Annual Report of the National Nanotechnology Infrastructure Network
(abridged)

March 1, 2004 through Feb. 28, 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.

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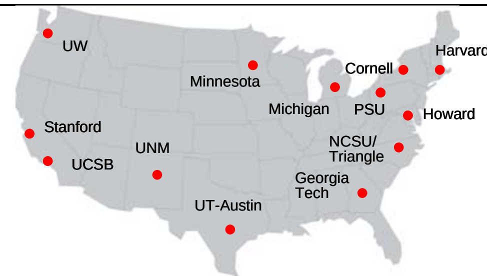
Abridged 2004 Annual Report for NNIN

1 Brief Summary of Annual Year 2004

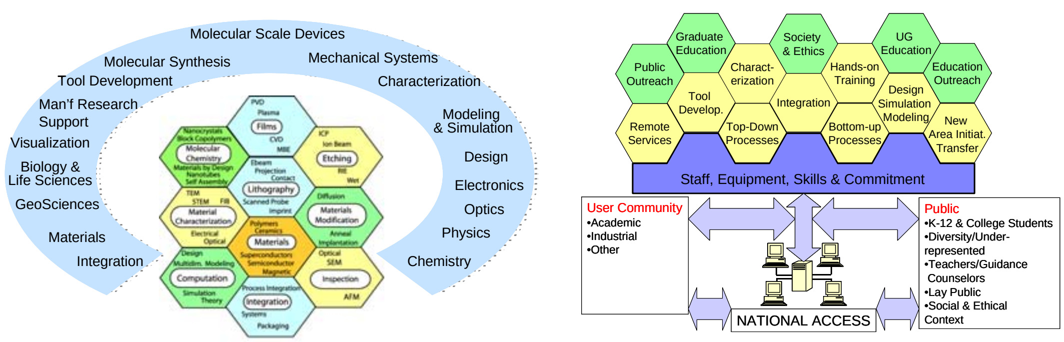
Figure 1: Member institutions of NNIN.



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 many disciplines that can benefit from nanotechnology. NNIN formally started operation on Mar. 1, 2004 with the mission to bring to fruition the promise of nanoscale science, engineering and technology. 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.

Science, Engineering and Technology Support: The network's current technology scope and activities are summarized in Fig. 2. We make continuous efforts through workshops, advertising, and presence at professional society conferences to assess needs of new directions developing through the worldwide nanotechnology activities, and to

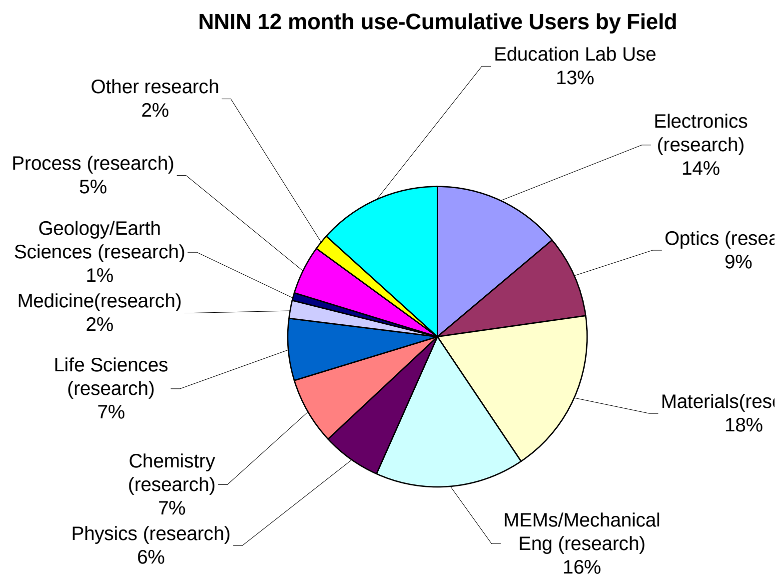
Figure 2: Network's scope of technical activities and organization of the support of national infrastructure goals.



