these conferences annually with booths or table top information displays in the exhibit area.

American Physical Society-March	AVS Technical Society Annual Meeting
Materials Research Society-Fall Boston	Materials Research Society-Spring San Francisco
SPIE Microlithography San Jose	Electron, Ion, and Photon Beams and Nanotechnology
Biophysical Society (new in 2006)	NNI Workshop on Regional, State, and Local Initiatives (2005)
American Chemical Society (Spring) (new in 2006)	Nanotech 2006 (new in 2006)

NNIN will continue to evaluate additional conference opportunities as they arise.

Typically, two or three NNIN staff representing different sites help staff the NNIN booth, talking to users and potential users about capabilities within NNIN and at their site. Staffing assignments rotate among the sites depending on interests, technology, and location. In addition, specific NNIN sites participate in regional nanotechnology events. NNIN has several attractive lightweight booths and tabletop displays which can be deployed with minimal effort.

NNIN also makes invited presentations in technical conferences with the goal of promoting technologies and techniques available for use by the technical community. Presentations have included the national yearly conferences of American Physical Society, Materials Research Society, Society of Photo Instrumentation Engineers. Presentations are also made to small company collectives and economic development groups.

Our users are often presenting the results of work done at NNIN facilities at these same conferences. Such presentations (and publications) by successful users is the singularly most effective means of promoting NNIN capabilities. We stress that all users must acknowledge NNIN in such publications and presentations. Our presence at the conferences reinforces this technology link to successful users. These venues are particularly helpful for reaching users who are new to nanotechnology. We will continue to participate in these and other appropriate nanotechnology conferences.

5.2 Education Outreach at Conferences

NNIN's Education and Outreach activities were featured at the annual meeting of the National Science Teachers Association (April 2005). NNIN had an exhibition booth which featured materials and resources developed for teachers. Our focus was on introducing the NNIN to science teachers and providing them with information, resources, and activities suitable for the K-12 classroom. The booth was very popular and we were able to learn from our informal poll of booth visitors:

- Teachers are seeking nano education materials for classrooms

- K-12 students are driving much of the teacher interest
- Teachers are seeking professional development
- Teachers are unsure where nano fits into the K-12 science curriculum

We will be returning to the NSTA annual meeting this spring with an exhibition booth as well as sponsoring a science coordinators breakfast. At the breakfast we will discuss the goals of the NNIN K-12 education program, discuss resources and opportunities, and gather information on teacher needs.

The NNIN education coordinator is working with the newly formed Nanoscale Informal Science Education Network (NISE-Net). This will allow two of the larger NSF-supported nano education programs to share materials and resources. NNIN attended the "kick-off" meeting of NISE-Net at the Exploratorium in November 2005. NNIN also supported a Nano Education Workshop at the Museum of Science (MOS), Boston (November 7, 2005) as part of NISE-Net's teacher training. NNIN presented two workshops at this meeting. In addition, NNIN's education coordinator and Carol Lynn Alpert of NISE-Net and MOS, Boston have organized a session at the upcoming AAAS annual meeting. The program will feature invited speakers from informal and formal nano education programs.

The NNIN is co-chairing a three-day symposium on nano education at the Materials Research Society spring meeting in April. The other co-chair institutions are Arizona State University, University of Central Florida, Sandia National Laboratory, and the German Aerospace Center. These sessions will feature a variety of national and international speakers involved in nano education, particularly at the undergraduate level.

As noted above, NNIN participated in the most recent NRCEN meeting at CalTech. This provided the NNIN with a forum to let other education coordinators know about our programs and activities. The education coordinator served on the NRCEN Strategic Planning Committee which met in Denver in June 2005 to develop plans for the organization which were presented to NSF in November 2005.

Several of the NNIN education coordinators attended the *NSF K-12 & Informal Nanoscale Science and Engineering Education Workshop*. The NNIN Education Coordinator made a presentation at this meeting on teacher professional development and facilitated two sessions. The coordinators indicated that this meeting was very valuable because of the networking that occurred, the information that they obtained, and the connections they made with other nano education programs.

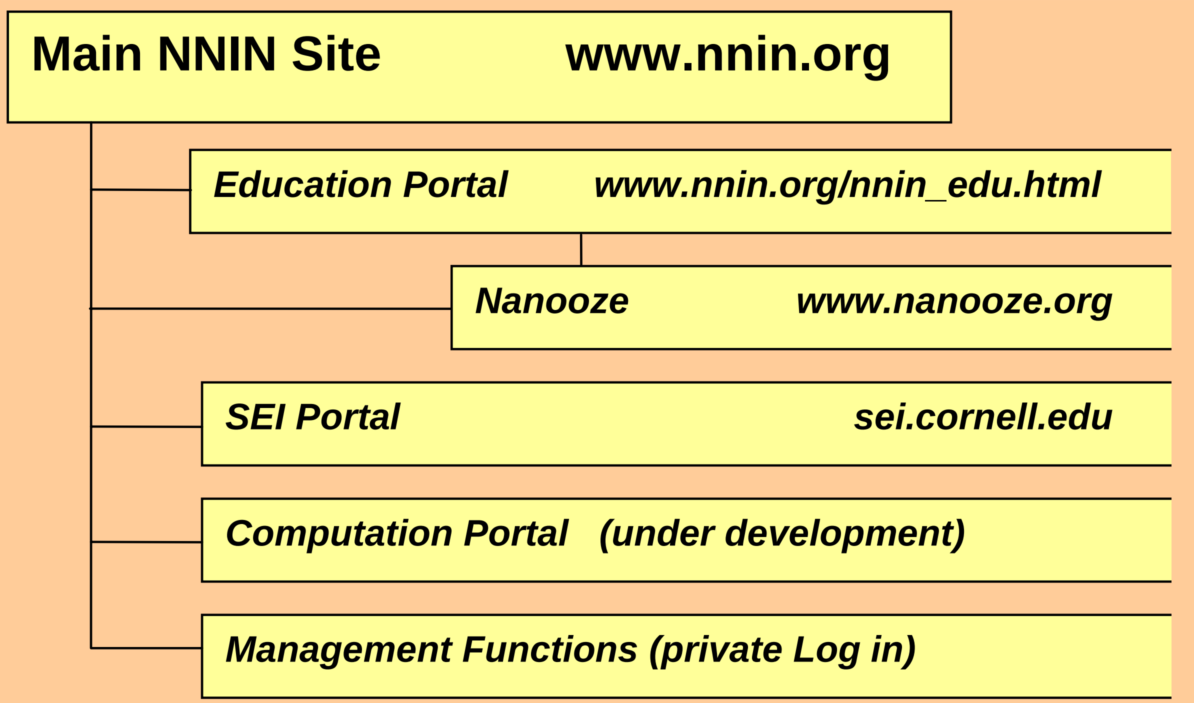
The NNIN Education Office assistant director attended the NNI Regional, State, and Local Initiatives in Nanotechnology II held in Chicago November 3-4. The program was linked to the efforts of the Nano Business Alliance and Small Times to launch networking between the various nanotechnology initiatives. The director of the NNIN served on one of the panels of the meeting.

As part of our web-based outreach, Cornell has recorded seminars which are available for viewing via streaming multimedia. Other sites also have video materials that can be viewed and downloaded by interested groups. Georgia Tech's training videos have been downloaded by many institutions for use in courses and lab activities.

Many sites participated in local and regional programs. Several sites provide activities and/or booths at campus community days or college of engineering open houses. These activities provide a forum to reach the general public regarding the NNIN. Penn State has been active in providing presentations offsite, particularly to other Pennsylvania institutions. They also assisted in the development of a statewide public service announcement featuring Pennsylvania Governor Ed Rendell. This site has also developed a nanotechnology module for the Semiconductor Equipment and Materials International (SEMI) organization for use in its educational outreach program High Tech U" for high school students. The University of Minnesota provided an exhibitors booth at local meetings such as the Minnesota American Vacuum Society annual meeting.

5.3 NNIN Web Site

Figure 34: NNIN web site structure



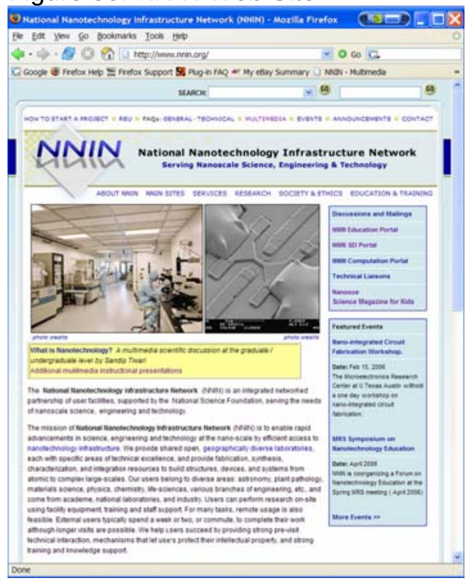
NNIN has developed an extensive web site, located at http://www.nnin.org, to act as a portal for users and the public to NNIN activities. This site has been expanded considerably and redesigned in the last year. The site is database driven to allow easy updating and permission based editing of selected sections by each site. The site is organized as the main technology and overview site for both users and the public, and a series of sub-sites, or Portals, that can be viewed as standalone sites or as part of the larger NNIN universe. (Figure 34)

Main Web Site

A NNIN web site is the primary interface to the public and potential users of NNIN. It has been extensively modified and expanded since December 2004. It is a flexible, database driven design, with capability to handle expanded new functions (Fig 35). Emphasis within the main site is on the research user support services offered by NNIN. Care is taken to explain to new visitors the mode of operation of NNIN as an open user facility and to explain the scope of services available. Extensive information is then given to allow a potential user to assess the capabilities of NNIN to meet his/her needs. Major functions include:

- How to start a Project
- Frequently Asked Questions
- Site Information
- Searchable Tool Database
- Process Capabilities Table
- Mailing Lists and Contact Info
- Multimedia Seminars and Instruction
- Technical Liaisons
- Events

Figure 35: NNIN Web Site



The entire site is searchable, via free text or assigned keywords. Editing and page creation permissions can be granted on a site by site, page by page basis. The editing tools available assure that existing and new pages remain within the format of the site. Similarly, each site can add tools to the tool database and add events to the event database.

Extensive multimedia and instructional content is available within the NNIN web site. These resources have dual appearance, appearing both as instructional materials for users in the main NNIN web site and as educational media within the NNIN Educational Portal.

Education Portal

The NNIN education portal, the primary face of all NNIN education efforts, was launched in July 2005. It is a self contained site within the main NNIN site. It is accessible via the main site at http://www.nnin.org or via direct link to http://www.nnin.org/nnin_edu.html. It was designed to appeal to mixed and generally less technical audiences—students, teachers and the general public. It is thus more easily navigable than the NNIN site, with more emphasis on graphical display of information and events (Figure 36). Events and activities and information that would be of appeal to a wide audience are presented on the front page. Additional information and events are sorted into separate sections for the main audiences: K-12, teachers, undergraduates, graduates and professionals and public. The site will be the repository of all the training materials, lesson plans, and activities developed by NNIN sites. In addition, content

Fig 36 NNIN Education Portal

generated outside NNIN may be distributed by mutual agreement. The site features a custom back end tool for managing content on a rotating basis.

In addition to network content, the site contains summaries of educational activity at each site.

Nanooze, the NNIN children's science web magazine, is a separate "kids" site within this umbrella, or directly accessible at http://www.nanooze.gov. *Nanooze* was developed by Cornell in collaboration Prof. Carl Batt and Main Street Science. This magazine is also featured at http://www.nano.gov, the NNI web site. The target group for Nanooze is grades 3-8 and it is written at a level and style appropriate for this age group. *Nanooze* is organized into four main sections: a primer, original articles, Web blog, and interviews with scientists and engineers. The primer consists of a core set of concepts:

- What is nanotechnology?
- What is a nanometer?
- How do you make things too small to see (part 1)?
- How do you make things too small to see (part 2)?

The original articles address interesting topics in nanotechnology, often taken from current events. Interactive science learning games are under development. An Editorial Board of teachers and a testing group of children advise the developers on matters of content. *Nanooze* is now also available in Spanish.

SEI Portal

The NNIN SEI portal (located at sei.nnin.org) is the central face for SEI efforts within NNIN. (Figure 37). The site is intended as an archive of all materials related to Social and Ethical implications of nanotechnology and act as a resource and a research tool for the SEI community.

Figure 37: NNIN SEI portal

The NNIN SEI site was initially development under the direction of Prof. Tim Lenoir of Stanford. Prof. Lenoir is no longer at Stanford and as a result has development has switched back to Cornell. As a result the site is undergoing a major restructuring and should be available in its new form by the annual meeting.

More details on the SEI portal are given in the SEI section of this report.

Computation Portal

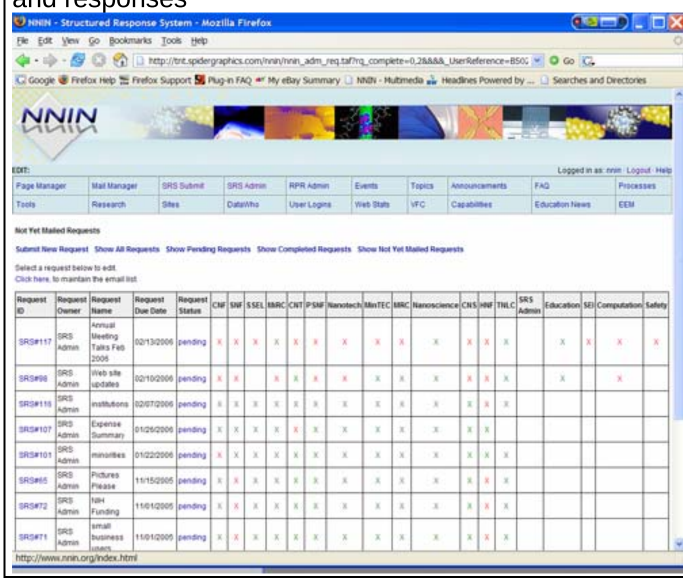
We envision a web based computation portal where jobs could be submitted to and results visualized from any NNIN computation resource. That level of functionality is not presently available. Currently the computation web pages are merely descriptive of the types of simulation and computation resources available at each site but it does not have the breadth or functionality of a full computational support site. This is a large task, however, as dozens of codes are supported by the NNIN computational resources and each code has a different front end. As an initial step, an NNIN REU student at Cornell began work on a universal input file for many of the solid state and nanostructure simulation codes. At some level, these programs all need the same information, basically the coordinates of all the atoms, but they all require it in different format. This effort would standardize some of that information. NNIN Computation staff will continue to work on implementing this computation portal functionality.

Management IT functions.

NNIN has developed a significant set of "back end" tools, running via the web, for management of the network. Much as Fastlane automates and structures many NSF communications functions, these tools automate and organize some of the information flow between NNIN sites and management, and among NNIN sites. These tools have been a tremendously cost effective investment. These tools are all accessed by private (site specific) login at the footer of any nnin.org page. Three of these tools are highlighted below:

SRS-The Structured Response System: The Structured Response System is a query and response tool for communication from NNIN management to the sites. Communication between management and sites is critical, and with 13 sites it is critical to impose some structure on this communication. Management is always looking for information back from sites—data on users, text for reports and proposals, etc.—responses that must be both correct and timely. At times there can be as many as eight open requests for information, each with a separate deadline, some with template files that must be returned, etc. This can get confusing for sites. And it can really be confusing for management, with up to 13 responses to each query, many with attached files, etc. SRS was created to put structure to these requests and their subsequent responses.

Fig 38. SRS Management Grid view of open requests and responses

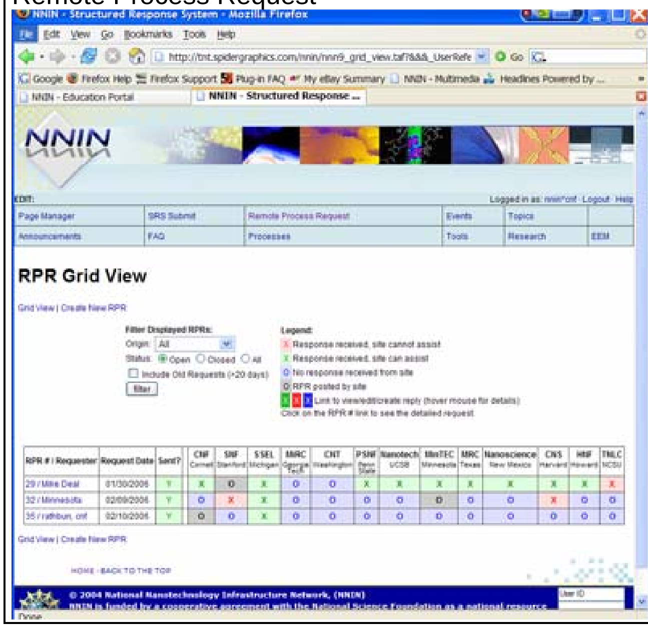


Via SRS, NNIN management can issue a request to all sites or selected sites. The request is logged, numbered, and databased, and goes out to each site by email. Files may be attached, e.g. a template for a spreadsheet, and each request has a due date. Sites respond by logging in and uploading the appropriate information or file as a Structured Response to the particular request. Management can review the status of responses, viewing the level of response in real time, and download information as appropriate (Fig. 38). Reminder emails can be sent to the group, and sites which do not respond in a timely manner are treated to an automatic daily email reminder until the request is closed. Uploads are filed by request number and site and given unique identifying file names so they can be identified once downloaded.

SRS has been in use for most of 2005, managing about 90 requests from management and their responses. Recently Network Coordinators (Education, SEI, Computation) have been added to the system, both as requestors and requestees—i.e. the education coordinator can solicit responses from the sites as well, and the Program Manager can request responses from the area coordinators in addition to the sites. As the activities of the 13 sites and the activity between management and sites have grown, it would have been quite impossible to do the necessary proposals and reports without this tool.

RPR-The Remote Process Request System: The RPR is similar to SRS in that it creates structure for certain communications—in this case, communication between sites regarding remote process assistance. Any site can issue a request to other sites, emails are sent to each site and sites that can help, i.e. have the appropriate technology, can respond through the system (Figure 39). All communication is logged and structured. The request originator can see at a glance the status of responses; he/she will also get email synopsis of all responses. While this all could be done by email, the system assures that a consistent, complete set of information is included in each request and that the requests can be easily managed and reviewed.

Figure 39: Site screen for entering or responding to Remote Process Request



Sample contamination is a critical issue whenever samples travel between sites—what contamination did it have when it went to the 2nd site, and what did it have when it returned to the original site. Misunderstandings in the level of cleanliness and in any cleanings that may be instituted at either site can be devastating. NNIN Staff have discussed this issue and determined what information is necessary to assure system and sample integrity during this process, and this protocol has been designed into the RPR system. RPR asks for and records all previous processes as well as substrate information so that the each site can make an honest determination of compatibility. This system was rolled out in January after extensive discussions between NNIN staff.

EEM-The Education Event Manager: With 13 sites, there are many events going on, particularly educational events. Some of these are major events such as workshops and camps. Others are minor events such as tours and small demonstrations. The major events should be posted on the NNIN web site, and all events need to be tracked for participation and outcome assessment. The Education Coordinator and NNIN Program Manager also need to be able to see major events as they are happening, to guide publicity and to promote interaction and synergy between sites when appropriate. They also need to be able to extract summary event information at any time–number of participants, number of events, event types, etc.

The EEM is a database and structured entry tool that sites can (must) record the detail of educational events as or before they occur. Access is via the NNIN web site, with each site having a distinct login. After an event has occurred they must log back in and enter event information, attendees, demographics, etc. Failure to follow up with post-event information will result in reminder emails until the event is closed out properly. As we develop assessment tools for educational events, this information will also be captured as part of the system. Notifications of event entries and event modifications are sent to the Educational Coordinator and Program Manager.

This system was recently deployed and has been well received by the educational staff. **Effective Jan 2006, all NNIN education events must be entered into EEM in a timely manner.** Education Users will be tallied and categorized via this new system automatically.

Multimedia

The NNIN web site serves a variety of multimedia resources. These are generally "double served", appearing both within the NNIN Education Portal and within the training and multimedia sections of the "research" site.

Training of users is a critical function within NNIN. Many sites have developed video training modules for either initial or refresher training of certain fabrication and characterization instruments. Over twenty equipment training videos are available covering SEM, AFM, thin film deposition, etching, and lithography tools are available. These modules are accessible not only from the developing site, but are shared with others within NNIN and other users around the country via the NNIN web site. We will continue to collect and make available these training modules. This section of the NNIN web site can act as a rich resource for nanotechnology facilities around the country (and around the world).

Also available are over 20 nanotechnology seminars and short course modules for technology instruction.

For many applications, NNIN uses a MediaSite streaming video processor, which allows almost hands-free creation of "Rich Multimedia" with concurrent slides, video, and index. Examples can be found at http://cnfx.cnf.cornell.edu/mediasite/viewer/. With the MediaSite a presentation can be recorded, composed into "Rich Multimedia" by direct capture, and streamed in real time, or posted for downloading within minutes of completion.

5.4 Contact Database and Newsletter

Through its web site and by efforts of NNIN staff, NNIN has developed a database of over four thousand contacts (names and email) of persons with nanotechnology interests. NNIN staff continues to expand this database. Use is limited to approximately one mailing per month to avoid becoming annoying. It is generally used for the monthly NNIN (email) Newsletter. The newsletter contains brief announcements of upcoming NNIN activities and workshops as well as brief announcements of new NNIN technical capabilities.

5.5 NNIN in Print

NNIN has a 12 page full color brochure describing the network, the network sites, and network activities. It was first printed in Dec. 2004 and over 4000 copies have been distributed by sites and by NNIN at conferences and to visitors. A second printing of 8000 was necessary in Dec 2005.

Most NNIN sites have developed their own brochures and newsletters that highlight recent site-specific accomplishments, equipment and resources available, upcoming events and seminars, among other items. These materials are typically shared with their users and others in their regions. These brochures along with the NNIN brochure will be available at the NNIN annual meeting.

At the time of the annual review, we hope to have completed and printed a nanotechnology brochure aimed specifically at NNIN high school students. The project is nearly complete as of the writing of this report but we are still waiting for two featured researchers to complete their interviews. The brochure will provide an introduction to nanotechnology and provide interviews with an undergraduate, graduate student, faculty, and industry representative who will explain how they became interested in their field and what attracted them to nanotechnology. In addition, the brochure provides information on what type of courses a student should take during high school to be prepared for a career in nanotechnology. It takes the broad view that there are many careers in nanotechnology—technicians, research scientists, service and support personnel, etc—but that they all require adequate preparation in high school. This brochure will serve as informational and recruitment brochure to be used with the high school groups which visit our laboratories.

5.6 Scientific Publications by NNIN Users

Scientific publications are one of the primary products of NNIN, particularly of the academic user community. In July 2005, NNIN compiled user publications from all sites for the period since the beginning of NNIN, March 2004. Over 1700 publications are listed from this period. Due to the difficulty in collecting publications from over 3000 users and almost 1000 PIs, this undoubtedly represents only a subset of the actual NNIN publications. Furthermore, new projects begun after the start of NNIN have barely had time to obtain publishable results. The NNIN Publications booklet will be available at the annual meeting, and is included as an appendix of this document.