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. 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. The key to success in this effort is openness and equal access to all, commitment to service, low costs, and rapid interchange. While the network has been in operation since March of 2004, as Fig. 3 shows, our outreach and success with serving the diverse user community has been very successful. An average of nearly 200 new research users per month are accessing the network currently. 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 in finding an efficient way for cross-training. For the infrastructure network, one of the best ways that we can support the research community is through an efficient continuous transfer and cross-fertilization of the knowledge of these techniques and new developments. Recognizing this, in addition to the staff for user support, we also have Technical Liaison staff (*Domain Experts*) at our sites to support research at the boundaries of disciplines. Examples of this 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 are some examples where the staff provides strong support.

Figure 3: Discipline breakdown, from the first ten months of the network operation, of 3468 users.



Our web-site (http://www.nnin.org) is a major link and store-house of information to technical and non-technical community. During the first year, the first generation web site was created including the database infrastructure to support the web site. This infrastructure is a necessary prerequisite to the creation of a broad web site with extensive information in a structured format, which is modifiable by all of the thirteen sites. With this infrastructure in place, NNIN is now rolling out the 2nd generation which will more extensively populate the web site with current information for technical users and the general public. The web site features a number of links encompassing technical information, education, information on equipment resources, accessing of the network, and outreach. Recent examples of research made possible through the network arealso included. A number of these examples, which have received extensive recognition as important contributions, came about due to the ability of bringing diverse techniques together through the staff. 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.), specialized sample preparation such as through focused-ion beam techniques, are available through the network. This work, in particular, can take advantage of remote usage, an area where we are placing increasing effort. Our remote usage in fabrication and processing increasingly supports 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. This allows us to provide the best resources and knowledge to the 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. Our web-site features a number of multi-media offerings related to education and outreach. There are lectures on the practice of nanotechnology, there are 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), as also instructional material related to social and ethical considerations. The network also conducts a very successful REU program, which had 72 participants in 2004, and a smaller RET 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. As the network activities build up, we will have courses and an open text-book that will become available on the web. As part of outreach and development activities, the network conducts workshops. To name two, a workshop in August of 2004 brought together educators and researchers from US and India to explore questions related to incorporation of nanotechnology developments in undergraduate and graduate curriculum, and one in December of 2004 to discuss the safe operation and conduct of nanotechnology research in facilities with large and diverse community of users. Reports of such activities are available on the web.

Societal and Ethical Implications: Integrated into our network activities are efforts 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.

Example Research: A number of examples of research from NNIN are available for viewing from the web-site.

2 Introduction

NNIN exists to fulfill the vision of the National Nanotechnology Initiative. The network is an interdisciplinary, multi-faceted and broadly-accessible infrastructure supporting near-term and long-term needs of necessary instrumentation, efficient access to the instrumentation and their use, and to conduct 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 coordination 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.

The thirteen sites of the National Nanotechnology Infrastructure Network began formal operation on March 1, 2004 in support of the objectives of the National Nanotechnology Initiative. This annual report reflects the first 12 months of operation - through Feb. 28, 2005. In some cases, data shown reflects statistics for 10 months through Dec 31, 2004.

NNIN is building upon the lessons learned and capabilities developed from a previous infrastructure network, the National Nanotechnology Users Network (NNUN), whose pioneering success provided incentive for the expanded NNIN program. The NNUN enabled and promoted the very rapid growth in applications of nanofabrication during the prior decade. The NNUN experience taught us how to effectively work 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. We have found that this 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 to train 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.

NNIN has a broader mission than NNUN – in technical areas, in education mission, in outreach activities, and in broader societal activities. The network serves these through an expanded network of university facilities, geographically dispersed across the nation, and by bringing new areas of specialization and complementary strengths. A key element in the assembly of network was 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 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 ownership, 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 not a research program and the funded activities at each site are not research programs or research centers. With the exception of the SEI activity (Social and Ethical Implications of Nanotechnology), no funds are expended to directly support research. 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 nature and scope of research performed within the NNIN facilities is determined by the users. That being said, there are certainly research programs and research centers located at or in close proximity to the user facilities. These research efforts do locally take advantage of NNIN facility resources, and NNIN facility in turn gains from techniques developed as part of these research efforts as well as the critical mass of usage that the centers provide. However, care must be taken to view the activities of the NNIN user facilities separate from any other university-based research centers. The facilities and the NNIN program are operated separately from these research activities. NSF Funds are provided to support the national nanotechnology effort and as a national infrastructure resource beyond the science, engineering and technology community. **A fundamental tenet of NNIN is that the units participating in NNIN control the resources committed to the network and treat all users, external or local, equally.**