5.7 International Nanotechnology Cooperative

Nanotechnology networks and national level nanotechnology activities are not unique to the United States. Every technological country in the world is developing nanotechnology centers or more commonly a nanotechnology network at the national scale As they are all operating with different histories and with different financial constraints, their organizational and technical approaches to this concept vary significantly but they all have a common goal—to leverage experience at multiple institutions to realize the scientific and economic potential of nanotechnology. All, however, recognize the experience and leadership of NNIN and seek to learn from our experience. At least one VIP delegation from each of the following countries has visited NNIN in the last 2 years: Denmark, Korea, India, Japan, Germany, Italy, Israel, Singapore, and Sweden, to name a few. Typically they visit both the management node at Cornell and one or more other NNIN sites. The questions all start out the same: “How do you handle users?” and “How do you allocate resources?” but then expand into more site specific questions. These meetings are very informative with much learned by each side. Unfortunately, there was little follow up and not long term communication from these bi-lateral discussions.

In response and to establish a mechanism for more ongoing dialog on a multilateral basis, NNIN has established the <u>International Nanotechnology Cooperative</u>, an informal group. .

Membership is by invitation only and is restricted to national level nanotechnology networks and centers in each country. Communication is by email list and web forum.

The cooperative is for the exchange of any information relevant to the operation of large nanotechnology organizations. We expect that it will include, at least, discussions of safety, training, equipment, funding mechanisms, equipment, and organization. Members may be in a position to provide backup services in case of equipment or laboratory failure. International workshops may be organized as appropriate..

5.8 Technology Forums

Information exchange within the network is extremely important. In both 2004 and 2005 NNIN held meetings of the Network Operations Committee and Lab Managers, those in charge of putting together the NNIN user program. The primary focus of both of these events was developing procedures across the network for handling new users in an effective way—safety, orientation, statistics, charges, etc. These meetings were largely successful. In 2006 we will be changing focus to concentrate on sharing information amongst NNIN Staff on specific technical areas of wide interest. We all have different tool sets to address similar problems so there is much to be shared. The first *Staff Technology Forum* will be held March 23-24, 2006 at Cornell University on dry etching equipment and processes. This forum will be followed by similar events in other technology areas including photolithography, electron beam lithography, and thin film deposition. We expect to complete at least 4 of these forums during 2006. The first round will largely consist of familiarization with resources around the network, both equipment and processes. Subsequent meetings on each technology can then focus in on synergies in particular sub-areas, e.g., III_V etching, deep silicon etching, etc.

6.0 Educational Diversity Programs

A primary focus of NNIN education outreach 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.

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 section 5.2 demonstrate that women and minorities have a higher participation rate in our program in comparison to the applicant pool.

NNIN REU Program 2005	
Women in the applicant pool	30%
Women participation	41%
Minorities in the applicant pool	15%
Minority participation	23%

In the recently submitted RET proposal, we indicated a commitment to serving underrepresented groups by two means. We will recruit teachers who are from underrepresented groups and we will place an emphasis on recruiting teachers who teach in schools with high minority populations.

Individual sites make every effort to ensure participation by underrepresented groups in the K-12 programs. With our new data management system, gender and ethnicity will be tracked for all activities (where possible). However, sites have collected gender and race data for most of their activities. Listed below are some **examples**:

Institution/Activity	Participant Diversity
UCSB Chip Camp	60% Hispanic 33% Female
MESA at UCSB	82% Hispanic 3% Black
University of Washington SFS summer program	70% Black 15% Hispanic
University of Michigan Micro & Nano Electronics	56% Minority 41% Female
Georgia Tech NanoInfusion	85% Minority
Georgia Tech Brown's Mill Elementary Program	99% Black 53% Female
Penn State Summer Camps	43% Minority

We have recently developed a Spanish language version on the online science magazine *Nanooze* and we will be offering our high school brochure also in Spanish.

The NNIN site at the University of Washington is sharing funding support with eight other initiatives and/or programs on campus to have a coordinated effort to enhance diversity in nanotechnology focused programs. They have hired a diversity coordinator for these research and education centers/programs.

The education coordinator at the University of New Mexico attended the annual meetings of the national engineering organizations for minority groups including: Society of Mexican American Engineers and Scientists, American Indian Science and Engineering Society, Hispanic Engineer National Achievement Awards Corporation, Society of Hispanic Professional Engineers, National Society of Black Engineers. At these meetings he provides informational material regarding the NNIN and nanotechnology education and careers. He has requested that other coordinators assist him in participation at these meetings and that the NNIN provide either an exhibit booth or a presentation to encourage participation by minority students in nanoscale science and engineering. This request will be part of the education coordinators meeting at UT.

At the October coordinators meeting we developed an action plan for diversity activities of the NNIN. Howard will expand its participation in offering a Nano Boot Camp at the NSBE and at the Black Engineer of the Year Awards. Other sites will assist in this camp by offering speakers and activities. NNIN will also participate in these two events by having an exhibition booth. Howard University is the lead on coordinating these activities for the NNIN.

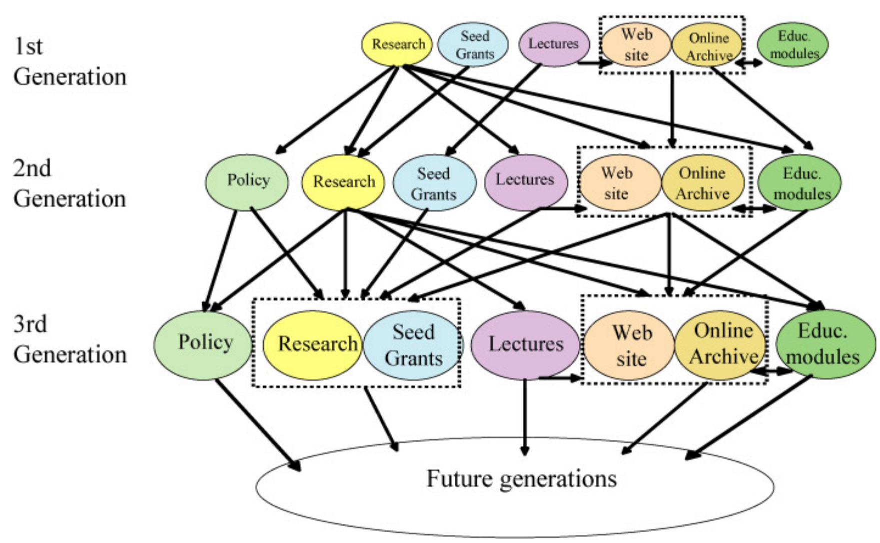
7.0 Social and Ethical Issues in Nanotechnology

7.1 Introduction

The goal of the Social and Ethical Issues component of NNIN is to increase the national capacity for exploring the social and ethical issues associated with nanotechnology. To accomplish that goal, the SEI component is developing an infrastructure for conducting research and disseminating information about SEI. That infrastructure is intended to serve both the NNIN itself and the national community interested in nanotechnology. The NNIN SEI web site is a critical part of this infrastructure, acting as a resource for current events and discussion and as an archive of historical information.

The internal infrastructure to address this goal consists of SEI coordinators at each NNIN site, who help organize talks, panels, seminars, courses, or other activities involving SEI. They also facilitate the conduct of research on SEI at their sites. The output of these activities is then distributed via the SEI website portal, workshops, presentations, and ultimately traditional peer-reviewed publications. As the number of activities and products increases, the capacity for informed exploration grows (Figure 40).

Figure 40: Growth of web of SEI instracture



To seed the growth of the infrastructure, the NNIN's SEI component includes funding for research on issues in ethics, innovation, workforce development, and history of nanotechnology. The work of the SEI component is directed by Bruce Lewenstein, associate professor of science communication at Cornell, and the SEI coordinator, Dr. Ana Viseu, a research associate at Cornell.

7.2 Network-wide activities

Annual meeting: Continuing a practice begun in the NNIN's first year, the SEI site coordinators held an annual meeting in April 2005 at Georgia Tech. At the recommendation of the NNIN Advisory Board, the meeting was combined with a public workshop. Working with the NNIN

Education Coordinator, Dr. Nancy Healy, the SEI component arranged a workshop on how to incorporate social and ethical issues into education at various levels – undergraduate, graduate, and community courses.

The annual meeting focused on strengthening the SEI infrastructure. It developed materials guidelines for the SEI portal, explored the possibility of creating an SEI training video for NNIN users, planned for greater involvement of the SEI component in the NNIN's REU program, and planned future workshops. The meeting devoted significant time to addressing collaboration issues, such as how to facilitate cross-site surveys (both in terms of logistics and in terms of IRB/human subjects issues).

REU program: The SEI component contributed significantly to the NNIN-wide REU program by stimulating discussion of social and ethical issues. At the beginning of the summer, all REU participants received a brief introduction to social and ethical issues, including suggested readings. One REU student, Priscilla Paul from Cooper Union, developed the script and filmed a video exploring social and ethical issues as identified by NNIN laboratory users. She then presented the video at the REU convocation in August 2005 at Stanford, where it led to a stimulating discussion among all REU participants. We anticipate using the video again in future years as a vehicle to stimulate discussion of SEI issues in the REU community.

SEI portal: The SEI portal was implemented during the year, with sections on activities, teaching resources, publications, and events. Videotapes of SEI lectures and workshops (including the REU video described above) are available on the portal. As the SEI community grows with new projects in the United States, Europe, and elsewhere, we expect the SEI portal to become a site where users can find pointers to resources and projects worldwide. The departure from an NNIN institution of the lead developer of the portal has led to new explorations of possibilities and collaborations; talks are ongoing with the Center for History and New Media at George Mason University to adapt its tools for the SEI portal.

Collaboration with SEI community: During the 2005 national competition for a NSF-funded Center for Nanotechnology and Society, the NNIN's SEI component offered to make its infrastructure available to any center that wished to collaborate. The NNIN's SEI capabilities were named by several of the proposals. The NNIN has working relationships with all of the successful programs, and will participate in the initial collaboration meeting in February 2006.

7.3 SEI research

Four of the NNIN sites have specific resources allocated to SEI activities, including research. The research activities include:

Cornell Lead researcher: Bruce Lewenstein.

Ongoing research on public communication of science and technology, including media coverage and public opinion. Preliminary results show that public knowledge of nanotechnology is limited, but that public opinion is likely to be shaped as much by emotion as it is by knowledge, even if knowledge increases.

- Gorss, J., & Lewenstein, B. V. (2006 (accepted)). The Salience of Small: Nanotechnology Coverage in the American Press, 1986-2004. *Science Communication*.

- Lee, C.-j., Scheufele, D. A., & Lewenstein, B. V. (2005). Public Attitudes Toward Emerging Technologies: Examining the Interactive Effects of Cognitions and Affect on Public Support for Nanotechnology. *Science Communication, 27*(2), 240-267.
- Lewenstein, B., Radin, J., & Diels, J. (2005). Nanotechnology in the media: A preliminary analysis. In M. C. Roco & W. S. Bainbridge (Eds.), *Societal Implications of Nanoscience and Nanotechnology II: Maximizing Human Benefit. (Report of the National Nanotechnology Initiative Workshop, December 3-5, 2004, Arlington, VA).* Washington, DC: National Science & Technology Council and National Science Foundation.
- Scheufele, D. A., & Lewenstein, B. V. (2005). The public and nanotechnology: How citizens make sense of emerging technologies. *Journal of Nanoparticle Research, 7*(6), 659-667.

Georgia Tech Lead researcher: Marie Thursby.
Ongoing research on innovation and productivity of large firms in nanotechnology, with particular attention to intellectual property and comparisons with biotechnology.

- Rothaermel, F. T., & Thursby, M. (2005a). Incubator firm failure or graduation? The role of university linkages. *34*(7), 1076-1090.
- Rothaermel, F. T., & Thursby, M. (2005b). University-incubator firm knowledge flows: assessing their impact on incubator firm performance. *34*(3), 305-320.
- Thursby, M., Thursby, J., & Dechenaux, E. (2005). *Shirking, Sharing Risk, and Shelving: The Role of University License Contracts* (No. 11128): National Bureau of Economic Research.
- Thursby, M., Thursby, J., & Mukherjee, S. (2005). *Are There Real Effects of Licensing on Academic Research? A Life Cycle View* (No. 11497): National Bureau of Economic Research.

Stanford Lead researcher: Robert McGinn.
Ongoing research on the ethical issues perceived by NNIN users. Key issues include whether the issues are intrinsic to nanotechnology or are contingent on general engineering practices; how ethics are defined (in terms of consequences, right/wrong, whether or not covered by laws); societal level ethics (e.g. technological momentum, downstream applications of upstream R&D, effect of societal accumulation of individual benefits); and individual level ethics (e.g., R&D lab safety, intellectual property decisions).

With substantial collaboration from NNIN site coordinators, human subjects approval was obtained at all sites for distribution of electronic survey. As of December 2005, just over 1000 surveys have been returned from NNIN users at almost all facilities.

University of Washington Lead researcher: Suzanne Brainard.
Ongoing research on three projects focusing on workforce issues:

- *Nanotechnology and public health*. The goal for this project is to help define appropriate regulations and safety measures. An online survey to compare perception of nanotechnology risks and hazards among over 70 UW nanotech faculty and more than 50 toxicology faculty has been fielded. *Preliminary results*: Toxicologists are aware of the implications of nanotechnology, and they perceive greater risks and hazards than nanotechnologists.

- *Nanotechnology and multidisciplinary communication*. The goal for this project is to help bridge gaps in understanding between disciplines. Data is being gathered through one-on-one interviews, participant observation, and analysis of written texts. *Preliminary results*: There are significant differences in the way different disciplines characterize the implications of nanotechnology and nanoscience.
- *Nanotechnology and the emerging workforce.* The goal of this project is to track nanotech students and document where they start their careers. Students are interviewed at program entry, during their program, and as they exit. *Preliminary results*: Although students feel that their nano education prepares them well for both academic and non-academic careers, most intend to work in private industry.

In addition, the University of Washington is developing a network-wide project for assessment of diversity and opportunity in the nanotechnology workforce. It is also developing databases for tracking the growth of nanotechnology as a field and discipline.

7.4 Other SEI site activities

In addition to research and general support, many of the NNIN sites contribute or host substantial guest-lecturing, public lectures, collaborations, and other activities. These include:

<u>Cornell University</u>

Public lectures

- Social Dimensions of Nanotechnology: Rethinking research in a changing context (Robert Doubleday, Cambridge University) (available on website) (June 2005)
- An Introduction to the Social and Ethical Dimensions of Nanofabrication (Ana Viseu, Cornell University) (available on website) (June 2005)

Campus collaborations

- Guest lecture in “Introduction to Nanoscience and Nanoengineering” (AEP 102), followed by laboratory exercise on writing and speaking about social and ethical issues in nanotechnology (Bruce Lewenstein, with graduate students from Communication and Science & Technology Studies assisting in the laboratory) (November 2005)
- Guest lecture in “Ethical Issues and Professional Responsibilities” (BMCB 781), for graduate students in life sciences including those working in nanobiotechnology (March 2005)
- Guest lecture in “Cornell Institute of Physics Teachers,” summer training program for high school teachers (July 2005)

<u>Georgia Institute of Technology</u>

Courses

- Completed draft of business school case on issues in university industry collaboration in nanotechnology (to be field tested at Harvard and Georgia Tech in Spring 2006)

Workshop

- “Addressing Social and Ethical Issues through Nano Education” (available on website) (April 2005)

- Developing a nano-ethics course (Kirsty Mills, University of New Mexico)
- Citizen' School on nanotechnology (Chris Toumey, University of South Carolina)
- Working with graduate students (Bruce Lewenstein, Cornell University)

Harvard University

Collaborations

- Ongoing collaboration with Museum of Science to include social and ethical issues in outreach activities

Stanford University

Courses

- Introduction of nanotechnology unit into "Ethical Issues in Engineering" (STS 115)

Campus collaboration

- Guest lectures to staff at SNF and to high school teachers

University of Michigan

Courses

- Continued development of "Societal Imapct of Microsystems" course, previously offered in 2002 and 2004. Next presentation of course will be in 2006; course is required for all students in MEng in Integrated MicroSystems.

University of New Mexico

SEI course

- New 400/500 level 3-credit course, "Societal and Ethical Implications of Nanotechnology," developed and led by Dr. Kirsty Mills. Core course for new UNM Nanoscience and Microsystems curriculum, Fall 2005

Campus collaborations

- Collaboration with MBA-level marketing class to develop marketing strategy for Nanoscience @ UNM, exploring business and organizational issues associated with nanoscience and engineering
- Seminar "The Societal and Ethical Implications of Nanotechnology" given to multiple groups, including lawyers, graduate student groups, high school teachers
- Program development for ongoing UNM "Science and Society" dialog - uniting artists, social scientists, historians, ethicists, etc, in discussion of nanotechnology

Outside presentations

- Dr. Kirsty Mills, "Addressing the Social and Ethical Implications of Nanotechnology within the US National Nanotechnology Infrastructure Network" (invited) at European Union Workshop "Research-Training in Nanosciences and Nanotechnologies: Current Status and Future Need," Brussels, April 2005
- Dr. Kirsty Mills, invited participant at workshop "What Can Nano Learn From Bio: Lessons from the Debate over Agrifood Biotechnology and GMOs" (First International IFAS Conference on Nanotechnology), Michigan State University, October 2005

University of Texas at Austin

Public panel

- Community-wide Civic Forum on Societal Implications of Nanotechnology, day-long event with more than 300 participants, October 2005

University of Washington

Courses

- New course on nanotechnology ethics

Collaborations

- Ongoing collaboration with nanotechnology seminar series, scheduling of talk on ethics education in nanotechnology for February 2006
- Ongoing interactions with UW Nanoscience and Nanotechnology Student Association (NaNSA)

7.5 Other publications and presentations

In addition to items listed above, members of the NNIN's SEI community have contributed to a number of publications, projects, panel presentations, conferences, and so on. Panels were held at the American Association for the Advancement of Science in 2005 (and are scheduled for the same meeting in 2006), and a presentation on SEI in nanotechnology education is scheduled the American Society for Engineering Education in June 2006. Some other specific citations include:

- Bassett, D. (2005). Promoting Cooperation in the Geographically-Distributed, Multidisciplinary Research Team: Using Communication Media to Implement Informal Sanctioning Measures. Paper presented at the National Communication Association, Boston, MA.
- Lewenstein, B. V. (2005a). Nanotechnology and the Public (introduction to special issue). Science Communication, 27(2), 169-174.
- Lewenstein, B. V. (2005b). What counts as a "social and ethical issue" in nanotechnology? Hyle: International Journal for the Philosophy of Chemistry, 11(1), 5-18. To be reprinted in J. Schummer & D. Baird (Eds.), Nanotechnology Challenges: Implications for Philosophy, Ethics and Society. Singapore: World Scientific Publishing (2006).
- Mills, K. (2006a). Ethics module. In Online MA in Nanotechnology: Oxford University.
- Mills, K. (2006b). Regulation module. In Online MA in Nanotechnology: Oxford University.
- Mills, K. (2006 (in press)). Developments in the USA. In G. Hunt & M. Mehta (Eds.), Nanotechnology: Society, Law and Policy.
- Mills, K., & Fleddermann, C. B. (2005). Getting the Best from Nano. IEEE Transactions on Technology and Society, 24(4), 18-26.

8.0 Computation

The computation project of the National Nanotechnology Infrastructure Network, NNIN/C, was established to leverage the existing computation and simulation tools at the NNIN sites and make them available to a wider community of users, just as the laboratory resources are made available to form the fabrication and characterization infrastructure of the network. Simultaneously, a critical goal of NNIN/C is to provide computational support to the experimental programs supported by NNIN either in the fabrication and characterization stages, or, of equal importance, in the measurement and analysis phases. The breadth of the types of computational users in the network has demanded above all that NNIN/C maintain a flexible approach to user services. For example, some users require only download of codes, such as UT-Quant/Marlowe, which they can build and run on their own machines. Other users are experimentalists who might wish to use a program such as SETE to investigate the electronic structure of their semiconductor device in order to plan fabrication or interpret results; and for these researchers a more user-friendly, web-based interface is helpful. Still other users have packages of their own and require only well-maintained hardware to accomplish their nanotechnology goals. For users such as all of these, the central objective is to provide user-friendly, well-documented code and/or transparent registration and hardware usage information and, above all, to automate the processes so that users can satisfy their own needs with minimal staff help.

However, the users described above are far from complete and NNIN/C is, in contrast to other computational facilities at DOE and NCN, highly personnel-intensive. First, the core codes supported by NNIN/C are developed principally at the NNIN nodes. Each code has computational scientists who are involved in its creation and maintenance with whom the user may consult. This feature of NNIN/C was emphasized at our first workshop (see below) at Cornell in the Fall of 2005, where hands-on sessions with a variety of core codes were held. Furthermore, even state-of-the-art computational codes are frequently ineffective in handling new problems in nanotechnology as they are constituted. Therefore NNIN/C operates on a principal similar to the “open source” revolution of consumer software wherein our codes can be modified to meet the requirements of developing research problems. This modification is generally made by the code creators in consultation with the users, but in some cases users are modifying source code themselves for their own research purposes. To date the SETE code, and to a lesser extent the HARES code, have undergone modifications to address the modeling requirements of various scientists.

In the spirit of flexibility to confront new problems and coordination of computational efforts with experimental work, the most innovative characteristic of the NNIN/C project is our incorporation of *code contributors* to the classes of NNIN users. Specifically, we have polled various experimental researchers to ascertain their needs for computational support. Frequently there exist computational scientists who are willing to make portions of their code user-friendly and post them on our servers, in exchange for which they obtain usage of the NNIN machines, collaborative interest from the experimentalists (and theorists) at our sites and a higher profile for their work in the community. We have thus far identified four computational groups whose basic themes overlap with our nanotechnology experimental thrusts and who are in the process of contributing versions of their code to our community. These four groups are described in slightly more detail below.

8.1 Mission and Scope

Mission: develop modeling, design and analysis resources that complement and extend nanoscale experimental and theoretical research. Identify and meet computational demands of the nanoscience community by providing hardware, software tools and, where necessary, consultation to the users.

The structure of NNIN/C as we conceive it has evolved in accordance with the following history and concepts:

- Begin from core codes and hardware facilities at NNIN computational sites;
- Be a *flexible* resource: many classes of users;
- Be a *dynamic* resource: expand and extend the code base to address new research problems.

Our early experience dictated flexibility in that multiple user classes with widely differing objectives could be identified. One categorization of these users is as follows:

(1) Remote and local users of NNIN codes run on NNIN computers;
(2) Download users – large packages and source-code modifiers;
(3) Hardware-only users;
(4) Code contributors.

8.2 Timeline

The timeline illustrated in Figure 41 provides basic information of the phases of development of NNIN/C. While the computation project existed at the time of the last annual meeting at Georgia Tech in December of 2004, it had only been active for three months and no report on its progress was presented at that meeting. Therefore we provide an overview of the complete timeline of the project, a description of which is as follows. The initial phase, beginning in Fall 2004, concerned benchmarking of core codes, purchasing of

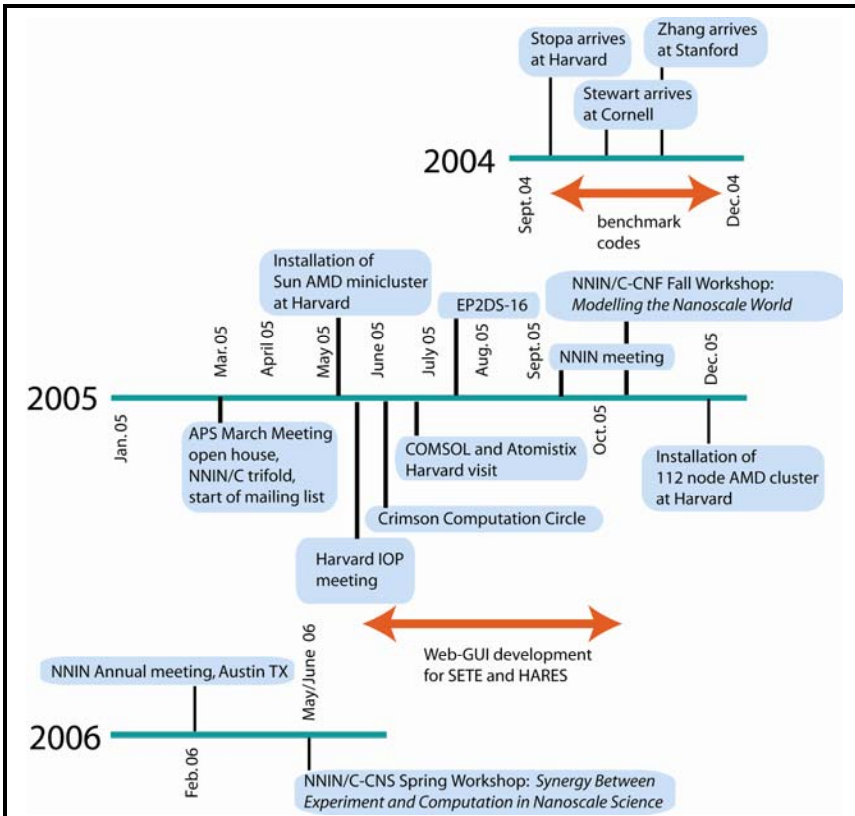


Figure 41: Timeline of NNIN/C from initial phase of the project in Fall 2004 until the present.

hardware and conceptualization of the main elements of NNIN/C. In the spring of 2005 the initiative got underway, more or less officially, at the American Physical Society March Meeting in Los Angeles, where an open house on computation was held, a mailing list was initiated and advertising at the NNIN booth took place. During the summer of 2005, work was begun and completed on the first graphical user interface (GUI) for an NNIN/C core code (developed for SETE and now extended to HARES). Simultaneously, planning was begun for the Fall NNIN/C workshop which was held in October 2005 at Cornell University. Through the summer and fall, the user base was expanded initially by registering the users at the home institutions but also by registering users in the communities of the various core codes which had already been in use. Also beginning in the late summer several computational projects at several locations were identified that corresponded closely with experimental programs of various NNIN users (but which were not already supported by any of the core codes). The principal investigators of those projects were recruited by NNIN/C to establish versions of their code on NNIN platforms with the specific requirement of stability, documentation and overall user-friendliness. Currently we are deep in the organizational phase of the spring 2006 conference, to be held at Harvard University. Hardware facilities pre-existing at Cornell, Harvard and Stanford have been available from the beginning for NNIN users. However, computers for dedicated use by NNIN/C have been gradually installed with the most recent installation being the 112 node AMD Opteron cluster at Harvard which was opened to the users in late 2005.

8.3 Participating NNIN sites

The following NNIN sites participate in the computation project by providing user-accessible hardware resources, download-able codes and/or computational consultation.

- Harvard University, Michael Stopa
- Cornell University, Derek Stewart
- Stanford University, K.J. Cho and Zhiyong Zhang
- University of Texas
- University of Michigan
- Georgia Institute of Technology

8.4 Core Codes

The basic codes, most of which were developed at the NNIN institutions, are as follows:

- **HARES** (High performance fortran Adaptive grid Real space Electronic Structure) Abinit plane wave pseudopotential first principles code.
- **EDIP** (Environment Dependent Interatomic Potential)
- **SETE** (Single Electron Tunneling Elements)
- **LM Suite –** Linear Muffin tin orbital software.
- **NWChem** is a computational chemistry package.
- **SEMC-2D** (Schrödinger Equation Monte-Carlo).
- **UTQUANT** is a quasi-static CV simulator for 1D silicon MOS structures.
- **ANEBA** (Adaptive Nudged Elastic Band Approach).
- **MIT Photonic Bands** (MPB).

- **UT-MARLOWE** is an ion transport code.
- **TOMCAT** (TOpography based Monte CArlo Transport).
- **CPMD** (Carr-Parrinello Molecular Dynamics code).
- **PARSEC** (Pseudopotential Algorithms for Real Space Energy Calculations).

8.5 Hardware facilities

Hardware facilities for NNIN/C users exist at four of the participating institutions. Dedicated machines (for NNIN users) are available at three of those locations (Harvard, Cornell and Stanford).

- At *Harvard University* -- NNIN users currently have access to the DEAS Cluster, comprised of 48 dual 32 bit Xeon blades (~3 GHz) each with 2 ½ GB of RAM with gigabit ethernet. P655 IBM Power 4 Plus processors, total of 20 processors with 80 GB RAM. 4 units of 4-way 32 GB Opterons from SUN Microsystems, for a total of 128 GB RAM. Recently installed: NNIN AMD Opteron cluster: 112 processors, 56 connected with Infiniband, 56 with gigabit ethernet.
- At *Cornell University* -- 48 node dual processor Xeon (3.06 GHz) cluster connected by gigabit Ethernet lines donated by Intel. (16 nodes currently running due to cooling constraints). Fifteen 64 Bit Opteron workstations. The Opteron workstations were donated by AMD Corporation.
- At *University of Texas, Austin* – ray-Dell PowerEdge Xeon Cluster with 600 3.06GHz Xeon processors within 282 Dell dual-processor PowerEdge 2650 compute-I/O server-nodes and 2 Dell dual-processor PowerEdge 2650 login/development nodesIBM Power4 System, with 224 total 1.3 GHz Power4 processors and over 500GBof memory across four SMP nodes IBM 64-processor Intel Pentium III Linux cluster with 64 1GHz processors and 32GB of memory.
- At *Stanford University* – 12 processor linux cluster for NNIN users.

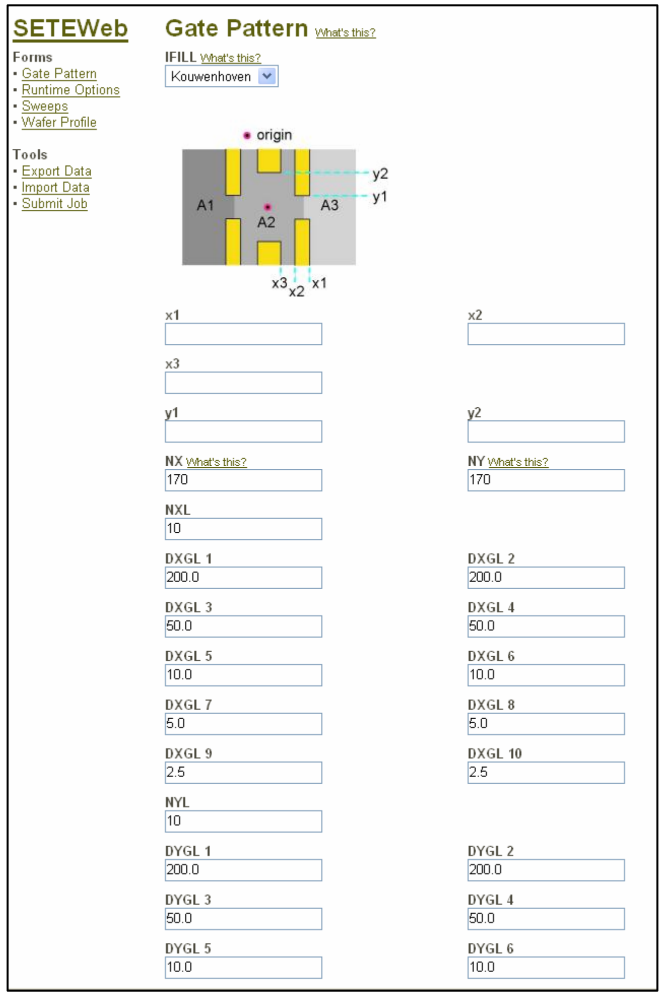
8.6 Graphical user interface

During the summer of 2005 a programmer (Cory Taylor) was hired at Harvard University specifically to develop a graphical user interface for NNIN/C codes. Working with the creators of SETE and HARES, Taylor modified the input decks to be logically more coherent and wrote a parser for that input (Figure 42). The parser, in addition to providing fields for the input data, performed logical checks of input parameters against one another and gave a graphical representation of some of the input data so that the user could visualize the simulation that was to be performed. The resulting web-based interface for the programs was implemented into the NNIN computational cluster by the operating system personnel of the Department of Engineering and Applied Sciences (DEAS) at Harvard University. The capacity to input the data and then kick off the job was implemented. Currently the interface is being updated to conform to the newly-installed 112-node Opteron cluster and further beta testing is also taking place. The GUI is sufficiently flexible that versions are being developed for the contributed code (specifically the Monte-Carlo code and the Casimir Force code, see below).

8.7 Code contributors

As noted above, a unique feature of the NNIN/C computational initiative is our effort to assemble state-of-the-art code that has been developed throughout the world and which can be made accessible to our user community. This often entails identifying needs and searching for related expertise. Heretofore, we have identified four computational researchers (and their groups) who have agreed to document their code and make it available to our users. Graphical User Interfaces will be developed on an as-needed basis for these codes.

Figure 42: Screen shot of SETE input parser



- John Shumway, (Arizona State University). *Path Integral Simulations of Semiconductor Nanostructures* Monte-Carlo code for the calculation of path integral relating to electron correlation in many-body systems.
- Normand Modine, (Sandia National Laboratories). *Socorro*. Highly parallel electronic structure code. DFT.
- Toshiaki Iitaka (RIKEN) and Shintaru Nomura (Tsukuba), solution of time-dependent Schrödinger equation in 2D billiard-like systems.
- Metin Muradoglu, (Koc University, Istanbul). Computational model of interfacial flows in Micro/Biofluidic systems.

8.8 Fall Workshop

The first NNIN/C workshop, ***Modeling the NanoScale World***, was held at Cornell University in the Fall of 2005. The workshop was highly successful and attracted roughly 50 participants. Specifically innovative was the hands-on training that participants received in the building and running of many of the core codes.

The workshop provided introductions to several computation approaches that are essential for work in nanoscale materials, nano-chemistry, and nanophotonics. Morning lectures on the theory behind approaches were followed by hands-on afternoon sessions on each code. In some cases, participants were able to learn directly from the code's creators. Graduate students and young researchers with theory and experimental backgrounds were strongly encouraged to attend. Tutorials were provided on codes such as Abinit, LM Suite, Layered KKR, NWChem, CPMD, MIT Photonic Bands, SETE and FDTD approaches .

Fig. 43: Fall Computation workshop at Cornell

The following topics were covered

Day 1: Nano Materials

- Intro to Density Functional Theory with Abinit
- Modeling Systems with Linear Muffin Tin Orbitals
- Quantum Dots and 2D Electron Gases with SETE
- Alloys and Multilayers: A Layered KKR Approach

Day 2: Nano Chemistry

- NWChem: An Introduction
- CPMD: Molecular Dynamics for the Nanoscale World
- Green's function approaches (molecular electronics, transport, etc)
- Poster Session

Day 3: Nano Photonics

- Photonic Crystal Band Structures
- FDTD approaches for waveguides and more

8.9 Spring conference

The NNIN/C Spring conference: "Synergy between Experiment and Computation in Nanoscale Science" is currently being organized and will take place at Harvard University from May 31 through June 3, 2006. See enclosed flyer in Figure 43.

Fiqure 43: Spring computation workshop

Synergy Between Experiment and Computation in Nanoscale Science

May 31 - June 3, 2006
Harvard University, Cambridge, MA

Nanoscience is interdisciplinary. Furthermore, at the nanoscale different degrees of freedom commonly have overlapping energy scales inhibiting the isolation of specific phenomena. Finally, specific geometry and configuration and connection to the larger scale world are often crucial, and simplifying assumptions (e.g. "circular parabolic potential") are inadequate. Consequently, one unifying feature of nanotechnology across all disciplines is that computational modeling is an essential complement to theory and experiment. In this conference, we will discuss a varied assortment of nanoscale systems and phenomena with an emphasis on computation. The main theme of the conference, the synergy between experiment and computation, will be explored in focused presentations from experimentalists who will describe the impact of computation on their research and what their desiderata might be for future computation. Correspondingly computational presentations will focus on experiment, from design of apparatus to interpretation of data.

We will also describe the computational tools that are currently available through NNIN/C and those that are being acquired specifically to dove-tail with NNIN experimental themes, from the state-of-the-art research of several groups. We will provide hands-on sessions in order for prospective users to acquire a quick rise on the often steep learning curve of complex codes.

Conference Topics:

I. Ab Initio Electronic Structure of Nanoscale Systems
II. Correlated Electrons in Low-Dimensional Nanoscale Systems
III. Casimir Effect
IV. Microfluidics
V. Photonics

Confirmed Speakers:

Normand Modine, Sandia Laboratories
George Whitesides, Harvard University
David Goldhaber-Gordon, Stanford University
John Joannopoulos, M.I.T. (confirmed)
Howard Stone, Harvard University
Sanro Succi, Instituto per le Applicazioni del Calcolo
Charles Marcus, Harvard University
John Shumway, Arizona State University
Federico Capasso, Harvard University
Derek Stewart, Cornell University
Eric Heller, Harvard University

Contact Information:

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nanobynumbers@cns.fas.harvard.edu
stopa@cns.harvard.edu

8.10 Conclusions

The computation initiative of the National Nanotechnology Infrastructure Network, NNIN/C, exists to complement the experimental efforts of NNIN users and provide state-of-the-art computational tools to the widest possible audience. Since the beginning of user registration in the summer of 2005, the number of NNIN/C users has increased to approximately 70 full time users. More detailed metrics will be presented at the NNIN annual meeting in February, 2006. The installation of hardware facilities, the offering of workshops and conferences and the recruiting of code contributors are all features of the project. The latter element, seeking computational efforts that dove-tail with user experimental efforts, is one of the unique hallmarks of the project and our intention is to continue to emphasize the experimental-computational synergy in the future of the project.

9.0 Health and Safety

The potential health and safety issues engendered by nanotechnology and nanomaterials must be addressed if this field is to grow to its potential. There are really two rather distinct facets to this nanotechnology health and safety: 1) occupational health and safety of laboratory workers and 2) health and safety of the public exposed to nanotechnology products.

It is this latter, the health and safety of the public, which has gained significant media attention in recent months. Major studies are being commissioned within the toxicology community to address this issue and the possibility of new government regulation exists. There is a range of views within the scientific community both on the level of these risks and the extent to which we understand them. The Nanotechnology SEI survey of NNIN users undertaken by Prof. McGinn, Stanford, as part of the NNIN SEI program begins to address this issue within the NNIN user community, i.e. from the technologist's point of view. A survey by Prof. Brainard, Washington, also part of the NNIN SEI research program, addresses the perception of nanotechnology risk within the toxicology community. Only preliminary results are available from these studies at this time. Together, however, these surveys will paint an interesting picture that can help guide policy and funding decisions and are an important part of NNIN's contribution to this area. Beyond that, however, toxicology and the health and safety of nanomaterials in the environment are largely outside our area of expertise. In October 2005, NNIN cosponsored with NIOSH and other agencies the 2nd International Symposium on Nanotechnology and Occupational Health held in Minneapolis. NNIN will continue to interact with this community and will incorporate any findings into our laboratory and research policies.

Occupational health of laboratory workers in our laboratories is also of major importance and is an area in which we can and plan to continue to make significant contributions. Here, nanotechnology safety is less an issue with exposure to nanotechnology products/materials themselves than with the potential exposure to toxic chemicals and other hazards in the manufacturing process. While some of this can draw on the admirable safety record of the semiconductor industry for the last 40 years, the scale, multidisciplinary nature and academic setting of our laboratories add additional dimensions to the problem. Occupational safety issues are magnified in user facilities such as ours by the large number of users with a wide range of laboratory experiences. NNIN facilities do, however, have significant experience in managing laboratory safety in this challenging environment and have much to share with each other, and with other academic research facilities. It is in this area where NNIN can make the most effective contribution.

Statement of scope:

Nano –science and –technology presents a broad spectrum of safety and contamination issues in shared research facilities. Our priority concern within NNIN is that if not properly handled these issues present risks for the health and safety or our researchers and staff members at these facilities. In addition, these issues present concerns for contamination which would compromise the work of our member researchers and therefore, the value of our shared facilities. These issues can be summarized as follows:

- **Diverse experience of the research community.** Nanoscale research demands cross-disciplinary approaches. This poses safety concerns when a researcher is performing experimental work outside of his/her area of expertise. An electrical engineer may be performing chemical reactions; a molecular biologist may be performing electrical connections. A researcher performing work outside of his/her discipline may fail to understand, overlook, or undervalue certain safety precautions that a practitioner in that discipline would take. Researchers and staff at shared facilities should be well-versed in and engage in standard safety practices across multiple disciplines.
- **Incompatible processes or unexpected process interactions.** In dedicated research labs, the repertoire of chemicals, materials, and procedures is limited and can therefore be managed with relatively simple engineering controls. The flexibility nature of a shared facility, however, means that a given station will witness a much broader range of chemicals, materials, and procedures, some of which may be incompatible under a certain set of conditions. Shared labs, therefore, may need to establish more complex or redundant engineering controls, in order to minimize any risk of incompatibility.
- **New nanomaterials and/or methods which may present new risks.** Nanoparticle materials, for example, are known to present health risks that their bulk counterparts don't. Many chemical precursors for applications such as nanoscale assembly or nanoelectronic films deposition have no documented exposure limit guidelines. Nanoscale research will continue to challenge our labs with materials and methods for which there may be no established or known processing protocols. Researchers at nano -science & -technology facilities cannot become experts in nanotechnology safety, but should keep up-to-date on best-known-practices. Shared labs should then institute conservative practices in handling these new materials as well as equipment and devices that come into contact with these materials and any waste that is generated.

In support of this scope, the NNIN EH&S and Contamination Program will:

1. Provide an information clearinghouse.
    a. Publish a survey EH&S practices across NNIN sites.
    b. Publish a survey of contamination control methods across NNIN sites.
    c. Host a discussion list for EH&S and contamination issues in shared facilities
2. Engage in education and activities that increase awareness of risks.
    a. Conduct workshops on health and safety issues within our area of expertise
    b. Host a website posting links to information about nanotechnology safety.

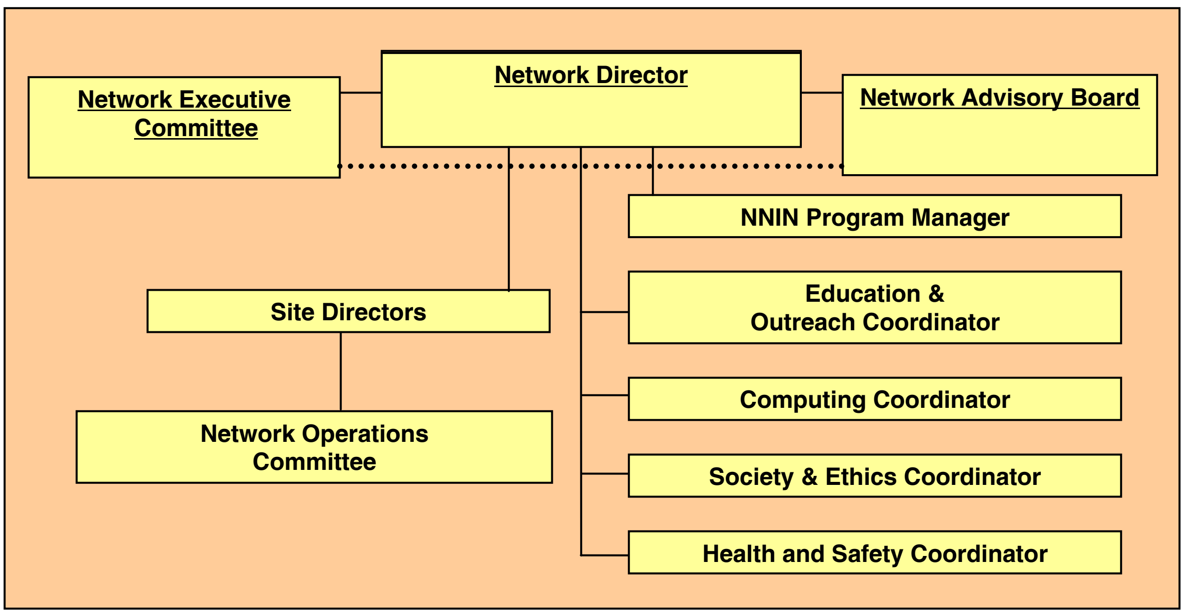
As part of this scope, NNIN held a workshop, **Nanosafe**, at Georgia Tech in December 2004 with over 40 attendees. Speakers included Lawrence Gibbs, Stanford EHS; Prof. Robert McGinn, Stanford Science, Technology and Society Program; Dr. Andrew Maynard and Dr. Anna Shvedova of NIOSH; Prof. Farhang Shadman of the Univ. of Arizona, and David Hoffman, attorney The program and presentations are archived at http://www.nnin.org/nnin_safetyworkshop.html A follow on workshop will be held at another NNIN site in 2006.

The other activities in the scope listed above will be undertaken in 2006.

10.0 Network Management

A cohesive management for the NNIN is essential to assure that network goals are met and network standards for operation and support of users are 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. It is organized as shown in Fig. 44.

Figure 44: Network Management Structure



Prof. Sandip Tiwari, Cornell, the NNIN Network Director, is the point of contact with NSF, and has responsibility for implementation of network policies and program. Prof. Tiwari is on sabbatical in academic year 2005-2006 but continues to actively direct network activities. In February 2005, Dr. Lynn Rathbun (Cornell) assumed duties of NNIN Program Manager to coordinate the daily activities and communication with network sites.

Four Network Coordinators are responsible for particular broad technical areas across the network.

- Education & Outreach (Dr. Nancy Healy, Georgia Tech),
- Society & Ethics in Nanotechnology (Prof. Bruce Lewenstein, Cornell),
- Scientific Computation (Dr. Mike Stopa, Harvard),
- Environment, Health and Safety (Dr. Mary Tang, Stanford).

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 for thrust activities.

The Site Directors are responsible for the operation of individual sites. A complete list of Site Directors is given in appendix 2. 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 (currently Georgia Tech, Michigan and Minnesota), and the Coordinators of special thrust areas of the network. The NEC meets monthly by conference call, or more often, if necessary. The Network Executive Committee convenes monthly by conference call.

The NEC receives independent advice from the Network Advisory Board (NAB), an independent body of leaders of the disciplines and communities that the network serves. The NNIN advisory board represents eminent scientists, engineers, administrators, social scientist. 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 Network Advisory Board has the following members:

- **Dr. Samuel Bader**; Assoc. Div. Director, Materials Science Division, Argonne Natl. Lab
- **Dr. William Brinkman**; Senior Physicist, Princeton & Retired VP, Research, Bell Labs
- **Prof. Harold Kroto**; Department of Chemistry, Florida State University
- **Dr. Carl Kukkonen**; CEO, ViaSpace Technologies
- **Prof. George Langford**; Professor of Biology, Dartmouth
- **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**; President, Cepheid
- **Dr. Tom Theis**; Director of Physical Sciences, IBM Research
- **Prof. Karen Wooley**; Professor of Chemistry, Washington University, St. Louis

Prof. Dan Kevles, the Stanley Woodward Professor of History at Yale University, resigned from the board in the fall of 2005. A search for a replacement is ongoing.

Appendix 3 includes brief biography of the network advisory board members.

The Network Operations Committee (NOC) consists of the Laboratory Managers/Associate Directors/ or equivalent personnel that have day-to-day laboratory responsibilities. This group is actually responsible for implementing NNIN user support procedures at each site. They also share best practices and process offerings between sites. They communicate primarily be a private email discussion list. The Network Operations Committee is ultimately responsible for collection of lab use information for submission to site management.