Primary among the objectives of NNIN is the **support of user research** through appropriate state of the art infrastructure. The network, through the complementary strengths of the individual sites, provides **on-site and remote** external-user access to advanced top-down processing and bottom-up synthesis and self-assembly, comprehensive integration capabilities for multi-step processes, state-of-the-art characterization for hard and soft materials, the development of tools and techniques, and a comprehensive web and computation infrastructure. For the research support objectives, the thirteen sites bring >$250M in tools, >80,000 sq. ft. in clean room space, and >125 technical support staff to the NNIN program. NNIN facilities include essentially all of the country's university-based 100 keV e-beam lithography machines, the premier biology-, chemistry-and manufacturing-tools-oriented nanotechnology efforts, and the country's leading systems-oriented process integration facilities.

The network allows straightforward user access that enables a diversity of projects efficiently and at low cost: e.g., molecular-scale electronic contacts; use of functionalized nanotubes; integrated mechanical, electronic, fluidic, and bio-systems; advanced types of microscopy; and a large ensemble of other projects. New tools will be developed in support of future research and nano-manufacturing, including imprint and soft-lithography with applications in electronics, microfluidics, and nanobiotechnology.

With our network, a well-equipped facility is within easy driving distance from almost all population centers in the continental US. We have also been careful to select only sites with a demonstrated history of effective sharing of facilities both among different departments within the university and with outside users.

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. Initially we are building upon activities and interests existing at each site. The goal however is to develop network wide educational activities with national impact. These activities are coordinated from the Georgia Tech site.

NNIN also supports an infrastructure and research environment to promote consideration of the **societal and ethical consequences of nanotechnology**, covering economic, political, educational, environmental, health, legal, security, and cultural implications.

This report covers the first year of operation of NNIN. This was an important building period for the network to lay the ground work for successful network operations. During this period, the 5 former NNUN sites continued to serve the community of users, even through a two month no-funding period (Jan-Feb. 2004), while expanding their activities in line with the new mandates. The new sites began the program fresh with considerable required activity to establish the personnel, administrative, and user service infrastructure required to meet NNIN commitments. All sites have begun reporting data on operation and users to NNIN management. Details of the activities, accomplishments, and plans are reported in this document.

3 Mission and Broader Impact

NNIN exists to bring to fruition the promise of nanoscale science, engineering and technology by providing access to critical research infrastructure to the national nanotechnology community. These resources are equally accessible to academic, government and industrial users to provide a vehicle for research, education, and technology development 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. 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.

NNIN is also 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. With participating universities located strategically in many 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 put in place strong directed programs for local outreach. As these programs develop, the successful efforts will be models for development of nation-wide efforts.

4 Research Support Program, Accomplishments and Plans

4.1 Strategic Plan

In April of 2004, NNIN formulated a strategic plan which is the basis for operation. This plan describes our vision, goals and plans in detail.

4.2 Network Sites

The network consists of 12 funded sites and one affiliate. The affiliate membership allows us to evaluate the need for the specific specialized technical capability of the site (193 nm lithography at Triangle Lithography Center/North Carolina State University) for the national community and helps us direct related user requests. In order to cover the broad scope and provide the most advanced technical capabilities, sites were chosen and assigned specific specializations based on internal research strengths. All sites have responsibilities towards education and outreach activities, with specific major efforts at Howard, U. of New Mexico, Georgia Tech, and U. of Washington towards under-represented community.