The Coordinators for Education & Outreach, Society & Ethics, Web & Computing, and Health and Environment thrusts implement the goals of their thrusts through regular interactions with the respective committees consisting of representatives from each of the sites.

The Society and Ethics, Education, and Health and Environment Coordinators are members of the Executive Committee, but do not vote on matters relating to technical research operations.

Significant management IT functions are carried out via special web based applications custom developed for NNIN. These primarily facilitate communication between management and the sites. These tools were fully described in section 5.3 .

Appendices

A1 Site Reports

A1.1 Cornell University Site Report

Overview

CNF's technical site focus and responsibilities are in the variety of nanotechnology areas with a strong focus on providing the complex integration capabilities as well as the support of the SEI, Safety, Computation and other thrust areas within NNIN.

CNF has operated as a dedicated user facility since 1979. Organizationally, it is separate from other Cornell nanoscale research activities, and reports to the Vice Provost of Research. It currently has a technical staff of 21 who maintain the equipment and process base and assist users at all levels, particularly focusing on the large external user community that CNF serves. None of the technical staff are supported from competing research contracts.

CNF maintains a full spectrum of processing and characterization equipment, with particular emphasis on electron beam lithography at the smallest dimensions, and a wide array of deposition and etching resources necessary to handle the needs of variety of materials while maintaining reproducibility in an open environment. CNF has traditionally been, and continues to grow as, an interdisciplinary facility, with activities fairly evenly spread across Physics, Life Sciences, Materials Science, Electronics, MEMS, Chemistry, etc.

Users and user base

The CNF user base, one of the largest in NNIN, is comprised of approximately 50% outside users. Within the outside user base, CNF has a particularly strong outside academic user presence with users from large universities and small colleges around the country. While there has been some ebb and flow among the particular community of users, CNF's industrial user base has remained strong during the recent economic slump. CNF and NNIN remain economical alternative for new nanotechnology ventures and both academic and industrial projects continue to grow.

CNF has a steady stream of new users which peaks during the summer months and valleys around Christmas. New users are accepted into the CNF each Monday. Typically 5 new users per week are accommodated, although more are accommodated at peak times. Basic orientation and training is accomplished within two days to allow rapid initiation of projects.

Equipment and Facilities

In late 2003, CNF moved its entire operation to a new laboratory space, abandoning Knight Laboratory, its home since 1981. CNF's new space, a 16,000 sq. ft. Duffield Hall clean room, has been operational for users since Aug. of 2003. While a large set of new equipment was brought directly to Duffield Hall from April, 2004 onwards, during the period Aug-Nov 2003, each piece of existing equipment was deinstalled from Knight Laboratory, decontaminated, moved and reinstalled, while the laboratory remained, for the most part, operational for the user community. The move presented CNF with an opportunity to renew and expand CNF equipment base in selected areas, and CNF was able to take advantage of this opportunity. This large infusion of new equipment, coupled with CNF's existing equipment, and the new state of the art facilities in Duffield Hall positions CNF well for serving users in the coming years.

The new space in Duffield Hall also includes wet and dry non-cleanroom labs for CNF. These laboratories have enabled expansion of CNF's chemistry and biology support facilities.

In 2005, CNF was able to orchestrate a complete upgrade of its scanning electron microscopy facilities. These tools are particularly critical given the high resolution lithography facilities within CNF. All of CNF's existing SEM facilities were sold and two new field emission SEMs were obtained by special arrangement with Zeiss SMT. CNF now has a Zeiss Supra 55 VP and a Zeiss Ultra 55 Digital Field Emission SEMs. These instruments are identical in most respects. The Supra, however, features a Variable pressure mode for ambient charge compensation making it ideal for imaging insulating structures. On the other hand, the Ultra features an advanced in lens detector giving high elemental and structural contrast at both high and low voltages.

Zeiss Ultra 55 SEM

CNF boasts a wide variety of dry etch tools with various capabilities, a total of fifteen tools currently. In early 2005 a plan was constructed to completely revitalize this area, involving acquisition of several new (used) tools as well as reconfiguration and reassignment of existing tools. Significant progress has been made on this plan with the recommissioning of three tools, reconfiguration of one, and the purchase of three additional etch tools. Additional funding will be required, however, to fully revitalize this area. Execution of this plan will continue into 2007 .

One of the etch tools purchased is an Xactix Xetch3 XeF_2 etch system. This tool was made possible by an MRI grant in August 2004. XeF2 etch is an isotropic etch of silicon most commonly used for dry release of MEMS structures. This tool is installed and working within CNF.

Xactix Xetch3

Premier to CNF's capabilities are its two 100 KeV ebeam lithography system. The facility operates a Leica VB6 which has been in constant use since 1997. In 2004, CNF installed a JEOL JBX9300F ebeam tool. Together these tools were used by 115 different users during FY95. Users can routinely fabricate complex, multilevel patterns with 200 nm feature size and sub nanometer placement accuracy.

CNF is one of two main hubs for scientific computation effort within NNIN. The primary scientific computation resource at CNF resides on a Linux based 48 dual Xeon^{tm} node Dell cluster donated by Intel in 2004 and 2005. Dr. Derek Stewart joined the CNF staff in December 2004 to initiate the CNF scientific computation effort. Derek has configured the cluster and installed an array of solid state and chemical computation software. A significant function of the computation position is scientific support of users with computational needs. Derek has the background to interact with users at this level. In October 2005, a workshop on computational science was held at Cornell (more fully described below). Since that time usage has increased dramatically.

In support of its computation efforts, CNF also received a donation of 15 Opteron based workstations and a server from AMD

As a result of further donations by Intel, CNF expects to expand its cluster by 8 nodes and configure part of the cluster with Infiniband connectivity.

Outreach

Throughout 2004 and 2005 CNF developed a set of eight six-page color brochures covering each of the primary technical areas covered by CNF users and resources: Electronics, MEMS, Optics, Biology, Materials, Electron beam lithography, Physics, and Integrated Structures. Used individually or as a set, these brochures describe both what can and what has been done within CNF. This project is now complete. These brochures will be the centerpiece of a marketing campaign to users both in NYS and around the county.

CNF annually publishes its annual CNF Research Accomplishments consisting of research reports from many of its users. One hundred and thirty seven two-page reports are included in the 2005 edition, which is available on request from CNF or via the CNF web site.

Education

As part of the NNIN proposal, CNF committed to develop a children's science magazine relating to physical sciences and particularly nanotechnology. In 2005, *Nanooze* (http://www.nanooze.org/)made its debut as a web based magazine, with kid-friendly text, topics, and navigation. *Nanooze* is predominantly the work of Prof. Carl Batt and Main Street Science. *Nanooze* is discussed in more detail in the education report.

CNF plays a leadership role and participates actively in the NNIN REU program. In summer 2005, CNF hosted 17 students, the largest group ever, including twelve funded by NSF plus 5 minority students supported by the Intel Foundation. CNF staff also provides most of the administrative support for the entire network REU program including advertising, processing of applications, initial interaction with participants, and preparation of the REU research accomplishments.

TCN Short Course at CNF

The remainder of CNF education activities primarily involves education at the graduate and professional level. For years, CNF has offered a set of lecture based short courses, the Nanocourses, each summer. These consisted of 24 hours of lectures with printed notes, spread over the course of 3 weeks. A survey of the user community revealed that a more compact format was desired, with some laboratory activities. In response a three day short course featuring approximately 10 hours of lecture and 10 hours of laboratory demo activity was developed by CNF staff during Spring 2005. The course, *Technology and Characterization at the Nanoscale*, or TCN was offered twice; the first offering in June for 60 students and, secondly, in January for 40 participants. Participants included graduate students and professionals from around the country. Many were interested in starting user projects at CNF, or became interested. CNF plans to continue to offer this experience twice each year.

To help kick off the NNIN Scientific Computation Initiative, CNF held a workshop *Modeling the Nanoscale World*. This workshop, held in October at Cornell, featured three half days of lecture and three half days of hands-on work at workstations connected to the CNF cluster. The workshop covered the basic chemical, materials, physics, electronics, and photonics codes of relevance to nanoscale simulation which are available on the CNF cluster. Speakers were primarily the developers of the codes so the participants at all levels had expert guidance. The workshop was well received drawing over 30 participants from around the world and resulting in immediate significant growth in the use of the CNF Cluster. This workshop will be held annually at Cornell during the fall student break.

Nanotechnology lab experiences are difficult for smaller colleges with smaller lab facilities. After some discussion with staff at Clarkson University (Potsdam, NY), CNF developed a 3 day lab experience for integration into an upper level undergraduate course. This was offered for 12 students and one instructor in March 2005. The on-site lectures and lab activity built upon prior introductory work done at Clarkson. The lab activity involved soft lithographic patterning of a structure for a bioassay. This lab activity will be refined for future use throughout the network. CNF is able to work with other colleges to integrate this or a similar activity into appropriate course work.

SEI Activities

Responsibility for coordination of network SEI activities resides with Prof. Bruce Lewenstien of Cornell, assisted by Dr. Anna Viseu, CNF Staff. The coordination activities are described in the SEI section of this report. Much of the CNF activity supports the expansion of the SEI web archive of research materials. CNF hosted a seminar "*Social Dimensions of Nanotechnology: Rethinking Research in a Changing Context*" by Dr. Robert Doubleday, Cambridge. CNF speakers also participated in the conference *"Science for Sale? The Public Communication of Science in a Corporate World"*, held at Cornell in April 2005. Prof. Lewenstein and Dr. Viseu hosted an NNIN REU student in both 2004 and 2005 exploring the Social and Ethical issues of Nanotechnology. An effective video on SEI from the students' point of view resulted from this project in 2005. It will be used to seed discussion in future REU programs.

CNF Web Site

CNF deployed a completely new, database driven web site in 2005, located at http://www.cnf.cornell.edu. The primary goal of the new web site is to make accurate and extensive process and equipment information accessible to users.

Staff

CNF has a staff of 28 technical and administrative professionals, all dedicated to CNF/NNIN user functions. In general, there is only small annual turnover in the staff.

In January 2005, Dr Anna Viseu joined the CNF staff to support CNF and NNIN activities associated with the Social and Ethical Implications of Nanotechnology. Dr. Viseu, a native of Portugal, has a Ph.D. degree in Human Development and Applied Psychology from the

University of Toronto. She works under the direction of Prof. Bruce Lewenstein of the Dept. of Communications, NNIN SEI Coordinator.

In Jan. 2006, Michael Guillorn, Ph.D, left CNF for a position at IBM Watson Research. Mike had only been with CNF for two years but had been a CNF user for 5 years prior to that so he brought a unique perspective to the staff. Mike supported CNF users in a broad range of lithography and process integration and served as a technical liaison within NNIN for materials characterization.

During 2005 Prof. Sandip Tiwari stepped down as Director of CNF while retaining Directorship of NNIN. He is currently on sabbatical at Harvard. In October, Prof. John Silcox, Applied and Engineering Physics, assumed Interim Directorship of CNF. Prof. Silcox has been associated with CNF since its formation as NRRFSS in 1979. John previously held positions as Vice Provost for Physical Science and Engineering at Cornell, Director of the School of Applied and Engineering Physics, and Director of the Cornell Center for Materials Research. Simultaneously, Dr. Jurriaan Gerretsen joined as Interim CNF Associate Director (50% time). Dr. Gerretsen is also Associate Director of the Cornell Center for Nanoscale Systems (CNS), an NSEC. The search continues for a "permanent" CNF Director.

A1.2 Stanford Site Report

Technical and Staffing Highlights

During the past year, SNF has lost our financial services administrator Jane Edwards and replaced her with Ms. Cam Chan.

For much of the past 2 years, industrial usage of our facility has fallen significantly while academic usage has continued to grow. We believe that this is largely the result of the economic conditions in California and have seen that a number of startups have either failed or at least downsized their efforts. Both of these factors have contributed to the reduced levels of industrial usage of SNF as compared to previous years. Most significantly, because industrial users at SNF pay user fees that are approximately twice those of academic users, this drop in industrial usage has had a dramatic impact on our laboratory finances. In order to return to a balanced budget, we increased the monthly equipment charge cap for both academic and industrial users on January 1, 2005. The hourly rate charged to users was not increased because we do not want to discourage users who may make only modest use of our facilities. It has been our experience that users from new disciplines often fall into this category and we wish to continue to make is as easy as possible, both logistically and financially, to make use of our facilities. While academic usage under this new rate structure has continued to increase, industrial usage of SNF has experienced a further drop. For example, during the period of March, 2004 to December, 2004, we had 294 cumulative local users, 75 cumulative other academic users, and 135 cumulative industrial users. During the same 10 month period of 2005, the number of cumulative users increased to 365 local users and 84 other academic users, even though academic users experienced a modest increase in their monthly cap. During that same period, however, the cumulative number of industrial users fell to 115. Expressed as hours of equipment usage, industrial usage has fallen nearly by 50% (2830 average hours for Mar – Dec 2004 vs. 1530 average hours for Mar – Dec 2005.) during that same time period. It appears as if our rate increase was of significant magnitude to force a number of our industrial users to look elsewhere for their processing services. We are currently studying this situation and exploring ways to attract more industrial users back to SNF.

During the past year, we have released several tools that make SNF more attractive to a broad range of users. Included amongst these new capabilities are:

1. A Nikon Body 9 stepper that allows the development of patterns as small as 0.35 – 0.40 μm. This instrument has completed initial characterization and is now being used by a small community of users.
2. A SCT sputtering tool that will broaden the range of metals that can be sputtered in our laboratory. This tool has been released for usage by our user community.
3. A second STS deep silicon etcher has been characterized and released to the user community. This tool uses the Bosch process to allow high-rate (3.0 – 5.0 μm/minute) etching of single crystal silicon and is a popular tool for many members of the MEMS community. Our staff is currently training people in the use of this tool and is helping them to migrate their recipes from the original STS machine to this newer, high-rate etcher.
4. An Electronic Visions Nanoimprint Lithography tool has been acquired for our facility. This is the first NIL tool at SNF and will complement Nanoimprint Lithography tools at Cornell and at the University of Texas within the NNIN.
5. We have installed and characterized an atomic layer deposition (ALD) tool for use in depositing very thin layers of Al_2O_3. This equipment is just beginning to be used by members of the user community and we are also beginning to explore the use of this tool for depositing dielectric layers other than Al_2O_3.
6. We have installed and are currently characterizing a chemical/mechanical polishing (CMP) tool. This will initially be used for planarizing oxide structures.

Dr. Ed Myers has significantly streamlined our New Materials Committee in an effort to more efficiently handle requests to support new materials in SNF. In particular, he has insured that the committee meets every two weeks and taken steps to insure that individual requests do not get forgotten. As a result, we believe that we are doing a better job of handling requests to process new materials in our facility.

Education/Outreach Activities

1. SNF's Education Director, Marni Goldman, who is also Education Director of CPIMA (Center on Polymer Interfaces and Macromolecular Assemblies) attended meetings with other NNIN education directors to better coordinate efforts between sites as well as with other NSF Research Center Educators (NRCEN) and the Nanoscience Informal Science Education (NISE) kick-off meeting.
2. SNF participated in the NNIN Research Experience for Undergraduates program, involving the 12 NNIN sites that included another group of 12 students working on projects supported by 8 different faculty members. Stanford hosted the Convocation at the end of the summer that was attended by all 75 NNIN REU students.
3. SNF continued its Research Experience for Teachers (RET) program this past summer. This year we had three teachers (two funded by NNIN) working under the RET program. Two of the teachers were mentored directly by SNF staff. All teachers were part of the new Stanford Summer Program for High School Science Teachers in which the participants spent Tues.-Fri. working on individual mentored research projects in labs

throughout campus and Mon. together as a group listening to faculty talks, touring facilities (including SNF one Monday) and pedagogical activities meant to help them translate what they were experiencing to their teaching

4. SNF took part in Stanford University's annual Community Day in April. As part of Stanford's effort to educate the surrounding communities about what is happening on the campus, SNF staff set-up and manned displays and demos about the Stanford Nanofabrication Facility and NNIN. Included was an activity in which kids put on cleanroom suits and got their names and photos printed on SNF "Junior Nanoscientist" certificates, as well as a "Look into the NanoWorld" micrsocope activity.

5. SNF continued its work on the Nanoleap NIMD project (http://www.mcrel.org/nanoleap-review/index.asp) in collaboration with Mid-continent Research for Education and Learning (McREL) and Aspen Associates was continued. The project is to develop two high school curriculum modules that address nanoscale science, technology, engineering, and mathematics (STEM) standards as well as accompanying resources and professional development for educators to facilitate implementation of the modules. This year SNF reviewed the initial content for each module. We also participated in a meeting with teachers chosen to assist with the modules for a remote question and answer session and a remote access demo (see below). Currently, we are soliciting other NNIN sites who wish to help with this project through content review and/or remote access.

6. SNF education web pages were developed that describe all the programs above as well as provide a virtual tour of SNF and links to other sites of interest.

7. Mary Tang of SNF organized the NNIN "Nanosafe" workshop, presenting and discussing issues in nanofabrication safety, held at Georgia Tech last May. NNIN personnel, NSF representatives, and lab managers from across the country attended.

Remote Users/Access

1. Number of remote users for last 10 months: 40 (19 industrial, 21 other academic). Of those, 7 were through MEMS-Exchange.

2. SNF staff did another remote demo for the McREL/SNF "Nanoleap into New Science" program (see Education section of this report). 15 master teachers (high school level) who were selected to participate in the program design process were given a live, remote lab tour from inside the cleanroom. Then we webcast a live demo of SNF's atomic force microscope (AFM) from inside the cleanroom, showing live images of setting up and operating the AFM, and then live screen shots of images acquired from the AFM. The teachers also asked questions about working in the cleanroom and nanotechnology. As part of the high school module developed by this McREL/SNF program, we plan to develop a remote access component in which live images from inside the SNF cleanroom are webcast to high school classes. We have also recently gotten agreement from 3 other NNIN sites (Georgia Tech, Minnesota, and Washington) to try out their remote access tools (including remote SEMs, AFMs, and cleanroom webcams) for possible inclusion in this program.

3. We have renewed our contract with CNRI to remain a member of the MEMS-Exchange for remote fabrication. However, due to the maturity of the program, we will only charge

them for work done on user runs, and not for extra salary for program development as we have done in the past.

4. We have organized a NNIN Remote Users Steering Committee which includes staff from 9 of the NNIN sites. The goal of this is to facilitate transferring wafers from one site to another for selected fabrication steps done on a "remote basis" (i.e. in which the staff does the processing for the lab user). This would be necessary if the lab user can not perform the fabrication at the site he/she is working at, due to lack of specific fabrication equipment or capability at the original site, or due to temporary downtime of a piece of equipment. Issues that will be considered include: contamination, cleaning procedures, paying methods, and requests/communication protocols. We have recently set up a system at the NNIN website to request processing on a remote basis from other sites, including methods for communicating contamination issues and protocols. This should greatly enhance the ability of the network to take advantage of its extensive and diverse processing capabilities.

Societal and Ethical Implications of Nanotechnology

Professor Robert McGinn has begun his activities at SNF and has worked closely with SNF staff members to develop a survey related to beliefs and background related to ethics in nanotechnology. The on-line survey is available via Survey Monkey and takes approximately 30 minutes to complete. Over the course of the summer, Professor McGinn distributed his survey to most of the NNIN sites after having gotten approval to distribute this survey by the appropriate human subjects committee at each institution. Thus far, he has received over 1000 responses. He is in the process of analyzing that data and expects to have a preliminary report based on the results of that survey in the near future.

Computational Infrastructure

Dr. Zhang at Stanford (working for Professor KJ Cho) is setting up a training program to instruct users in the proper use of a DFT (Density Functional Theory) simulation package. Once this training program is complete, he will be working with Dr. Michael Stopa at Harvard to make sure that it is available to the NNIN user community.

A1.3 Georgia Tech Site Report

Georgia Tech NNIN Facilities

The Microelectronics Research Center (MiRC) provides expertise, facilities, infrastructure and teaming environments to enable and facilitate interdisciplinary research in micro- and nano-electronics, integrated optoelectronics, and microsensors and actuators. The MiRC, housed in a 100,000 square foot building and a 20,000 square foot annex, provides facilities including six electronic and optoelectronic materials labs, eight labs for microelectronics design and testing, eight labs for electronic device design and testing, and a 7,000 square foot cleanroom providing complete micro- and nano-fabrication facilities.

The Nanotechnology Research Building (NRCB) is currently 100% complete with construction drawings. Utility relocation is underway. Demolition of the Electronics Research Building and reactor dome is due to start mid February. Building completion is targeted for January 2008

New Equipment and Capabilities

The Karl Suss MA/6 mask aligner with DUV capabilities offers standard front-side illumination (no back-side IR illumination) for substrates up to 6-inch diagonal. A variety of mask holders can accommodate masks from 4 to 7-inch with "exposure windows" of 2, 3, 4, and 6-inch diameters. The mask aligner can expose at either 220nm (CI1) and 320nm (CI2) wavelengths with the mercury lamp. Exposure can be performed in soft contact, hard contact, proximity, vacuum, and low vacuum modes.

An Obducat Nanoimprint Lithography (NIL) system was delivered and installed at the Georgia Tech Microelectronics Research Center (MiRC) in July of 2005. The system enables a low-cost process of mass replication (batch fabrication) of nanoscale and microscale structures. This tool, along with the MiRC's state-of-the-art electron beam nanolithography facility allows MiRC users the rare opportunity to have in one facility the ability to design and fabricate sub-20nm stamping templates and use them for nanoimprinting. The system features a 6" chamber, UV exposure module, automatic demolding, and a heated stage. The maximum temperature and pressure that can be applied during the imprint process are 300°C and 80 bar, respectively. The imprint process works by applying a pneumatic force (and temperature when needed) on a template that is positioned above a substrate (typically Si wafer) with a thermoplastic or UV curable resist. Following the imprint process, the template is removed from the substrate leaving behind the deformed resist. Subsequent processes, such as a dry etch, are used to pattern the underlying material. Imprint technology has also been used to fabricate a wide range of devices such as polymer optical waveguides and fluidic channels.

Two new Kurt J. Lesker multi-technique systems were installed in the MiRC to be used for sputtering, e-beam, and thermal evaporation. The tool features an integrated touch screen control, standard 250 L/sec turbomolecular pump with throttle plate pressure control, 2 sputter guns for muti-layer depositions and a removable substrate heater with a maximum temperature of 600° C.

Conversion of the existing CVC RF Sputterer to a PLC based, DC sputtering system that will hold (4) 4" targets and process up to a 6" wafer capabilities was begun and will be completed by March 2006.

A new P15 KLA/Tencor profiler with extended range capabilities was installed for use in MEMS device characterization

New Cleanzones Polypropylene Fumehoods were installed to replace and upgrade the fumehood capabilities of the MiRC.

A number of system upgrades were made to the website to enhance user capabilities. Upgrades were made to the cleanroom billing program, the cleanroom training program, the PI authorization, the equipment scheduler program, and the overall look and feel of the website. Process control charts are being added to provide baseline data on key equipment, and new training videos were added for the STS PECVD, CEE Spinner, and PVD75 Filament Evaporator.

Efforts and Success at Expanding User Base

During 2005, Georgia Tech MiRC, as part of the NNIN outreach efforts, has increased the number of external users by 114%. The increase in usage by External Academic users was 106% and the increase in usage by Industrial users was 130%. The MiRC ended December with 60 users from industry and universities other than Ga. Tech.

As part of the outreach efforts, the MiRC provided a booth at the Florida Chapter of the American Vacuum Society. The booth provided potential users of the MiRC with information about the NNIN user program, educational opportunities, and clean room user opportunities. The MiRC also provided a booth at the 2005 NSTI BioNano Conference in Anaheim, California.

The MiRC co-chaired the Oak Ridge Associated Universities Partners in Technology Forum, where we were also able to present to over 100 regional researchers in the area of nanotechnology.

The MiRC also hosted the Nanotechnology Processing Workshop, which drew 11 graduate student researchers from Southeastern Universities: Ga. State University, University of Alabama, University of Alabama-Birmingham, University of Georgia, Alabama A&M University, Auburn University, Florida International University.

The MiRC ran 5 equipment training workshops during 2005: Advanced Silicon Etching Workshop, ST Systems, August 9-10, 2005 (10 attended), WiTec Confocal Raman Microscope Demo Workshop, July, 2995 (15 attended), Veeco AFM Equipment Demo Workshop, June, 2005 (10 attended), High School Atomic Force Microscopy Demo Workshop, May, 2005 (25 attended), NanoCamp Atomic Force Microscopy Demo Workshop, June, 2005 (35 attended).

Other outreach efforts included visiting and lecturing to Southeastern universities about the NNIN and how researchers from other colleges can use the NNIN resources. Presentations were made at GA State University, Clark-Atlanta University, Morehouse College, University of Georgia, Emory University, Wake Forest University, University of Louisville, Clemson University, Auburn University, and the University of Alabama.

The MiRC launched a bi-monthly newsletter titled “GT NanoNews”. There have been 2 editions to date, each with direct mailings to 500+ researchers in the Southeast. In addition, direct mailings of NNIN brochures were sent out to over 700 researchers in the Southeastern United States.

Technical Highlights and Accomplishments:

Emory and Georgia Tech were named one of the Centers of Cancer Nanotechnology Excellence by the National Cancer Institute. The MiRC contributed to the proposal submitted by Dr. Shuming Nie (Emory/GT) and will contribute the MiRC resources in the research of nanoscale devices for the detection of cancer indicating proteins so that cancers can be predicted, detected earlier and treated more effectively.

The acquisition and installation of MiRC’s JEOL JBX 9300FS electron beam lithography (EBL) system in March 2004 has enabled unprecedented research. Prof. Mostafa El-Sayed (GT Chem) has demonstrated electrodes with a gap of 3.19 nm for the detection of single molecules. Such small gaps between electrodes enable hazardous substances such as Cyanide and Anthrax to be confidently and efficiently detected below the infectious concentration.

The EBL system has also enabled the semiconductor industry, through R&D performed at International Sematech, in Austin, TX, to investigate the effect of interconnect line scaling. MiRC has drawn serpentine interconnect line test structures of 30 nm for ISMT.

Greyscale Lithography capability is being developed at the MiRC. There has been significant interest from Brandywine Optics, Inc. and NovaSol in using the EBL capabilities of the MiRC, and having a greyscale lithography process in house will greatly increase the external user base of the EBL system.

The EBL system now includes the capability of alignment of small substrate sample pieces. The alignment system consists of a high precision stage and a microscope. The EBL system requires less than 1 degree of rotation of the sample when aligning one layer to another. The alignment system enables easy alignment of small samples to meet these limits imposed by the EBL system.

The MiRC's Adjunct Staff Physician, Dr. Jaswant Chaddha, has engaged with the medical staff of Cobb WellStar Hospital regarding educational programs on Nanotechnology and introducing nano to Physicians of various specialities. He has also engaged with Dr. Shuming Nie (Emory/GT) in his project for using a nanoparticle gel/spray as a non-invasive method of diagnosing and treating breast tumors.

Professor Anil Cashikar from the Medical College of Georgia's Institute of Molecular Medicine and Genetics, Molecular Chaperones and Radiobiology Program, has begun using the MiRC's atomic force microscope (AFM) to investigate neurodegenerative diseases such as Alzheimer's, Parkinson's and Huntington's disease. Conformational changes in proteins and polypeptides, including misfolding and aggregation, indicate the presence of proteinaceous inclusions and amyloid deposits characteristic of these neurodegenerative diseases.

Dr. David Wilson, of Georgia State University, is using the AFM to determine the effectiveness of various drugs to alter the shape of disease DNA which will prevent the disease from reproducing

NNIN Personnel Hiring:

The MiRC has hired Dr. Paul Joseph (previously a researcher with Ga. Institute of Technology) as a NNIN process domain expert in the area of Bio-related sciences. The addition of Dr. Joseph provides the NNIN and the MiRC with bio-domain expertise.

Education and Outreach Activities:

Georgia Tech hosts the NNIN's Education and Outreach office. This benefits our site's local efforts because the national coordinator is in constant communication with NNIN sites and other national initiatives. From this she learns about great education models and approaches as well as instructional materials that are shared with the Assistant NNIN Education coordinator at our site who focuses on Georgia Tech initiatives.

During the past year nearly 700 K-12 students have participated in NNIN activities at our site. Several school groups have visited for hands-on activities and lectures that introduce them to nanoscale science and engineering. For example, in March 2005 over 300 middle school students and teachers participated in a two-day event titled "NanoInfusion." Over 70 volunteers from 15 research labs on the Georgia Tech campus provided hands-on activities, lab tours, and career information. The event culminated with the students creating short advertisements about "nanoproducts" based on what they had learned during their visit. We filmed these and shared them with the school. Staff has also visited metro Atlanta schools to provide demonstrations, lectures, and participation in school career days. During summer 2005 we hosted a high school intern for seven weeks who evaluated instructional materials, learned to use cleanroom equipment, and undertook experiments in the cleanroom. We also offered for the second year our week long summer high school nanocamp for 35 high school students. Students are engaged in hands-on activities, lab tours and lectures, and career information.

Our site hosted six NNIN REU students (4 females and 2 males) from Johns Hopkins, Clemson, University of Virginia, Rice, University of Florida, and Vanderbilt. These students had joint workshops/seminars with Georgia Tech's SURE program, an REU program for underrespresented students run by the School of Electrical and Computer Engineering. A description of their research projects can be found on the NNIN REU web site.

The graduate student volunteers who participated in NanoInfusion requested that we develop a formalized network to continue their interaction with fellow nanotechnology graduate students at Georgia Tech and Emory. As a result, we organized Nano@Tech which has more than 100 members. The group meets monthly for seminars (from leading GIT nano researchers), lab tours, and networking. In addition, they are developing an equipment list for dissemination that will provide information on equipment available across the nano research labs on the two campuses. This organization also developed a subgroup called NanoPartners who volunteer to assist in K-12 and community group presentations. They had their first training on January 24, 2006.

Our site hosted and supported two teachers for the Georgia Intern-Fellowships for Teachers (GIFT) program which is a collaborative effort designed and run by Georgia Tech's Center for Education Integrating Science, Mathematics, and Computing. The program seeks to enhance mathematics and science experiences of Georgia teachers and their students. The teachers spent seven weeks at our facility where their research established growth and characterization methods for plasma enhanced chemical vapor deposition. The teachers developed an implementation plan on how they would incorporate their experiences into their classrooms.

REU Summer Experience:

Georgia Tech (Microelectronics Research Center (MiRC)) participated in the NNIN network-wide REU program during summer 2005. The project supported 6 undergraduate students from a variety of institutions from across the United States. Each student conducted a real research project in nanotechnology as a member of an established research team at Georgia Tech. Students worked with a faculty mentor and a graduate student mentor and experienced research with state-of-the-art instrumentation.

RET Program:

Two Georgia high school classroom teachers were incorporated into the MiRC's research program for an 8-week summer experience for teachers (RET). Both teachers worked on PECVD of SiO_xN_y and used the experience to develop teaching material for their high school science classes at Cedar Grove High School.

Societal and Ethical Implications:

The MiRC and Professor Marie Thursby hosted the Spring '05 meeting of the NNIN SEI team to promote collaboration among SEI investigators across sites. Georgia Tech administered two SEI projects during 2005: a Harvard Business School case on issues in university-industry collaboration in nanotechnology and research on the productivity of large firms in nanotechnology. Prof. Thursby and Prof. Frank Rothaermel also published a paper titled "Creating Intellectual Property in New Technologies: Evidence from Biotech and Nanotech", which analyzed how large firms have created IP portfolios in the nano area and how this differs from the biotech revolution.

A1.4 University of Michigan Site Report

Site Description and Technical Capabilities:

The Michigan Nanofabrication Facility (MNF) (formerly called the Solid-State Electronics Laboratory, SSEL) provides users with access to technologies and materials covering all aspects of micro and nano technologies and nanosciences. The principal focus of the MNF under the NNIN program is to provide facilities and processes for the integration of Si integrated circuits and MEMS with nanotechnology, with applications in integrated sensors/actuators, microsystems, biology, medical microsystems, chemistry, and environmental monitoring. At the present time, micro and macroscale devices are often needed to provide interfaces between experimental nano devices and the macroscopic world. Even with revolutionary developments at the nanoscale, practical realization of nanotechnology-based systems will require this type of micro/nano integration. The MNF will continue to build on its experience in integration of Si-based electronics with MEMS transducers and micropackaging to push these interfaces into the nanometer regime with emphasis on the fabrication, packaging, and testing of integrated devices for chemical and biological sensing, electrical stimulation of biological systems, and integrated fluidic systems. Michigan has been one of the leading centers worldwide on MEMS and microsystems and is the home of the NSF ERC on Wireless Integrated Microsystems (WIMS).

Facilities, Services, Equipment

The MNF facility consists of a 6,000 sq. ft class 100/10 cleanroom backed by ~25,000 sq. ft. of support facilities. It contains five process bays (silicon lithography/diffusion, silicon LPCVD, compound semiconductor devices, thin-film deposition, and dry etching) plus five connected rooms for e-beam lithography, metrology, and III-V materials growth. In-house metrology includes SEM, spectroscopic ellipsometry, Hall, AFM, and profilometry. Further characterization facilities are available through the U of M Electron Microbeam Analysis Laboratory (EMAL) and the Hannawalt X-Ray Diffraction Laboratory, which include FE-SEM, Auger, XPS, TEM, and high-resolution X-Ray diffraction and grazing-incidence X-ray reflectometry. Dr. John Mansfield, the manager of EMAL, has agreed to serve as a domain expert for NNIN in the area of nanostructural and nanochemical analysis of materials via transmission electron microscopy, scanning transmission electron microscopy, scanning electron microscopy, X-ray energy dispersive spectroscopy, electron energy loss spectroscopy and electron diffraction. Dr. Sandrine Martin, the NNIN technical coordinator at the MNF, will serve as a domain expert for organic semiconductor materials and electronics. In addition to EMAL, the Michigan Ion Beam Surface Modification and Analysis Laboratory (MIBL) provides additional metrology capabilities such as Rutherford Backscatter Spectrometry, Nuclear Reaction Analysis and Elastic Recoil Detection. U of M NNIN staff will assist users with this full battery of characterization tools.

The University of Michigan is home to the MGRID, a networked computational resource that could be used to attack complex computational problems facing the nanoscience community. The director of MGRID, Dr. Tom Finholt, will coordinate the requests that come from outside users for MGRID use and discussions are underway to integrated MGRID into the larger NNIN computational programs as needed.

During the last year we also continued our efforts in creating a unified online system for users to be able to look up all information pertaining to the MNF and for MNF staff to collect and maintain necessary data on users and equipment. Our system of charging users will be changing in 2006 from a monthly rate to an hourly rate based on equipment use, in order to make the MNF more affordable to less frequent users. The development of the fully automated online system for lab access, equipment training, user data tracking, accounting and charging continued in 2005. A custom scheduler was developed that supports tool interlocking by way of network-based interlock devices. A new website that describes SSEL, the MNF and the NNIN programs at Michigan was developed and released. Plans for the coming year include further feature enhancements and implementation of fail-over capabilities to ensure 24/7 operation.

The MNF is making progress towards expansion of its cleanroom. Groundbreaking for the new cleanroom was in April 2005, and the projected completion date is 2007. The new expansion will add 4000 sq. ft. of Class 10/Class 100 cleanroom space, and will increase our processing capabilities to include 6” wafers, and new materials and processes.

New equipment was added to the MNF in 2005. We have acquired three new SUSS MicroTec tools to enhance our capabilities in contact lithography, and low-temperature wafer bonding. These tools will be of use in applications such as wafer level integration of CMOS and MEMS or CMOS and nanoscale devices, polymer bonding and material transfer for a variety of MEMS and bioMEMS applications, as well as heterogeneous integration of different devices and materials. They are described below:

- **SussMicrotec nanoPREP 12 Surface Plasma Activation tool**: Allows users to bond wafers at lower temperatures (as low as 200°C) and pressures than previously possible.
- **SussMicrotec CL200 Cleaner and Fusion Bonder:** Allows users to clean single masks and wafers using megasonic and chemical cleaning and/or to clean two wafers simultaneously and prebond them in preparation for direct wafer bonding.
- **SussMicrotec SB6e Substrate Bonder**: Allows wafer-to-wafer bonding for all types of wafers and substrates, using anodic, eutectic, adhesive, fusion, or thermo compression bonding.

User Outreach, Training, and Support

One of the most important changes that the NNIN program has brought to the Michigan site has been the ability to better support and train users. Having added personnel to the process staff, we are now able to meet the training needs of new and existing users. Any new user who does not have a mentor is assigned one from the MNF staff. The mentor shows the new user how to use the clean room, the process equipment, and the online systems. The new user may work with their staff mentor for as long as they need to meet their training requirements. We have also established a rotating schedule of staff-led training classes on operating process equipment. The added staff members have also allowed us to increase and improve the quality of lab documentation available online. To assist MNF users from other institutions, we offer information on housing, parking, and transportation, and provide them office space and access to computers, CAD tools, and Internet.

We have continued to make efforts on behalf of the NNIN to publicize the objectives of the NNIN and inform potential users about its technical capabilities. We have done this by giving talks at meetings and other institutions, and creating and distributing written material on the NNIN and MNF. User outreach activities conducted in 2005 are summarized below:

- Distribution of NNIN at Michigan brochure: about 1000 potential users reached
- Michigan Small Tech Association, 5th Annual Emerging Industry Symposium: The Business Reality of Micro and Nano Technologies, March 2005 (Oral presentation by F. Terry and visits of MNF, 200 attendees)
- Mailing of brochure to 250 potential external users (May 2005 – mostly academic)
- 4th International Dendrimer Symposium, May 2005 (brochure & material available in booth)
- Michigan Small Tech Association and Automation Alley meeting, Micro and Nanotechnology: How Small Tech is Changing Business, June 2005 (Oral presentation by S. Martin, 50 attendees)
- Compilation of report on research activities of the Solid State Electronics Laboratory and distribution to some 400 people
- Michigan State University, July 2005, (oral presentation by K. Najafi, 45 attendees)
- Western Michigan University, October 2005 (oral presentation by D. Grimard, 30 attendees)
- Stanford University, meeting with Korean researchers, Oct. 2005, (presentation by F. Terry)
- American Chemical Society meeting, October 2005 (oral presentations by F. Terry and D. Grimard), 100 attendees).

In addition, in July 2005 we held a free, 1-day workshop entitled "Introduction to Micro and Nanofabrication Technologies." Twenty-five people attended the Worskhop, including people from industry, and undergraduate and graduate students from four-year colleges and universities. The morning session consisted of classroom instruction on fundamentals of micro and nanofabrication techniques. The afternoon consisted of hands-on sessions in the cleanroom covering optical lithography and RIE, UV imprint lithography, and pattern generation and mask making.

We have a diverse user base, both in terms of research area and institution. 34% of our users are from outside the University of Michigan, and of those 15% are from other academic or research institutions and 19% are from industry. The cumulative number of users for March to November of 2005 was 321. We have an average of 112 active users/month, who use the cleanroom for an average of 3279 hours/month (i.e., 31.2 hours/user/month). From March-November 2004, the cumulative number of external users at Michigan was 6; in comparison, from March-November 2005, the cumulative number of external users was 15.

The majority of our current users are on-site, but the MNF also serves a number of remote users through both the NNIN and DARPA's MEMS Exchange programs. From March to November of 2005, the MNF completed 25 remote runs, using about 180 hours of lab time. In addition, we have been participating in the remote users steering committee, which is developing policies regarding remote usage.

Education, Outreach, and SEI Activities:

In 2005, the Michigan site put a great deal of effort into developing and conducting education and outreach activities. The activities are summarized below.

Pre-college

- Microfabrication technology experiences, March 2005. 45 middle school students (Forsythe Middle School, Ann Arbor, MI) participated in clean room activities on micro/nano fabrication technology:
    - 56% girls, 4% minority students
    - Students performed photolithography, etching and metal deposition. Each student left with one patterned, personalized wafer (see photo).

- Microelectronics and Nanotechnology experiences, April-May 2005. 40 high school students (Holy Redeemer High School, Detroit, MI) and 20 middle school students (Forsythe Middle School, Ann Arbor, MI) participated in several activities:
    - 41% girls, 56% minority students
    - Microfabrication technology in the clean room: students performed photolithography, etching and metal deposition steps.
    - Introduction to nanotechnology in classrooms: hands-on experiences on size and scale, Lego models of photolithographic process, clean room gowning race. Each student left with one patterned, personalized wafer.
- Liquid nitrogen experiments conducted at Forsythe Middle School, Ann Arbor, MI. MNF staff provided directions and guidance on how to handle liquid nitrogen (safety precautions, equipment and tools needed), supplied liquid nitrogen, and assisted teachers in developing experiments.
- Collaboration with NSF WIMS ERC, June-August 2005. 100 high school students participating in several summer programs (DAPCEP Detroit-Area Pre-College Engineering Program, WIMS for teens and Women in Engineering) were also able to go in the clean room and learn briefly about micro/nano fabrication.
- Tech Day, November 5th, 2005, an engineering fair organized by the U of M College of Engineering for ~800 high school students and their parents. The MNF had an exhibit of MNF and NNIN information, semiconductor wafers and devices that participants could handle, and several "Nano Product" displays developed by Penn State University. Tours of the MNF were given to about 150 high school students.

- Visit by George Washington Carver Academy, High Park, MI, November 10, 2005. Middle school students were given a tour of the MNF instructional laboratory and Prof. Emmett Leith's optics research lab.
- A workshop was held at the Michigan Nanofabrication Facility on January 19th, 2006 for about 15 K-12 teachers and principals. It included a brief overview of micro and nano technology, some hands-on activities in the clean room and a discussion of non-clean room activities (both onsite and in the classroom) to introduce students to nanotechnology.

College: NNIN REU program

- The University of Michigan hosted five undergraduate students during the 2005 summer. They performed research projects in the departments of the Electrical Engineering and Computer Science and Materials Science and Engineering. Projects were very broad in nature and touched upon several technical areas:
    - Biomedical engineering (Fabrication of nanostructured conducting polymer films on the surfaces of neural prosthetic biosensors; a microfluidic system for the assembly and culture of tumor spheroid);
    - Nanofabrication (Characterization of nanoimprinting of HSQ material);
    - Computation (Computational studies of quantum dot formation and morphological evolution);
    - Materials science (Fabrication of Hall bars to characterize dilute nitrides).
- Students also participated in several other activities at the site level (in addition to the network-wide webcast seminars and the REU convocation): lab tours and discussions about career plans at a local pharmaceutical company R&D lab (Pfizer), weekly technical meetings, final presentations of research accomplishments to all PIs and NNIN site senior staff, director and deputy director.

Staffing Report. Level and Changes, Organization

The main personnel of the Michigan site have continued in their positions. Prof. Najafi and Terry continue to serve as the Michigan site's director and deputy director, and Dr. Dennis Grimard is the manager of MNF and serves as the manager of NNIN at Michigan. During this second year, we hired one new staff member whose main duty is to support laboratory users and their research. In addition, we re-assigned several of our existing staff members so that we are better able to meet the training and mentoring needs of new and existing users, especially external users. A new IT engineer has also been hired to support the increased development of our automation system and web-based tools available to the laboratory users. Finally, a graphic designer contributes 50% of her time to the development of publicity material for NNIN and various announcements (workshops etc). Dr. John Mansfield, the manager of EMAL has agreed to serve as a domain expert for users needing assistance in characterization services offered by EMAL. During Fall 2005, our NNIN technical manager, Dr. S. Martin took a maternity leave and was replaced temporarily by Dr. Nadine Wang. We anticipate to reassign one additional process engineer (currently on our staff working on other projects) to help with he increasing demand of external and internal users.

A1.5 University of Washington Site Report

Mission and Scope

The University of Washington NanoTech User Facility (NTUF) was established in 1998 through a $500K yearly award to the Center for Nanotechnology (CNT) to provide the Pacific Northwest nanotechnology community with access to advanced characterization and nanofabrication equipment. In 2004, NTUF expanded its role to the national level by becoming one of 13 nodes of the National Nanotechnology Infrastructure Network (NNIN). NTUF's mission within the NNIN network is to provide access to emerging nanoscale tools with an emphasis on the applications of nanotechnology in biology and life sciences. NTUF operates as an open, hands-on facility available to academic and industrial users nationwide.

NTUF houses leading-edge instruments for characterization and fabrication at the micro- and nanoscales. Imaging tools include a Leica inverted fluorescence microscope, a Renishaw inVia Confocal Raman Microscope, a two–photon ready Zeiss LSM510 laser scanning confocal microscope, an FEI field-emission SEM with energy dispersed spectrometer, a Vecco Bioscope Scanning Probe Microscope (SPM), a Veeco Dimension 3100 SPM, and a Multimode SPM. Fabrication tools include soft lithography for rapid prototyping and a Nabity system for Electron-Beam Lithography.

NTUF plays a crucial role in the University of Washington (UW) dual Ph.D. degree in Nanotechnology, which is supported in part by a NSF-NCI Integrative Graduate Education and Research Traineeship (IGERT) award. Our highly motivated technical staff consists of three Ph.D.s and three research engineers with expertise across broad spectrum of disciplines. We draw upon this expertise to offer a superior learning, working and problem-solving environment. We have designed and implemented training programs that allow users from different disciplines to master the operation of our sophisticated tools after a few hour-long training sessions. The facility is accessible to qualified users on a 24/7 basis. In addition, our team can perform projects for remote users and provides a variety of micro- and nanofabrication services. Through courses, training and close interactions with users, NTUF has created a learning environment that fosters interactions and synergies among users from different disciplines.

NTUF brings exceptional value to the nanotech faculty from UW's Schools of Medicine and Pharmacy, the College of Engineering, and College of Arts and Sciences. It also supports the mission of several UW centers including the Genetically Engineered Materials Science and Engineering Center (a NSF-MRSEC), the Microscale Life Science Center (a NIH-CEGS), and the Center for Materials and Devices for Information Technology Research (a NSF-STC)

Technical Highlights

Through the use of NNIN and CNT equipment funds, a successful NNIN-MRI, and UW matching funds, NTUF added three new instruments to its inventory in 2005.

1. Zeiss LSM 510 Confocal Microscope with integrated Veeco Bioscope Scanning Probe Microscope - To meet the increased demand of biological science users for cell and tissue imaging, NTUF acquired a Zeiss LSM 510 laser scanning confocal microscope in April 2005. The system allows optical sectioning of whole specimens of cells and small organisms, such as developing embryos, and that of very thick sections from bone, brain, and other organ tissues that have been tagged with fluorescent or reflective probes. Success in the NNIN-MRI 2005 competition led to the purchase of a Veeco Bioscope scanning probe microscope that was integrated with the Zeiss confocal system in December 2005. This combination of instruments enables users to perform in-situ confocal microscopy and force measurement on biological species. Applications range from the study of ligand-receptor interactions to DNA melting, protein unfolding and colloidal forces measurements. We believe that this unique capability – the only one in the NNIN network and one of the few available in the US – will become a major asset in support of nanobiotech research across the nation.