- **Cornell:** Cornell, along with Stanford, has the broadest NNIN mandate with capabilities in biology, chemistry, MEMS, characterization, electronics, materials, and optics, and integration. Leadership of the network SEI activity (Prof. Bruce Lewenstein) resides at Cornell. Cornell is also be one of the sites responsible for nanoscale scientific computation support. Management of the network resides at Cornell.
- **Stanford:** Stanford is broadly responsible for user support across the entire range of nanotechnology, including capabilities in biology, chemistry, MEMS, characterization, electronics, materials, and optics, and integration. Stanford will also be one of the sites responsible for nanoscale scientific computation.
- **Georgia Tech:** Georgia Tech is responsible for Biology and Life Sciences applications of nanotechnology, with additional considerable expertise in electronics, MEMS, and optics. In addition, Georgia Tech is responsible for education and outreach coordination throughout the network. The Educational Coordinator for the network (Dr. Nancy Healy) resides at Georgia Tech.
- **University of Michigan:** The Solid State Electronics Lab at Michigan provides leadership to the network in integrated systems, i.e. integration of electronics, MEMS, microfluidics to create complex systems for biological sensing or 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. Washington has specific responsibility for serving the biology, medicine, and life sciences communities in their needs for nanotechnology, and participates in the SEI activities.
- **Penn State:** Penn State has specific NNIN leadership in the Chemical Nanotechnology (molecular nanotechnology) area.
- **UCSB:** The lab at UCSB has network leadership responsibilities towards support of electronic materials and physics applications of nanotechnology.
- **Texas:** The University of Texas has responsibilities to support chemistry and chemical nanotechnology, including soft lithography. They are also committed to efforts in tool development for nanotechnology and through such activities support of manufacturing research.
- **Minnesota:** The Minnesota NNIN Node (MINTEC) consists of the capabilities of three laboratories: the fabrication facility, the characterization facility, and the particle technology lab. The latter two are the primary focus of the Minnesota site, providing NNIN leadership in remote access characterization and in particles and nanomaterials. Particles and nanoporous materials are the primary overlap of nanotechnology to 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.

- **Harvard:** The Harvard node is located within the Center for Imaging and Mesoscale Systems (CIMS). Primary responsibilities for Harvard are leadership of the network in nanoscale computational effort and support for chemical nanotechnology processes including soft lithography. The Computation Coordinator of the network (Dr. Mike Stopa) resides at Harvard.
- **Howard**: The facility at Howard supports a variety of specialized materials activities as well as education activities, particularly to the minority community.
- **Triangle National Lithography Center (NCSU):** NCSU is an affiliate member of NNIN, for the sole purpose of providing access to 193nm deep UV 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.

Leadership areas and assigned activities across the network are summarized in Table 1.

Table 1: NNIN Focus Areas and Responsibilities.

	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

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. These resources can and, in most cases, are made available to the user community as well through the NNIN program. One of the lessons of NNUN was that it is difficult, and indeed counter-productive, to define that certain resources are available to users but other related ones aren't. Our goal is to provide service and help the user accomplish tasks well and rapidly. If a specific characterization is necessary in the middle of processing, and the resource is available on campus, we put effort in getting the user take advantage of those capabilities. This requires leveraging 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 will be 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. Sites are expected to allocate resources in accordance with the assigned focus areas and should be held specifically accountable for success in those areas, separately from research or educational user numbers, or quality of technical accomplishments made possible, or other derived data metrics.

4.3 NNIN Funding

The network is structured as a primary agreement between NSF and Cornell, with subcontracts 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. Integrative network activities, such as advertising and NNIN's national outreach, development of multi-media and national educational resources, web-site creation and maintenance, supplementary costs of integrative workshops, travel costs of affiliate member, etc. are funded through the management budget.

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.

The specific technical focus responsibilities of each site are detailed elsewhere.

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.

Most NNIN support is directed to the laboratory research support activities. Approximately 83% of NNIN funds are budgeted for laboratory support, with 13% for education, 3.4 % for Society/Ethics, and 1.8% for unassigned management expenses. This is shown in Figure 4.