2. Renishaw inVia Confocal Raman Microscope - Raman spectroscopy provides information on the chemistry and structure of materials in a non-contacting, non-destructive manner by analyzing the frequency shift of scattered laser light caused by molecular vibrations in the sample. A Renishaw inVia confocal Raman system was added to our 6-year-old Leica DMIRBE inverted optical microscope in May 2005. The instrument boasts two laser excitation sources at 514 nm and 785 nm. The highly collimated, monochromatic light is focused on a sample through the Leica objective. Raman scattering is collected through the objective and analyzed with the inVia spectrometer while the sample is imaged using a CCD camera. Applications range from the study of wet interfaces and biological hard tissues in aqueous environment to the characterization of mineral inclusions and nanotubes. In 2006, NTUF plans to acquire a motorized stage to upgrade the system to full Raman imaging/mapping capability. This tool will be unique in the NNIN network.

3. Veeco Dimension 3100 - While negotiating the purchase of the Veeco Bioscope, NTUF leveraged equipment reserve funds to add a Veeco Dimension 3100 SPM to the facility inventory. Although the Bioscope and Dimension 3100 SPMs share a single NanoScope IVa controller, the Dimension 3100 works as a stand-alone system when the Bioscope is not in use with the LSM 510 confocal microscope. Integrated with the Hybrid XYZ Closed-Loop Scanner, and equipped with a Motorized Precision Sample Stage, the Dimension 3100 can perform a full range of scanning probe microscopy techniques, offering new features in imaging, manipulating, and pulling with high sensitivity and accuracy in both air and liquids.

Accomplishments

NTUF continues to grow as an interdisciplinary facility, serving life science, medicine, chemistry, materials science, MEMS, and electronics users. In the March 2005- December 2005 period, NTUF provided service to 138 cumulative users, 38% of which work in life sciences and medicine (a 26% increase in biological users compared to the March 2004-February 2005 period). Approximately 20% of our clients are external and 43% of these are from small companies. NTUF-NNIN was acknowledged in approximately 30 peer-reviewed papers and 10 proceeding papers in 2005. With new tools available, we expect growth in user and usage portfolios in 2006.

Staffing and Facility Management Highlights

NTUF is not only a repository of tools, but also an environment for the active transfer of knowledge from staff to users. Our staff plays a key role in attracting new users by helping design proof of concept experiments and performs in-house tool development by drawing on faculty research and expertise at UW.

In 2005, NTUF hired a new lab manager (Qiuming Yu, Ph.D. Chemical Engineering, Cornell) to replace Dr. Lara Touryan who relocated to San Diego area. We also added a new research engineer (Ada Chan, M.S. Materials Science & Engineering, University of Washington) to provide service on newly acquired equipment.

NTUF is becoming firmly established as a centralized user facility on the UW campus with strong support from students, faculties, and administrators. Instead of bringing major equipment to individual research groups, faculty members at UW are buying into the idea of "centralization", working closely with NTUF on equipment grant applications. In these proposals, NTUF commits to: (1) developing user training programs, (2) providing technical assistance on equipment operation, and (3) covering service contract costs. This is with the understanding that any and all equipment will be made available to the academic and industrial user base nationwide through the NNIN network. Currently, NTUF is working with several faculty members on a NSF-MRI proposal for the acquisition a high end FEG-TEM that will be housed in the NTUF.

NNIN funding has enabled the rapid development of NTUF as a cost center. We expanded our technical staff by two and spent approximately $750,000 on new equipment in 2005. NTUF is supported by NSF-NNIN (60%) and a self-sustaining budget relying on user fees (40%). NNIN moneys support 4.0 FTE staff salaries and provide equipment funds. The self-sustaining budget covers the balance of operational expenses including 1.8 FTE staff salaries, equipment service contracts, lab supplies, and equipment depreciation with anticipation to recover the cost of equipment at the end of their five-year life span. We were financially profitable in 2005. This success relies on two factors: (1) the expanded staff was able to provide better service to users and to ensure minimum equipment downtime, and (2) the expanded equipment inventory fostered growth in lab usage.

Cyber Infrastructure Development

NTUF developed a database driven website that went live in March 2005. This site serves as a portal for inquiries, new user registration, equipment scheduling, and account management for registered users. It has emerged as an effective vehicle for promoting the facility and to foster interactions between staff and users as well as the public. Our system is also designed to automatically generate monthly user/usage reports.

NTUF recently installed software and hardware allowing internet-based access to our SEM. This is the result of a collaboration with the Department of Chemistry and Biochemistry at Bradley University (BU) to develop a nanotech research experience for undergraduates. BU provided seed funding to establish the Internet 2 connection. NTUF staff will use the SEM to analyze samples while in real-time communication with BU. Usage of this connection should range from 1-6 hours per course. We believe that this cyber infrastructure will prove extremely valuable in support of nanotech education for those schools that cannot afford to purchase and maintain advanced equipment. We also anticipate that it will play a major role in attracting remote users.

Promotion and User Outreach Effort

In the March–December 2005 period, NTUF promoted NNIN through the following activities:

- Designing and publishing NNIN-NTUF brochures and banners (04/05)
- Collecting mailing list from local nanotech community; distributing brochures (04/05)
- Participating in the UW College of Engineering Open House for K-12 students (04/05)
- Exhibiting in the Washington Technology Center 10^{th} Anniversary Celebration (05/05)
- Participating in Microtechnology and Nanotechnology Forum in Portland, OR (05/05)
- Organizing a Nanotech Short Course (40 participants) and an "Art as Science" competition open to graduate students (09/05)
- Organizing the 2005 UW/PNNL Nanoscale Science and Technology Workshop (120 participants, 09/05)
- Organizing NTUF open houses and research showcases (05/05 and 09/05)
- Participating in exhibitions at MRS Spring and Fall meetings (04/05 and 11/05)

Educational and Outreach Activities Highlights

In 2005, NTUF sponsored 4 REU students who performed 10 weeks of research in affiliated faculty laboratories, participated in weekly Science Communication classes and Journal Club meetings, and presented their results locally and at the National Convocation. Our RET program enabled 2 high school teacher participants to immerse themselves for two weeks in nanoscale research. Classroom material was developed, field-tested, and sent for posting on the NNIN Education Portal. In summer 2006, this material will be incorporated in a planned two-week intensive teacher workshop. NTUF also sponsored a "Nano Week" of the Science For Success (SFS) program, which is offered jointly with UW's Engineered Biomaterials ERC. This four-week-long summer program involved 14 economically disadvantaged and under-represented high school students.

NTUF participated in an Introduction to Nanoscale Science presentation for about 100 5th-6th graders at Seattle's Science Fiction Museum and two days of public exhibits at UW's College of Engineering's Annual Open House. Over 125 K-12 students (3rd grade – high school) toured the NTUF. Along with the CNT IGERT and JIN programs, NNIN organized three Student Symposia in which graduate students learn to communicate nanoscale research results effectively and to a broad audience.

Our ongoing collaboration with North Seattle Community College (NSCC) continues. Eight NSCC faculties participated in a 4-hour-long hands-on experience on NTUF tools. We assisted NSCC with their newly WA state-approved 2-year nano AAS-T degree program and collaborated on grant proposals. A new collaboration with Pacific Science Center (PSC) was initiated. Plans are being made to incorporate the NNIN NanoPACE kits into PSC "nano carts" and to foster a broader dialog about public education activities dealing with nanoscale science and technology. An initial meeting with a dozen of Seattle Public Schools Career Specialists has begun the process of assessing the needs of guidance counselors for nanoscale information and education materials.

UW educational staff joined other NNIN educators at the National Research Centers Educators Network Annual Meeting and participated in the NNIN Education Activities Development Committee that is developing nanoscale science and technology educational materials for middle school students.

Societal and Ethical Dimension

About 20% of the UW-NNIN budget goes to the UW Center for Workforce Development (CWD) to support research on Societal and Ethical Issues (SEI). CWD focused activities include:

- A study of nanotechnology and public health that aims at helping define appropriate regulations and safety measures. By surveying over 70 UW nanotech faculty and 50 toxicologists, CWD hypothesizes that toxicologists aware of the implications of nanotechnology perceive greater risks and hazards than nanotechnologists do.
- A study of nanotechnology and multidisciplinary collaborations aiming at helping bridge the understanding gap between disciplines. Through one-on-one interviews, participant observation and analysis of written texts, CWD finds that there appear to be significant differences in the way different disciplines characterize the implications of nanotechnology and nanoscience.
- A study of nanotechnology and the emerging workforce that tracks nanotech students and documents where they start their careers. Using initial, continuing and exit interviews, CWD established that although most students feel that their nano education prepares them equally well for careers in academia and industry, most intend to work in the private sector.

In addition, CWD closely collaborates with other NNIN SEI groups to: (1) carry out a longitudinal assessment of diversity and opportunities in the nanotech workforce which will eventually be expanded to all NNIN sites; (2) develop a variety of databases tracking the growth of nanotechnology as a field and discipline; and (3) administer surveys developed at other NNIN sites at UW. Finally, CWD has taken the lead in the organization a two-day SEI international conference in Seattle in Fall 2006. Scholars from a variety of disciplines will discuss the social and ethical issues associated with emerging technologies that converge with science, such as nanotechnology and biotechnology. A proposal is currently pending approval by NSF.

A1.6 Penn State Site Report

Overview

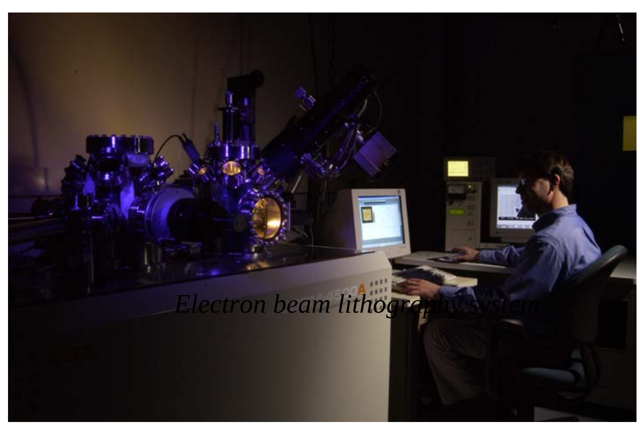
The Penn State Nanofabrication facility (Nanofab) is an open access national NNIN user facility containing over $32 million dollars of state-of-the-art 6” and 8” compatible micro and nanofabrication equipment in class 10 and 1 clean rooms. The facility is supported by 14 technical staff on the associate to Ph.D. level with cross-disciplinary expertise in the areas of spectroscopy, biology, chemistry, physics, optics, electrical engineering and engineering science. The Nanofab was established to enable advanced interdisciplinary academic and industrial research and development in the semiconductor electronic and optoelectronic, micro and nanoelectromechanical systems (MEMS/NEMS), materials, biological and pharmaceutical fields. It also has a designated NNIN focus on materials and chemical and molecular scale technologies with unique strengths that include surface chemistry, self-assembly, and the fabrication and processing of novel, nontraditional materials such as porous silicon, a-Si:H, deposited low-K and high-K dielectrics, deposited polymer films and novel optoelectronic and piezoelectric ceramics. Operating for over 12 years, the Nanofab has an established performance record of proactively identifying and engaging non-traditional users of nanotechnology and of bringing nanoscience and engineering to new disciplines. The experienced technical staff supports industrial and academic users through comprehensive education and training on instrument operation, process development and integration, and the application of micro and nanofabrication techniques to device, system and process development. The Nanofab staff teaches users to use the facility themselves or provides remote access services to the facility's extensive established process base.

Capabilities

The Nanofab's broad equipment and staff-expertise base support all aspects of 'top-down' and 'bottom-up' fabrication and has been a key resource for cutting-edge research in nanofabrication, nano-sensors, nanoelectronics and optoelectronics, nanoelectromechanical systems, and nanobiotechnology. Lithography capabilities include optical, deep ultraviolet, laser, step and flash, probe, embossing, focused ion beam and electron beam. In particular, the facility houses one of only a few 100keV capable electron beam lithography systems available at a U.S. academic institution. This e-beam tool is capable of 20nm lithography, and has been the key instrument enabling numerous nanofabrication research programs. A number of new lithography instruments have also been installed this year including a Molecular Imprints Imprio 55 step and flash system and an FEI dual beam focused ion beam and scanning electron microscope. The FEI dual beam system is also one of only a few systems in existence which also contains a cryogenic stage for handling biological samples. In addition, a Nikon EX-12 deep ultraviolet stepper lithography system capable of handling both 6 inch and 8 inch wafers is under installation currently. This system is capable of patterning <0.28 micron features.

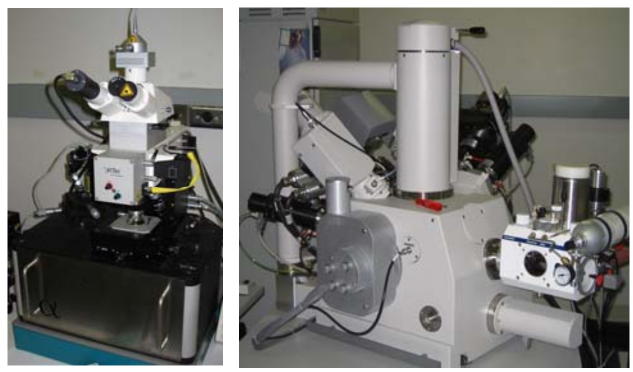
JEOL AFM/STM/FESEM

The Nanofab also has the full compliment of wet chemical and dry etching approaches as well as standard and unique chemical and physical deposition capabilities. Dry etching equipment includes an inductively coupled plasma decoupled plasma reactive ion etching (RIE) tool, a magnetically enhanced RIE, and several other conventional RIE units. Deposition capabilities include a number of Plasma Enhanced Chemical Vapor Deposition (PECVD) systems including an Electron Cyclotron Resonance PECVD, and a Liquid Source Misted Chemical Deposition (LSMCD) System. Equipment can accommodate 6 inch and 8 inch diameter substrates in addition to small samples.



Electron beam lithography system

The extensive lithography, deposition and etching capabilities are complemented by a suite of electrical, optical, and scanning probe characterization equipment. This includes a Scanning Electron Microscope (SEM), Field Emission SEM and an integrated Atomic Force Microscope (AFM), Near Field Scanning Optical Microscope (NSOM) and confocal fluorescence microscope (AFM/NSOM/CFM). This instrument allows biological and molecular level processes such as self-assembly to be studied in liquid and atmospheric environments and enables new, cutting edge chemical and molecular nanofabrication research and development including probe based nanolithography and probe directed self-assembly. High vacuum probing instrumentation includes an integrated Scanning Tunneling Microscope, Atomic Force Microscope, and Field Emission Scanning Electron Microscope (STM/AFM/FESEM) which exhibits atomic resolution in all scanning probe modes. This instrument can measure electron transport through atoms, molecules, and structures, thus probing the operation of molecular devices fabricated using chemical nanolithography.



Witec AFM/NSOM/Fluorescence microscope (left) and FEI Dual beam FIB/SEM (right)

The extensive facilities available at the Nanofab are supported by a skilled professional technical staff, which consists of 14 scientists, engineers, and technicians. The senior technical staff includes Ph.D. level engineers and scientists with cross-disciplinary expertise in the areas of spectroscopy, biology, chemistry, physics, optics, electrical engineering and engineering science. This year, the Nanofab adds to its staff Dr. Khalid Eid, NNIN Domain Expert and Senior Process Engineer. Dr. Eid holds a Ph.D. in Physics and is experienced in electron beam lithography and many other nanofabrication processes. The broad background of the Nanofab staff enables the Nanofab to support a wide range of research spanning from nanoelectronics to NEMS to nanobiotechnology. The Nanofab serves more than 300 academic and industrial users per year including representatives from over 25 external academic and industrial institutions. In addition, the PSU Nanofab is the leading NNIN site for the integration of nanotechnology research and education, and supports the nation's leading nanotechnology educational and workforce development program: the Nanofabrication Manufacturing Technology (NMT) Partnership.

Programs and technical outreach

The Nanofabrication Facility is also a foundation element for many interdisciplinary research programs spanning the disciplines of chemistry, biology, physics and engineering. These programs have helped establish the national leadership of Penn State in nanoscience and engineering research. Some of these major nanoscience and engineering research programs at Penn State include NSF Nanoscale Interdisciplinary Research Team grants and an NSF Materials Research Science and Engineering Center (MRSEC) Center for Nanoscale Science. Penn State nanoscience and engineering research programs underpin the ability of the Nanofab to constantly offer new processes to its users, thus enabling new nanoscale research to be conducted. Examples of such processes emerging from Penn State research include molecular ruler nanolithography (Science, 291, 1019, 2001) capable of producing features with dimensions

<5nm, and nanopore (J. Am. Chem. Soc., 125, 9298, 2003) fabrication for producing oriented fibers of engineered polymers, semiconductors or nanotubes.

The Nanofab also actively identifies new non-traditional nanotechnology users and disciplines through its role within the NSF NNIN. Over the past year, Nanofab staff have been actively engaging scientists and engineers from academia and industry involved with forest products. The forest products industry contributes over $240 billion per year to the gross domestic product and employ over 1.1 million Americans making products that are indispensable to our modern society. Emerging nanotechnologies offer the potential to develop entirely new approaches for producing engineered wood and fiber-based materials. They can also enable the development of a wide range of new or enhanced wood-based materials and products that offer cost-effective substitutes for non-renewable materials used in the manufacture of metallic, plastic, or ceramic products. The Nanofab has introduced the resources of the NSF NNIN to this group through national workshops and national working groups and has participated in the development of a national vision and technology roadmap for this industry (www.nanotechforest.org).

Education and Outreach

The Penn State Nanofabrication Facility also supports the nation's leading nanotechnology education and workforce development program, known as the Pennsylvania NMT (Nanofabrication Manufacturing Technology) Partnership. The NMT Partnership, which was established in 1998, provides semester-long, hands-on undergraduate and graduate education to students enrolled at more than 30 different institutions across Pennsylvania. The nation's first associate degree programs in nanofabrication were established in Pennsylvania through the NMT Partnership. Nanofabrication associate degree programs are now offered by every community college in Pennsylvania, as well as several other institutions. The NMT Partnership also supports development of baccalaureate and graduate degree programs within Penn State and at other Pennsylvania universities. The NMT Partnership continue to teach, three times per year, the six courses (18 credits) that comprise the nanofabrication capstone semester, and continuously evolve these courses in very close consultation with industry to address new product and process technologies that are constantly being developed by industry. Since the inception of the NNIN, 135 students from the various partner institutions have completed the nanofabrication capstone semester. Over the life of the program, a total of 356 students have completed the capstone semester.

In addition to supporting associate and baccalaureate degree programs in nanofabrication, the Penn State Nanofab supports professional development workshops for educators and industry personnel, along with numerous outreach programs targeting secondary schools students. Since 1999, over 461 educators have attended professional development workshops at the Nanofab. Since NNIN inception in 2004, 140 individuals have attended these workshops. The Nanofab also supports three-day summer Nanotech Camps for middle school and high school students. More than 781 secondary students have attended Nanotech Camps since 1999, with more than half coming from underrepresented groups. Since NNIN inception in 2004, 305 students have attended these 3-day camps. The PSU NNIN site also supports the continuation of the NSF Research for Undergraduates (REU) program. In 2005, 8 REU students, representing undergraduate institutions from across the US, were involved in this unique 10 week research experience. As a culmination of their experience, the students presented their research on August 11-12, 2005 at the 2005 NNIN REU Convocation at Stanford University.

An extensive student outreach effort with Pennsylvania high schools and vocational-technical schools is accomplished through the staff of the NMT Partners. Most recently, steps have been taken to upgrade outreach materials. A Power Point outreach presentation entitled *Nanotechnology Principles, Applications, Careers, and Education (NanoPACE)* has been developed to ensure a consistent message is delivered by Partner outreach personnel. The Nanotech Products activity is a major component of the NanoPACE activity. Through the NanoTech Products Activity, students are introduced to products that are on the market and are being enhanced utilizing nanotechnology. This activity has also been shared nationally with other members of the National Nanotechnology Infrastructure Network (NNIN) Education network, through Educators Workshops and at multiple national conferences. Additionally, the CNEU website (www.cneu.psu.edu) was upgraded substantially this past year. The website is now designed to better serve the needs of prospective students and of the Center's nationwide audience.

The Semiconductor Equipment and Materials International (SEMI) organization enlisted Penn State personnel to create a nanotechnology module for their educational outreach program "High Tech U" for high school students. The goal of "High Tech U" is to reach over 33,000 students with its key messages by December 2007. This nanotechnology module was piloted by Penn State personnel and evaluated in a special "High Tech U" workshop in San Jose, California on January 29, 2005. The module makes use of Penn State's remote educational access Atomic Force Microscope (AFM) capability and will continue to be used by SEMI and their industry partners, who assist in sponsoring and delivering this program.

A series of Nanotechnology Education Modules were produced in 2005. These video modules are intended to be used by institutions for introductory and orientation course work. The 4 modules which focus on what nanotechnology is, the impact it has on today's world of industrial products and services, how nanotechnology influences multiple scientific disciplines, how current advancements in nanotechnology will be influencing our lives in the future, and highlights career and educational opportunities available through the NMT Partnership. These modules are available for viewing via the Center website at http://www.cneu.psu.edu/edTools.html.

A1.7 UCSB Site Report

UCSB has extensive facilities and research in nanotechnology. Research is highly collaborative, involving Materials Science, Chemistry, Physics, Biology, Chemical, Electrical, and Mechanical Engineering. Areas of excellence include: compound semiconductor electronic and optoelectronic devices in GaAs, InP and the semiconductor nitrides; 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. Our highly varied distribution of users is indicative of the breadth of research done through the facility. Specific facility strengths include leading expertise in compound semiconductors, photonics, and quantum structures, substantial cross-fertilization of research across disciplines, and expertise with non-standard materials and fabrication processes. A wide range of lithographic, thin film deposition, etching and characterization systems are housed in the facility.

Facility

The move to the new 12000 ft^2 cleanroom facility has progressed much slower than anticipated. Thirteen of the fifteen new wet benches are in place, with the rest slated for delivery in the coming two months. Most lithography and evaporation remains in the old facility, but is expected to be moved by March 2006. We now expect the entire move to be finished by the end of Q2 2006. The new i-line GCA Autostep200 wafer stepper was installed in September, doubling our 350-500nm resolution lithography capabilities to allow for continued external user expansion. The system is performing well and regularly producing 400nm isolated lines. Scheduling has now been made for the installation of an Intel-donated 3-bank Tystar furnace. We will use this furnace system for dry and wet oxidation of silicon (first tube), III-V compounds (second tube) and for general high temperature annealing of other materials (third tube). We have also scheduled installation of our Intel-donated Veeco Nexus ion-beam deposition tool, which will give us state-of-the-art capabilities for high precision dielectric optical coatings. Designs for the large environmental chamber for our new JEOL 100kV ebeam lithography system are nearly finished. The JEOL ebeam writer will be capable of writing 8nm lines and will be a pillar of our nanotechnology effort in the coming years. This system should be installed by Q3 of 2006. We have added one full-time lab assistant to the equipment and facility support staff during this period.