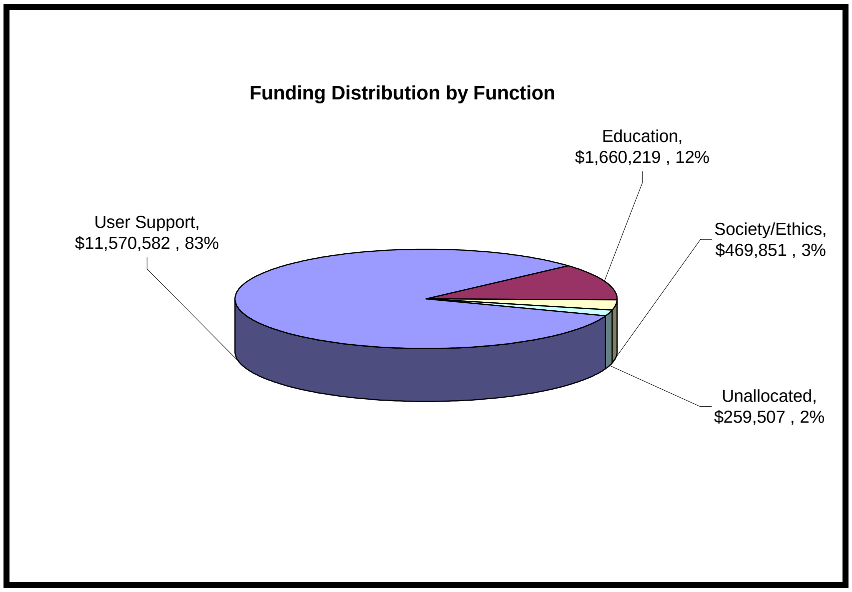


Figure 4: Network Budget by Function.

NNIN will be a highly dynamic infrastructure, continuously evolving 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 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 will 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.

At this juncture, there is considerable variation in the utilization of budgeted funds and the assigned personnel. This reflects the various rates at which sites have been able to ramp up to the network responsibilities. In particular, hiring of some of the specialized technical liaison staff to support users in biology, chemical nanotechnology, and computation, for example, requires many months and is only now being completed. The personnel report is a snapshot of FTE on Jan 31, 2005.

4.4 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. 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 another important consideration in performance evaluation. The quality and impact of the work performed — the research by our users — is largely intangible or/and not easily quantifiable.

By design, each site is different with different types of activity and different laboratory structures. In addition, few of the facilities exist in isolation from other related centers which are not part of NNIN. 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. 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, for example. 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, satisfaction surveys, etc., which will be 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 has 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 be consistent with the NNIN scheme.

For sites which overlap considerably with other activities, creating definitions of use, users, facility equipment which were inclusive enough to account for the diversity of sites and activities at those sites, but not so inclusive as to count activities not part of NNIN mission, or activities that are part of other centers and program, has been and remains a challenge. Considerable more work needs to be done, however. These data are reported regularly to NSF. Since this is still the initial period of the functioning of the network, and given the complexity of collection and assessment described above, NNIN is still going through the refinements to make sure that the data are reliable, truly reflective of the site efforts, and consistent across sites. There remain some inconsistencies between sites in the manner that activities are counted and the accuracy of the data, and we continue to make progress in clarifying issues in the collection of statistics as issues come up. It will remain a major priority of NNIN management and the site management to refine the algorithms and definitions, confirm the accuracy of each metric, and streamline the reporting process as the year progresses. It is our intention to use the results of these for performance evaluation and ultimately funding judgments so every effort must be made to make the data accurate and reliable.

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.

- **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.

- **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 to the other user counts, and can not be derived from them. Specifically it is **not** the month to month change in cumulative users. Note also that new user training is particularly time intensive.

Each major metric is subdivided and data collected both by 1) technical field, and 2) 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.

In addition, two "cross-cutting" activities - "advanced characterization" and "advanced computing" - are also tracked. Admittedly, there are no sharp boundaries between these categories, and due to the interdisciplinary nature of nanotechnology, most projects 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, 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

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.

4.5 Network Performance Profile

4.5.1 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. 5 shows the distribution of users, and new users and usage across the network. Even at this early date, the broad distribution of network users is apparent. As time progresses, however, two things will be important: 1) the evolution of the user field profile over time, and 2) the correlation of site specific activities with the NNIN assigned focus activities. These, however, require a larger data set over a longer period.