Outside Users

Our outside user numbers are continuing to increase in 2005. In 2003, before NNIN, we had 281 total research users, with 60 external (18 academic) users. In 2004, we jumped to 335 total research users, with 99 external (36 academic) users. In 2005, (March-Dec) we have logged 111 external (37 academic) out of 348 total users. This represents a doubling of external academic research users and a doubling of the total external users since the inception of the NNIN. The number of internal users has steadily increased from 221 to 237 users from 2003-2005 (March-December). From the data, we are currently at 32% external users (11% academic). The external industrial user base has increased primarily through an increase in small business activity since 2003. These small business users come primarily from new local companies and small companies that have employed previous UCSB nanofab researchers. The external academic research user increase has primarily come from a larger research education program and from users across the country who have found us on the internet. Our remote user numbers have increased from 19 to 25 from 2004 (12 months) to 2005 (10 months only). 10 of this year's to-date remote users are from academic institutions.

During this last year we focused on external user recruitment from the southern California geographic region. To increase our presence in this region, we have made visits to UC Santa Cruz and to UC Irvine this past year, spending the day with and giving presentations to researchers and lab personnel about our capabilities and accommodation of outside users, highlighting the NNIN capabilities that we can offer as a supplement to their local resources in nanotechnology. This, so far, has not had large impact. However, we believe we should continue the effort and will arrange more trips during this coming year, tracking the progress. As a broader outreach to the region, we prepared and sent out almost 900 facility/capability brochures to professors, post-docs, and graduate student researchers identified as potential users of the facility in the areas of engineering, materials, physics, chemistry, and biology. These went to all of the Southern California Universities. We have had some limited success from this and at least 3 new users are entering the facility in the beginning of 2006 due to this outreach. We will continue this course of action with an expansion to other colleges and universities beyond southern California, extending into Nevada and Arizona. We will also be including a nanotechnology newsletter with brochure mailings. Finally, since the internet has provided a good means for recruiting external users, we are revamping our web-site to be more user-friendly, to obtain more hits related to nanotechnology process searches, and to provide more in-house process information.

NNIN Funded Educational Activities

Middle School

<u>Science and Technology Day, featuring Nanoscience and Nanotechnology:</u> NNIN at UCSB collaborated with Mathematics, Engineering, Science Achievement (MESA) to host this event on March 5, 2005. This event targeted middle schools and high schools from low-performing schools in Ventura, Santa Barbara, and San Luis Obispo Counties. NNIN collaborated with the Materials Research Labs to put together all of the (6) nanoscience and nanotechnology workshops. This event reached 825 (over 80% Latino (primarily Mexican descent); 1% American Indian; 4% Black; 5% Asian; 7% Anglo; 3% Mixed Heritage) middle school and high school students in southern California, ranging from Oxnard to Santa Maria. This event was featured in El Mexicano de Santa Barbara magazine, Volume 1 No. 2. in an all-spanish article.

High School

Science and Technology Day, featuring Nanoscience and Nanotechnology: See Above Middle School section

Chip Camp for High School Students: UCSB created a weekend "chip camp" (March 15, 2005), where 6 students and 1 teacher from Santa Maria High School learned photolithography and metal deposition and how to use this in wet etch and liftoff techniques. Then, graduate student mentors guided students in an exploration of various parameters in these processes, so that they could use this experience in the Santa Barbara County Science Fair. Graduate students gave talks on nanotechnology careers and an informational/motivational talk on pursuing higher education. Four of the 6 students are Hispanic, and 2 students are female. In an exit survey, ALL of the students said that they are seriously considering careers in science. Five out of 6 students said that the chip camp affected their career choice, and these students are now considering a career path in nanotechnology.

Nanoscale Education and Applications in Technology (NEAT) After School Program: The NEAT after-school program brought 4 high school students from Dos Pueblos High School to do the chip camp activities once per week for 3 hours/day over the course of 5 weeks. Three of the four students used what they learned in the Santa Barbara County Science Fair.

Apprentice Researchers Program (ARP) : UCSB funded 2 ARP students in 2004 and 4 ARP students in 2005. ARP is an REU program for high school students.

Research Mentorship Program (RMP): NNIN at UCSB provided a project for and mentored high school student Meenal Datta, which resulted in the design of a portable device that could be used to teach photolithography in high schools. The write-up for this lab and the teacher's preparatory notes will be distributed this fall and we will be testing out the apparatus on a larger scale this March in one at a large campus-wide outreach nanoscience event.

Public

New UCSB Education Web Portal! www.nanotech.ucsb.edu/education/htm.

College

Technician Internships in NanoTechnology (TINT) : The TINT program brings 4 (primarily foreign students from Germany) undergraduate students each year to the UCSB nanofabrication facility for a 6-month apprenticeship. This is essentially a 6-month REU program for foreign students. This past year the students worked on process development for reactive sputtering, optical lithography, and AFM-based nanolithography.

Nanofabrication Short Course: UCSB recruited 7 students from Ventura College (a non-research institution) for participation in a free, week-long nanofabrication short course. Students spent 1 hour in lecture and 6 hours in the lab every day for that week. The short course took place Aug 1–5. Of these 7 students, 3 students are female and 5 students are Hispanic. In an exit survey, students ranked the likelihood of their continuing their education in science and engineering by attending a summer with intense nanofabrication courses. On a scale of 1 (least likely) to 5 (highly likely), the average was 4.4.

Research Experience for Undergraduates (REU): As part of the NNIN REU Program, UCSB provided nanotechnology research projects for 12 students (3 female, 1 Hispanic)—3 of the 12 students were from non-research institutions.

Teachers

Research Experience for Teachers (RET): UCSB partnered with other NNIN sites to submit an RET grant proposal to the NSF.

Teacher Professional Development: UCSB is in the development stages of providing courses for teachers to earn professional development credits. The course and agenda is ready, and UCSB is currently working to get the course recognized by the California Department of Education as professional development credits.

Developed another K–12 teaching module & teacher's preparatory notes: Developed a lab activity that teaches photolithography by using a portable device that teachers can make (includes teacher's preparatory notes). Activity will be disseminated (posted on NNIN and UCSB website) in 2006.

A1.8 Univ. of Texas at Austin Site Report

Site description and capabilities

The Microelectronics Research Center at The University of Texas at Austin (MRC) is located on the JJ Pickle Research campus. The MRC facilities primarily serve the UT community, i.e. more than 140 UT students working with more than 30 UT professors. The UT academic users (internal users) represent ~60% of the total users. The ~30% outside users mainly come from Universities in Texas and small companies around Austin. We would like to emphasize that our outside user numbers have doubled from Dec. 04 to Dec. 05.

The NNIN team at MRC consists of 15 people (compared to 9 when we started the program in March, 04). We have 4 staff members who have two main tasks: (i) train all new users and (ii) process support.

(i) The training sessions are organized on demand. A strict training calendar was not imposed because most of our users are from academia with varying schedules.

(ii) Process support is a consulting service provided to users working in the MRC to optimize his/her process. With most of our outside users coming from industry with little experience in developing research projects, the process support involves process development, and process integration. Additionally we have process engineers, working directly on projects in the cleanroom. The user is in this case is a “remote” user.

The up-time of the 50 major tools for diffusion, photolithography, dry and wet etching, metalization and characterization is maintained at a high level due to the full-time dedication of our 3 repair technicians.

In order to ease the access of the cleanroom to outside users, we have an on-line reservation system for the high demand tools (EBL, CHA Industries evaporator, IMPRIO100). The other tools are on a first-come, first-served basis.

Niche within the network

The MRC is technically focused on crystal growth and device processing. The MRC/NNIN program is centered on imprint lithography activities. In that domain we are developing tools and processes.

Description of new facilities, equipment, and capabilities

The **Step and Flash Imprint Lithography (SFLI)** is an alternative to the new generation lithography systems in which no optics or other light sources are used to cure the photoresist material. The SFLI-IMPRIO100, a high resolution molding system, has been fully operational since Dec. 2004. With this system, we can reach sub-100nm device dimensions.

The process of SFLI is based on a quartz template. The template is written with Electron Beam Lithography (EBL) and etched with Reactive Ion Etching (RIE) system. A low viscosity liquid fills the fine cavities etched into the quartz. After Ultraviolet Light exposure the film turns into polymer and the features from the template are transferred to the substrate. Because the quality of the imprint with SFIL is directly dependent on the template, we are focusing on template fabrication. Special materials have been ordered to process the template: EBL cassette, spin coated chuck, template labware.

Technical highlights and accomplishments

The template process starts with a quartz plate size of 6”x6”x1/4”, coated with chromium. From this plate we make 4 templates with a centered active area (the mesa) of 10x10mm. With such a mesa size, we are able to imprint 32 dies on a 4” wafer (instead of 6 dies with a 25mmx25mm mesa). After dicing and polishing the template (a square of 65mmx65mmx6.35mm), the mesa on a pedestal of 0.15µm is ready to write in the **JEOL FS/X 6000 EBL.** The template mesa is exposed with different currents and doses depending on the features size (nanometer scale for device features and µm scale for alignment features).

The dry etching processes (Chromium and quartz) are done in a RIE chamber of **Oxford Plasmalab-80 or Plasma Therm 790**. The features size obtained after etching have sub-50nm size. We should push this resolution feature size to 20nm with the new **TRION RIE** chambers that we recently acquired. We expect this tool to be available for processing in March 2006.

Two workshops have been organized on this novel lithography technique in 2005/2006. Indeed the SFIL techniques could serve a broad range of applications from media for magnetic drives, to micro optics, to LED’s, micro fluidics and biomedical applications or high-resolution filters in projection televisions. A large community should be interested by this system.

Efforts and success at expanding user base

After a mailing campaign without any success to bring new users into the MRC, we started visiting universities in Texas. During those visits we presented the MRC facilities, the NNIN program, described tools and projects. The payback of these seminars already appears in 2005 statistics: the number of academic research users –outside UT- tripled. With these good relationships that we started with other Universities, we expect to increase this number in the next year. We will expand out tours to neighboring states.

Education and outreach activities

Facility tours: Tours of the MRC facilities were given to over 250 people in 2005. The people attending these tours include many elementary and middle school students, as well as many attendees of the Coordinate Metrology Systems Conference, Taiwanese delegates (includes the National Director of the Nanotechnology Program of Taiwan), and Argentinean delegates.

REU program: The MRC hosted 3 undergraduate students for the 2005 summer REU program. These students worked with Principal Investigators in the Electrical and Chemical Engineering departments. The program ran from June 6-Aug. 15, 2005 culminating at the annual convocation where the students presented their research findings to their peers and the outside world via live webcast.

Young Scientist program: NNIN funds were used for a variety of activities and events that help to prepare 156 Young Scientists, most of them low-income Hispanic students, to be successful as they move from elementary to magnet middle school and from magnet middle school to magnet high school.

Many Young Scientists come from limited English speaking homes and the largest part of these funds provided much of the salary for a full time student advocate, a bilingual counsellor working in the magnet middle school, whose charge is to help students and their families manage the transition to Austin's most rigorous academic curriculum.

NNIN funds also contributed to:

- Field Trips to The University for 98 Young Scientists
- Two-week summer science camp at UT – 76 Young Scientists attending
- 5-week math summer camp – 20 Young Scientists attending
- 1-week summer Young Scientist Genetics Teacher training
- Genetics classroom supplies for 5 teachers
- Young Scientist teacher fees and travel to the state science teachers convention
- 7 Parent Education Meetings
- Family Chemistry Circus Event Nights at 3 Young Scientist Schools

- School supplies for Young Scientists entering 6th grade
- Application fees for S.A.T. and other tests as needed
- 6 UTeach Math and Science tutors

A1.9 University of Minnesota Site Report

The node at the University of Minnesota combines the efforts of three organizations. The Nanofabrication Center (www.nfc.umn.edu); the Characterization Facility (www.charfac.umn.edu) and the Particle Technology Lab (www.me.umn.edu/divisions/environmental/ptl/). In addition to MEMS and micro/nano fabrication expertise, the Minnesota node brings two areas of technical excellence to the network: 1) nanoparticle-based research, especially environmental work, and 2) characterization. In the first area, The University of Minnesota Particle Technology Laboratory (PTL) provides a broad and in-depth expertise on particles with an emphasis on gas-borne nanoparticles. This is backed by an extensive array of particle generation and measurement and collection equipment. The capability of this lab is unique within the NNIN structure. Examples of currently available commercial systems include the CNC, for detecting nanoparticles in the atmosphere, nano-DMA for size selecting nanoparticles, the aerodynamic lens for concentrating nanoparticles, and the particle beam mass spectrometer for detecting nanoparticles in low pressure environments. The second area of specialization at Minnesota is characterization. The Characterization Facility houses multiple TEMs, SEMs, XRDs, scanning probe systems, thin film chemical analysis equipment, and a wide variety of other tools that are available to NNIN users. New tools are being added to the Lab to broaden the suite available to the user. Specific changes to each of the labs will be covered below.

During the second year of NNIN support, one of the primary goals was to increase the number of external users. This has largely been done through a variety of outreach activities as described below as well as the new PathFinder program which underwrites the cost of the node usage by the first user from an educational institution. Access to characterization tools, in particular, has proven interesting to small colleges with very limited research funds and capabilities. Overall, the number of facility users increased by about 8% in the first 10 months of this year compared to the same period of the first year. This increase was evenly distributed across all technical areas. The external users is up only slightly, however, we expect this to change significantly during 2006 as new external users, who are already committed to node usage, begin to arrive.

The Nano Fabrication Center (NFC)

Several updates were accomplished in NFC during the second year of NNIN support. An FEI Quanta 200 D focused ion beam (FIB) system was purchased and installed, primarily using local funds, but also using a small amount (~10%) of match funds provided by the University for the NNIN project. This system enables our users to carry out surface modifications, write Pt lines without a mask and drill holes through layers. Most importantly for NNIN users, however, it enables users to rapidly prepare cross sectional TEM samples. This is critically important in our role as a primary characterization node within NNIN. NFC also continued to work with Stanford to fully integrate the Lab's Coral operating system. First adopted in 2004, the Lab has now fully transitioned to this system and has interlocked major pieces of process equipment to the Coral software. This has enabled us to better control access and ensure that all users are properly trained for the systems that they use. The lab also completed a major upgrade of its low pressure chemical vapor deposition capabilities.

Since the lab was fully staffed at the end of the first year, no major staffing changes occurred, however, the NFC accountant, Jennifer Reilly, was replaced by Mr. Bruno Scalici. Mr. Scalici holds a B.A. from the University of Minnesota and has approximately 6 years of accounting experience.

The Characterization Facility (CharFac)

New proximal probe systems were added for nanoindentation and scanning probe microscopy (SPM). A Hysitron Triboindentor was added to provide a stand-alone system with imaging and dynamic capabilities, complementing our existing MTS Nanoindentor XP and Hysitron Triboscope systems (the latter attaches to a Digital Instruments Multimode SPM). Together this suite of instruments provides the broadest capacity to explore both load and length scales, implementing various measurement modes. These capabilities are further marketed to our user base via occasional workshops and "master classes" with cosponsors Hysitron and MTS (the world leaders in this industry, and both based in Minneapolis).The new SPM is a Molecular Imaging PicoPlus with special capabilities including Witec digital pulsed force mode, control of gaseous environment and sample temperature, and conducting AFM; the system can be remotely controlled via UltraVNC. We have also added a CCD imaging system to the JEOL 1200EX TEM (and thereby revamped the bio clientele); refurbished older X-ray photoelectron and Auger spectroscopy (+sputtering) systems and trained users, thereby resuscitating a user base (some external) that had decayed at Minnesota, and positioning us to vie for grants for modern systems that will not only bolster internal research but also attract external users.

Robert Hafner was hired in April. Bob has both an education background (Ph.D.) and more recently a technical degree in electron microscopy (EM). His responsibilities span two sets of labs emphasizing materials and bio research. Bob is the key liaison for remote operation of the CharFac scanning (materials lab) and transmission (bio lab) EM's. He also interfaces with a new electron microscopy committee that manages strategic directions for both Twin Cities campuses. Bob also has revamped instructional and training documentation for several of our EM labs.

Ryan Wold (M.S.) was promoted from a temporary to a permanent position in early 2005 to work primarily in our extensive X-ray scattering labs, both wide-angle (six) and small-angle (three) systems. He also manages stylus profilometry and lab safety. The X-ray areas are historically our most active labs in terms of external users, a client base that has nevertheless continued to growth over the past year.

Particle Technology Lab

The Particle Technology Laboratory (PTL) became an open lab under NNIN and is working to build its client base through several venues. Along with two pages of content in the Nanotechnology Newsletter and newly added Web content, two events helped to broaden our exposure profile to potential clients in the aerosol community. The Aerosol and Particle Measurement Short Course held in August attracted an all-time high of 78 registrants from industry, government and academia, most of whom indicated an interest in our newly added curricula on Nanoparticle Technology and Bioaerosol Sampling and Measurement. The 2nd International Symposium on Nanotechnology and Occupational Health, hosted by the Minnesota

Node of the NNIN in October, was a resounding success. The Symposium attracted 416 registrants from 20 countries. In addition, approximately 150 attendees also registered for the optional tutorial sessions.

PTL has worked with six clients in the past year – one from the university, four from industry including Seagate, Entegris and two startups, and one independent entrepreneur. Several other potential clients expressed interest in measuring particles in liquids prompting us to begin refurbishment of three liquid-borne particle detectors. A business plan has been formulated including one third-time laboratory manager and two half-time postdocs which are currently paid by NNIN but will ultimately be self-sufficient. Staff and equipment rates have been set and client billing awaits university approval of the business plan. Educational efforts included hosting two students seeking Nanoparticle Science and Engineering minors and preparing syllabus and lesson plans for five laboratory sessions in the nanoparticle sequence of the AAS NanoScience Program.

NNIN Node Educational and Outreach:

The node was actively engaged in numerous recruiting and educational activities. Educational activities included (a) graduate courses in broad-based materials characterization as well as focused, advanced courses on SEM and TEM; (b) laboratory courses for materials science undergrads (structural characterization) and electrical engineering graduates (thin film characterization); and adjunct teaching by one staff member at Dakota County Technical College (DCTC; specifically, an NSF-funded Nanoscience Technology degree program). This program saw heavy activity in 2005 as the first participants are just beginning their capstone experience in January, 2006. Specialty junior-level lecture courses have been developed in Micro and Nano Fabrication, Materials Characterization, Thin Film Technology, and Bio Technology. In addition three labs have been developed: Micro/Nano Fabrication, Introduction to Materials Characterization, and a split lab which is 50% Biotech and 50% Nanoparticle Synthesis and Measurement. 15 students are currently taking the capstone experience and another 15 are planning to take the program in the summer of 2006. In addition, we have begun exploring the idea of expanding the program to Physics and Chemistry majors at liberal arts institutions, who would treat the nano coursework as a minor to their traditional degrees.

A large number of seminars were held in 2005. These included the annual Aerosol and Particle Measurement Short Course and the 2nd International Symposium on Nanotechnology and Occupational Health, both of which are discussed above. In addition, the 2nd annual Nanotherapy workshop was held at the May Clinic. This workshop will now rotate between the Twin Cities campus and Mayo on an annual basis. Characterization related workshops attended by both internal and external clients included two scanning probe microscopy (AFM) events in collaboration with Molecular Imaging (MI), an AFM vendor, involving talks, demos and specimen analysis. Further guest lecturing by one staff member took place at MI's AFM user training course in Phoenix. The CharFac also co-organized (with our affiliated industrial-partnership research consortium, IPRIME, www.iprime.umn.edu) a cryo-TEM workshop attended by a couple dozen industrial personnel from several member companies. The Minnesota node also participated in the NNIN REU program, hosting three students in the summer of 2005.

Recruiting continued through the triannual newsletter which is sent to current and past users along with Department Heads of physics, chemistry, and engineering at all schools in the 9-state upper Midwest region along with a specific invitation to use the NNIN facilities. This was supplemented by visits to four schools in the area. The node also held four exhibits (representing all of MiNTeC) at (i) the IPRIME annual meeting poster/exhibit session (included a demo of the new MI AFM), attended by a couple hundred industrial personnel representing some 35 member companies; (ii) the Particle Society of Minnesota annual meeting; (iii) the NSTI Nanotechnology annual conference in Anaheim; and (iv) the Minnesota American Vacuum Society annual meeting. Numerous tours were also given. More extended time was spent in special camps/sessions that included (i) the University of Minnesota Summer Day Camp Program, (ii) DCTC summer NanoCamp; (iii) Micro Camp; and (iv) a Jr High School Group. Also, a DCTC remote control SEM session using WebSEM and UltraVNC to demonstrate secondary and backscattering imaging and energy dispersive spectroscopy. The node has also agreed to host the ASME Nano Bootcamp during the summer of 2006. This is expected to bring in roughly 100 visitors that will spend two half-day sessions in the node's labs.

A1.10 University of New Mexico Site Report

During the past year, Nanoscience @ UNM has increased the capability of their user facility providing rapid access for academia and industry to high technology cleanroom, advanced lithography, and characterization equipment as well as to quantum nanostructure growth facilities. Users have increased by 16% over Year 1. In particular, geology users have increased by 33%, and remote usage by 17%. New tools include a suite of LAM plasma etchers, Karl Suss Mask Aligner, Cymer UV laser for IFL applications and MOCVD capability.

Nanoscience is distributed in three locations at the University of New Mexico - in the Center for High Technology Materials, the Department of Earth and Planetary Sciences, and the Center for Microengineered Materials. The University of New Mexico has demonstrated expertise and capabilities in several areas of importance to nanotechnology including: nanoscale interferometric lithography; nanoscale catalysis, and nano-geo-bio-chemistry

The routine growth of high quality self-assembled quantum nanostructures (quantum dots) based on the Stranski-Krastonow (S-K) growth of InAs and other semiconductors is another capability of the UNM NNIN site. Quantum dot laser diodes operating in the 1.0- to 2.0-um range possess the lowest threshold current density and largest tuning range demonstrated in any semiconductor laser system. Nanoscience at the University of New Mexico provides users with the means for the synthesis and characterization of nanophase catalytic materials. Heterogeneous catalysts are important for energy conversion (fuel cells), environmentally benign processes (catalytic combustion) and the synthesis of a wide range of economically-important raw materials. The catalysis requirements of high surface to volume mean that these materials must contain nanosized active phases. UNM has unique capabilities in the synthesis and characterization of such nanostructured materials.

Between January 11-13, 2006, UNM's Department of Earth and Planetary Sciences hosted a workshop, Nanoscale Processes in the Earth and Planetary Sciences (NANOPEPS). This brought together interested researchers working on earth and planetary materials to review and discuss the current state of the art of nanoscience in the geoscience community, and to increase awareness of the facilities available for nanoscience research in the NSF-NNIN network. Attendance was good at approximately 65, with 24 presented papers. Keynote speakers were Professor Alexandra Navrotsky of UC Davis, Professor Rod Ewing of the University of

Michigan and Professor Mike Hochella of Virginia Polytechnic Institute. The EPS department operates a user facility with 2 TEMs and one SEM, an electron microprobe and a SIMS instrument that will be available to users of the NNIN. Some 30% of the usage of this facility is by external users.

Nanoscience @ UNM's database for tracking users, consumables and related costing issues has matured. Work is progressing on a Tool Interface Project. Project will provide equipment control and usage tracking. Additional benefits will include real time equipment availability tracking. Plans are to integrate this data with spare parts supply/ consumption figures, user consumables, and the like. Work continues to move the facilities from an academic culture to a user-facility culture. Attacking issues that impact equipment downtime, instituting regular maintenance schedules, building a spare parts inventory, and training users in operational procedures, have been management's primary focus. During the next year, more emphasis will be placed on documenting defined maintenance procedures.

The UNM Nanoscience @ UNM documentation package has been distributed extensively over the year in response to telephone, Web based and referral inquiries. A professionally designed brochure was created during summer 2005, and is now included in this package. A database of users and user metrics has been established with expanded capabilities to track unique users per NSF /OMB request. A uniform system of calculating user time has been adopted, and is being regularly reviewed. Invoices are sent out monthly and collections are running at a minimum of 87%. Collection efforts are on-going for some high risk ventures.

One staff member was replaced during 2005. No new headcount has been added beyond the current staff of two direct non-exempts and one direct exempt. The direct exempt is being developed into a database administrator to support the large volume of data required to operate the facility efficiently. Safety training (awareness level) has been completed for direct personnel involved with semiconductor materials growth. A major renovation of the facility was completed including correction of code issues involving hydrogen gas.

During the Fall 2005 semester, Nanoscience @ UNM collaborated with Professor Mary Margaret Weber, of UNM's Anderson School of Management. Nanoscience @ UNM became the project for her MBA marketing class, which analyzed the nature and extent of demand, the nature of our competition, the environmental climate, organizational strengths, weaknesses and objectives; performed a market assessment and developed a new marketing strategy. Some 30 students were actively involved in this project, which as well as benefiting Nanoscience @ UNM's business focus also served to raise local awareness of nanotechnology. They were introduced to nanotechnology, and to the associated social and ethical issues, and were given in-depth tours of the facilities. They were were in regular contact with Nanoscience @ UNM personnel throughout the semester. The collaboration with Professor Weber, and her colleagues in the professional schools will be continued and expanded in future program years, particularly in the areas of promotion, sales and additional marketing reviews. The project report is currently being critically reviewed for implementation of a long term marketing strategy.

Education

The University of New Mexico is creating a new Nanoscience and Microsystems (NSMS) Curriculum to prepare a highly trained nanotechnology workforce. A unique core course in this curriculum, **Societal and Ethical Implications of Nanotechnology**, was given for the first time in the Fall 2005 semester. A 3-credit, 400/500 level course, cross-listed in the School of Engineering and the College of Arts and Science, it attracted and enrollment of 9 students. Enrollment is expected to increase once the NSMS curriculum is in place. The course prepares students for a rapidly evolving, multidisciplinary environment by developing their capacity for critical analysis and their awareness of the multiple issues they will meet as they work in nanotechnology, as well as inculcating the flexibility and insight necessary to take an ethically responsible position when faced with unprecedented circumstances. A survey of the students at the beginning and end of the course indicated that their awareness of nanotechnology, and the associated issues, had increased significantly.

The class project was to write, administer and analyze a survey instrument to assess public awareness of and attitudes to nanotechnology. This encouraged interaction of students with the public at large, introduces ethical issues implicit in human subject research, and increases awareness of nanotechnology among the survey recipients, in addition to providing some insight on local public reaction to nanotechnology.

- *"This experience has impressed upon me the realistic difficulties of truly assessing public opinion."*
- "This experiment and survey have definitely opened my eyes to the need for the scientific community to actively engage the public in these sort of debates,"
- "The survey results have convinced me that more effort from the scientific community is needed in educating the public if the dreams of nanotechnology are to be realized,"
- *"I am glad I got to participate in this project especially because it allowed me to explain what nanotechnology is to others when I would not have been able to do that just four months ago."*

The student reaction to the class was positive. Typical student comments at the end of the semester include:

- *"I gained an enormous amount of knowledge concerning the main subject matter – which I knew nothing about previously – as well as a sense of how to explore further."*
- *"I thoroughly enjoyed this course."*

The course curriculum and materials will be made nationally available through the NSF NNIN Societal and Ethical Implications (SEI) website. A paper on this course has been accepted for presentation at the annual conference of the American Society for Engineering Education (ASEE).

Inclusion

This NNIN location is uniquely placed with respect to minority populations. The State of New Mexico has diverse demographics with a 42.1% Hispanic and an 8.9% Native America population base (2000 Census). UNM is classified as a Hispanic Serving Institution with a significant minority population. At present, over 40% of the undergraduate enrollment in the School of Engineering is from underrepresented groups. The University of New Mexico has leadership responsibility for the NSF NNIN network program in Inclusion and Diversity. Workshops tailored to high school students will be presented in 2006 at venues including the meetings of the Society of Hispanic Professional Engineers, the Society of Mexican-American Engineers and Scientists, the National Society of Black Engineers, and the American Engineering Science and Engineering.

A1.11 Harvard University Site Report

Overview:

2005 was a year of major changes for CNS. The inaugural Director of CNS, Bill Appleton left Harvard in November 2004. CNS Scientific Director, Professor Charles Marcus took over as Harvard NNIN Site Director. In December 2005, Dr. Eric Martin was hired as the new CNS Technical Director.

Also, in April 2005, The Center's name was changed from the Center for Imaging and Mesoscale Structures (CIMS) to the Center for Nanoscale Systems (CNS.) The new name is more descriptive and puts an emphasis on the concept of the fabrication and construction of nanoscale "systems."

Mission and Scope:

<u>NNIN users have access to the full capabilities of CNS, which includes the following</u>:

- Two research cleanrooms for nanofabrication and soft lithography
- Electron-beam and optical lithography
- Advanced electron-beam, optical, and atomic imaging
- Materials synthesis and characterization
- Ion beam processing and characterization
- Computational resources

<u>The Harvard NNIN technical focus areas</u>:

- Soft lithography and the assembly of nanoparticle and molecular electronics
- Theoretical simulations of electron states and transport in nanoscale systems
- The establishment of core computational resources and staff to assist users

Progress and Accomplishments
User Program:

The CNS Administrative Office and IT Manager created an extensive backend, web-based database in order to streamline the user program and make user data more accessible to the staff. Several aspects of the program previously tracked separately or by hand have been integrated into the new database.

Also, our CNS website was completely redesigned with an updated user section to consolidate information regarding enrollment, safety requirements, and training. These changes have led to an easier enrollment process and allowed users to start their projects without any substantial administrative delay while still providing CNS with the user info needed for reporting and tracking.

NNIN Technical Focus Area: Soft Lithography and Assembly:

A Soft Lithography Foundry (SLF) has been formed under CNS to facilitate the application of soft lithography techniques. Key activities include:

- CNS has expanded its support of soft lithography and nanofabrication, including; dedicated facilities, technical staff, equipment, and supplies necessary for soft lithography.

- Multiple new nano- and microfabrication processes have been developed in the CNS Nanofabrication Facility and Soft Lithography Foundry and made available to users. Examples are:
    - Deposition of high quality, nanometer-thick thin films using Electron Cyclotron Resonance (ECR) Plasma-Enhanced CVD.
    - SU-8 resist photolithography, particularly used for master preparation in soft lithography.
    - Microfluidic channel fabrication by soft lithography.
    - Self-Assembled Monolayer (SAM) formed by Microcontact Printing.
    - Replica Molding using PDMS and soft lithography.
    - Micromolding in Capillaries using PDMS mold and UV-curable polymers.
    - Microtransfer Molding for 3-D structures.

NNIN Technical Focus Area: Computing and Visualization, NNIN/C:

The National Nanotechnology Infrastructure Network Computation project denoted, "NNIN/C," with Harvard as the lead institution, provides core computational resources and dedicated staff to assist users in the understanding and visualization of next generation electronic structures, and access to these programs over the web. Key activities include:

- Benchmarking of the core codes and acquisition of computational resources optimized for our nanosimulation tools.
- Migration of core codes to available architectures including the new AMD Opteron platforms, Xeon blades, and the existing Crimson Grid.
- Development of common graphical user interface "GUI" for input parsing of codes "SETE" and "HARES." Summer intern, Corey Taylor, created GUIs to be maintained and modified by CNS IT Manager, Vincenzo DiBernardo. GUIs include applets for visualization of input molecular structure (in HARES) using "vrml" file format. GUIs sufficiently general to allow rapid interface construction for new code. Creation of custom GUI employed as an attraction for potential acquisition of code from outside researchers.
- *Code acquisition:* in coordination with experimental thrusts of NNIN, computational researchers have been identified and recruited to build versions of their software for NNIN users on NNIN/C computers. These include:
    - John Shumway, (Arizona State University), Quantum Monte-Carlo calculations for path integral simulation of semiconductor nanostructures;
    - Metin Muradoglu, (Koc University, Istanbul), Immiscible Flow: Interfacial Flows in Micro/Biofluidic systems;
    - Martin Tajmar, (Space Propulsion ARC Seibersdorf, Austria), Finite-Element Simulation of Casimir Forces in Arbitrary Geometries;
    - Toshi Iitaka and Shintaro Nomurs, (RIKRN and Tsakuba, resp., Japan), Quantum Dynamics: Time-dependent Schrödinger Equation by Explicit Symmetric Multi-step Scheme.

- Modification of core codes, particularly SETE, to address specific needs of various users. Modifications include:
    - Exact diagonalization module for treating correlation within a realistic geometry for quantum information studies.
    - Extension of simulation domain to model influence of scanning probe microscope tip on quantum dots and electron gas properties.
    - Quantum *wire* version of SETE developed to study the properties of nanowires.
    - Random impurity version to help model narrow constrictions for origin of "0.7 structure."

Equipment Acquisition:

NNIN/C made two major hardware acquisitions in 2005 with NNIN funds. The first set of computers, installed in May, consisted of four, 4-way Sun v40z workstations, each with 4 AMD Opteron 64-bit processors and large memory (24 GB or 32 GB per unit). The second acquisition, installed in November, comprised of 28 dual processor dual core AMD Opteron 64-Opteron 64-bit blade units. Each processor has 4 GB of memory and a clock speed of 2.0 GHz. Half of the units (56 processors) are connected with Infiniband® interconnects, the other half with gigabit Ethernet.

Beyond its' NNIN support, CNS used University funds to expand its nanofabrication and advanced imaging facilities during 2005. These additions include:

- JEOL 7000F E-Beam Writer for e-beam lithography.
- SUSS MA6 and MJB3 Aligners for optical lithography.
- LOOMIS LSD-200 Wafer Cleaver and Agilent 4156C Precision Semiconductor Analyzer for back-end processing.
- GAERTNER LSE-WS Ellipsometer for wafer-level metrology.
- JEOL 2100 200Kv TEM w/EDS for general purpose TEM imaging.
- UNAXIS Shuttleline ICP RIE system for etching nanometer-scale features requiring high aspect ratio. (Going online in February)
- Multi-ion Focused Ion Beam (MIFIB) developed by CNS and Lawrence Berkeley National Lab (LBNL) as part of NSF-MRI project. (Coming in Spring 2006)
- AJA ATC-2200V Sputtering System for multipurpose sputtering. (Spring 2006)

CNS' new building, LISE (Laboratory for Integrated Science and Engineering) will be ready for occupancy in February 2007. Phase 1 of equipment purchasing for LISE will begin in mid-2006. An estimated $20M of equipment Is slated to be purchased in advance of the move-in date.

Personnel Additions:

In the past year, CNS has hired new staff in order to meet the needs of a rapidly expanding user base. These new hires include;

- <u>Rhonda Gibson</u> – Assistant CNS/NNIN User Program Coordinator. Rhonda works with CNS Administrative Manager, James Reynolds, to manage the flow of CNS users from enrollment to project end.
- <u>Edwin Macomber</u> – Cleanroom/Nanofabrication Laboratory Technician. Ed is working behind the scenes to keep the cleanroom tools fully operational. This hire has freed the

NNIN Liaisons and other Nanofabrication staff to spend more time working directly training and assisting users.

- Two new hires are planned in early 2006. An Electron Microscopy Sample Preparation Technician, and a Soft Lithography Engineer (NNIN Liaison) are currently being recruited.

Education:

- CNS participated in the 2005 NNIN REU Program and hosted four summer interns.
- An Open House event for all Harvard REU students (40+) was hosted by CNS. This was an all day event where CNS staff gave tours and demonstrations to undergraduates visiting Harvard for the summer.
- CNS Nanofabrication and Imaging Groups participated in preparing undergraduate and graduate level classes for Harvard students.
- Mike Stopa of NNIN/C participates in the weekly group meetings of multiple theoretical groups at Harvard and works with them to find computational-based solutions to their projects.
- Dr. Kathryn Hollar of DEAS jointly coordinates the education and SEI programs for the Harvard NNIN as well as two major NSF-funded research centers; NSEC and MRSEC. Dr. Hollar has organized many facility tours, science museum talks, and pre-college school visits that are considered joint NNIN/NSEC/MRSEC activities.

Outreach:

- CNS organized an exhibition booth in Nanotech 2005 Conference (NSTI Nanotechnology Conference and Trade Show.) The process for deposition high quality, nanometer-thick thin film using ECR PECVD developed by CNS staff was presented at this conference.
- CNS staff supported the NNIN booth during the MRS 2005 Conference in Boston.
- A meeting was held between Soft Lithography Foundry staff and NanoTerra Co., on the subject of joint efforts in soft lithography application and development.
- As a result of CNS outreach efforts, there has been an increase in the number of "first-time" users from institutions that have not collaborated with Harvard previously.

Workshops:

Planning is ongoing for a NNIN/C conference, "Synergy Between Experiment and Computation," to be held at Harvard, May 31 – June 3, 2006. Confirmed Speakers include (to date):

- George Whitesides (Harvard University)
- John Shumway (Arizona State University)
- John Joannopoulos (MIT)
- Charles Marcus (Harvard University)
- David Goldhaber-Gordon (Stanford)
- Federico Capasso (Harvard University)
- Derek Stewart (Cornell)
- Sauro Succi (Calcolo)

A1.12 Howard Site Report

Howard University research community has been lifted to a 'new height' with the Howard Nanoscale Science and Engineering Facility (HNF). Additional fund for major nanotechnology projects have been obtained from both private and public sources (i.e. Keck Foundation, Ford Foundation etc.) This funding has allowed departments in chemistry, physics, biology, engineering and the medical school to work on nanotechnology research that is multi-discipline in nature. This research and the speed at which these various department works together on nanotechnology research projects has clearly been aided with HNF as a major resource at Howard and the Washington Region. The university has matched the funding of the HNF for the pass two years with renovations dollars of $750,000. This has expanded the HNF research facility by over 1000 square feet with 500 square feet of additional class 100 cleanroom space that is shared with the CREST Program. Three new courses have been added to the engineering and physical science curriculum. They include: Introduction to Nanotechnology, Nanotechnology and Nanoengineering, and the laboratory based course on Instrument for Nanoscience and Nano/Micro Fabrication. Students at Howard can also take a web-based course on MEMS taught at the University of Michigan.

Progress in attracting new users: The HNF staff is quite aware of their mission to bring in outside users. This funding cycle we will have over 200 (Research plus Education) users. HNF is working actively to advertise and market to outside users from various populations and regions. 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:

- Northrop Grumman/Litton Electro-Optical Systems
- Morgan State University
- Bluewave Semiconductor Inc.
- Army Research Laboratory- Adelphi, MD
- John Hopkins University

Presently, we are also in the process of developing a community college Associate Degree program model after the practice started at Penn State. This program will involve Prince George's Community College, the University of the District Columbia and Montgomery College –Germantown Campus.

In next year's budget, we are going to include funds for the Director's administrative time, which has increased tremendously under this program. The staff support by HNF include the following:

Name	**Title**	**% NNIN support**
James Griffin	Lab Manager	0
Tony Gomez	Support Technician	100
Crawford Taylor	Research Associate	100
Juan White, Ph.D.	Post-Doc	100
Maoqi HE, Ph.D.	Senior Research Associate	50%
Peizhen Zhou, Ph.D	Senior Research Associate	100%

The HNF has an impressive portfolio of educational activities across the K-Grey both formal and informal. One major addition this year will be the **NanoExpress**. **The NanoExpress** presents the complex, 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 help supervise hands-on experiments. We estimate that **The NanoExpress** will touch over 5,000 visitors 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. We will leverage the existing programs as well as new projects under development. This will help to build the network strengths of the various partners and has distributed major tasks across sites. Additional programs of note this year at HNF include:

- Black Engineer of the Year Awards-Nanotechnology Booth Camp
- Science Spectrum Trailblazer Conference of Minorities in Research Science , 2005 Nanotechnology: The Next Big Thing
- ASME Nano Boot Camp – Four special hands-on laboratories
- Jack-n-Jill Nanotechnology: The Next Big Thing, Community Academy Public Charter School
- Mini-course: Howard Math and Science Middle-School, Introduction to Nanotechnology
- Nanotechnology and the Law - Spring 2006

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 is being accomplished by providing open shared facilities and the HNF site has provided some free users time to "get researcher hooked". The results of experiment are not in yet and we hope this with additional equipment will attract new users.

We have obtained the following equipment this year:

- SIMS/Auger System (Wright Patterson Air Force Base)
- Chemical Spray Pyrolysis System
- AlN and AlON CVD System
- Raman/FTIR System
- Microwave Assisted CVD System
- Nano Zetasizer
- Equipment for the NanoExpress

Plans are underway to obtain additional equipment: i.e. ICP plasma etcher, e-beam lithography system, etc.

The main research thrusts for HNF are: Electronics and Materials (wide band gap devices and applications to nanotechnology- complete device processing capability, emphasis on wide bandgap semiconductors (SiC, GaN, AlN, BN, etc.). 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-

Membrane processes such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF), which has 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.

In these areas in the past year we have over 20 presentation and publications by users. Some small companies have chosen not to publish but to continue the development of their proto-types.

A1.13 Triangle National Lithography Center (NCSU/UNC) Site Report

During the last year, state-of-the-art nano-lithography capabilities at the Triangle National Lithography Center (TNLC) were expanded and and provided to the NNIN community of users. The centerpiece of this capability is an ASML 5500/950B step and scan system utilizing an ArF Cymer 6610A laser light source at 193 nm wavelength, which produces 80 nm isolated features and 120 nm line/space arrays. This year, two SVG 90-SE coat and develop wafers were installed and used for NNIN projects. The installed tracks are shown in Fig 2, with the track used for resist coating and for post exposure back directly connected to the scanner. These tracks were originally built by the Silicon Valley Group (SVG) but are now supported by Rite Track, Inc., which has taken over the SVG track business. They are configured for 150 mm (6 inch) substrates, having either flats or notches.

The coater track includes one spin-coating module with two dispense heads: one for photoresist, the other for anti-reflective coating (ARC). The coater module also has a top and bottom Edge Bead Removal (EBR) system. In addition, the track has 3 hotplate modules along with three chill plates. The track has an interface system with the step-and-scan system. It loads wafers directly to the 950B to be exposed as part of a continuous flow. After exposure, the wafer is then transferred back automatically to the coater track where it receives a Post Exposure Bake (PEB) and is returned to the send/receive cassette in the track. The develop track includes two develop modules, two hotplates, and two chill plates The advantages of the track include: a) process control, b) particulate control, and c) airborne contamination control.

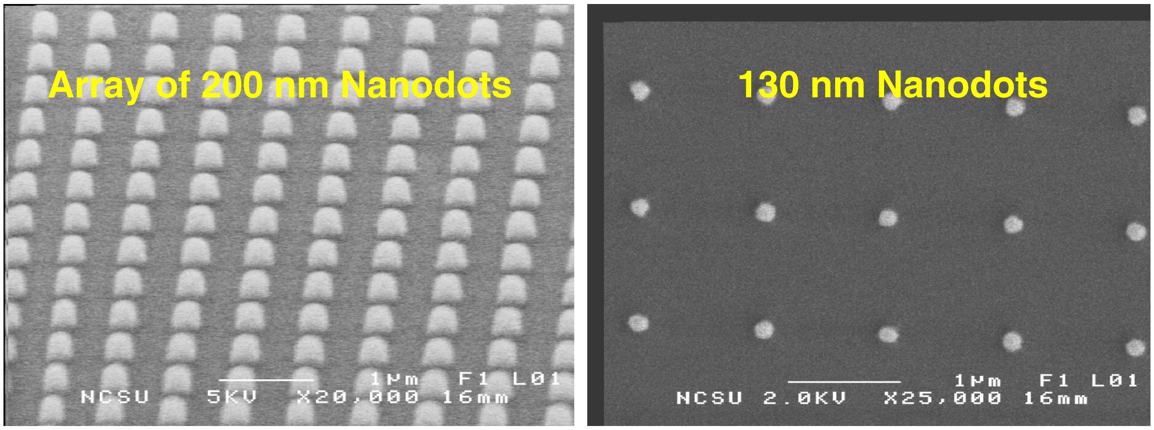
In a low volume, research mode coater track allows for manual dispense of resist on a wafer. This means it is possible to coat wafers with a very small stock of photoresist (It typically requires about 3 ml of resist to coat a single 6 inch wafer). Thus a small batch of an experimental resist could be coated on this track, and still utilize the high quality hotplates, the EBR system, and the exposure tool. Utilization of the manual dispense and the flexibility of the programming of the track also allows the creation of spin speed curves, contrast curves, and so on, for different resists, when used in conjunction with the 950B and the other metrology tools in the clean room.

With the installation of the coating tracks, the scanner was able to be used in a high volume mode. The combined tool sets were exercised in a marathon mode—being used to continuously process 200-300 wafers in sequence. The ability to provide volume exposures in this manner is a distinguishing characteristic of the TNLC within the NNIN. E-beam tools have higher resolution, but are not able to match the throughput or low cost afforded by this system.

A key emphasis is being placed on expanding the TNLC user base. Starting from a modest revenue base in its first year of operation (~$25k), the TNLC’s revenue more than quadrupled during the second year of the NNIN. This is especially significant since the overwhelming user base is external to NC State and UNC-CH. The expanded user base this year has provided the user fees to pay for the wafer track installation which was over $100k. Expanding the user base will continue to be a high priority during the next years. The TNLC still receives considerable operating funds from NC State, which will be phased out over the next few years and need to be replaced with user fees. We have showcased our capabilities at the Nanotechnology Conference in Charlotte NC in October at at the SPIE meeting in February. A second generation brochure is in production. In keeping with our priority to provide high quality service to users, a lot of time was spent training TNLC staff on the use of the tracks and the scanner. Two weeks of time were spent on track training at the Rite Track facility and one month of training at ASML's facility.

SVG 90-SE Wafer Tracks: left-coat/PEB track shown connected to scanner; right – develop track

Good technical progress was reported by a number of TNLC users this year. One important application of the scanner is the development of resists for 193 nm lithography. 193nm is the wavelength used in leading edge lithography, and with the use of immersion lithography, 193 nm is expected to be the workhorse for a number of years to come. Accordingly, there is considerable research and development interest in optimizing existing materials and developing improved resists. Two of the TNLC projects are aimed at improved materials. Other projects make use of the readily available resolution of the scanner (100-200nm) to make optical elements on glass substrates. We are now able to expose substrates that have either notches or flats and that are somewhat thicker than conventional silicon wafers. One particularly exciting project uses the scanner to produce full wafer arrays of nanoscale pillars that are subsequently used as molds for imprinting arrays of holes that make large numbers of controlled dimension particles for drug delivery applications.



Nanodot arrays fabricated with the ASML step and scan stystem

The educational activities of the TNLC have expanded during the past year. Although we have not received funding for such activities, we have adopted the NNIN's educational program priorities. This past summer we were able to host three important K-12 programs. First was the Talent Identification Program (TIP) program run by Duke University for middle school students. Second was the NC State Materials Camp for high school students. Both of these programs brought students into the TNLC cleanroom and allowed students to do hands-on lithography to produce substrates containing their school logos and other artwork. Finally we hosted a summer Emerging Science and Technologies Program on Nanotechnology for middle and high school science teachers . This week long experience included both classroom discussions of nanotechnology and cleanroom processing.

Middle and high school teachers learning lithography at the TNLC/NNIN

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