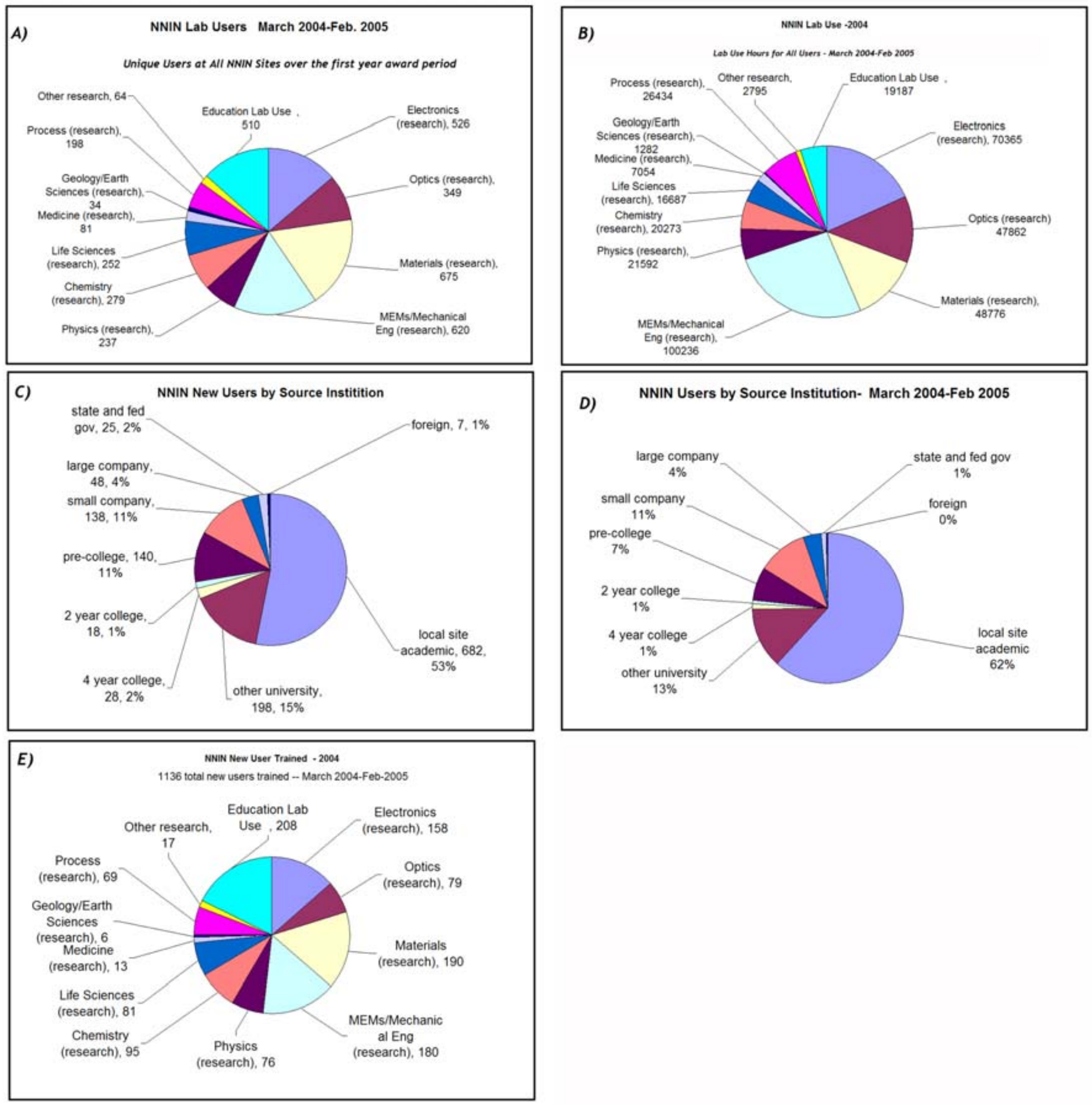


Figure 5: Users, Usage, and New User distribution of NNIN for the period March 2004-Feb 2005 : A) Distribuition of Users by Field ; B) Distribution of Lab Use Time by Field ;C) Distribution of New Users by Field;D) Distribution of Users by Source Institution.; E) Distribution of New Users by Source Institution. .

4.7 Site and Network Performance Summary

The five sites which were part of NNUN have continued to serve a larger group of external users. The new sites have all begun the complex process of becoming a user facility. Each site has had to hire staff, develop administrative and tracking procedures, develop database structures, develop training materials, and have begun recruiting new users. Some already have made significant progress in building an outside user base and others are just beginning. During the upcoming months, network management will monitor progress of each site using the performance metrics and will continue the efforts at attracting external users.

5 Education and Human Resources

5.1 Objectives and Program Challenges

As a national network, NNIN can make very key contributions at the national scale in addition to those possible in the local environment. Highly successful activities at the local site can be transformed by the network for national impact and it is the plan of the network to keep this in mind as our activities develop and their impact is assessed. NNIN has as its goals a wide variety of educational outreach that spans the spectrum of K-gray, i.e., school aged children through adult professionals. 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. The NNIN has established the following goals for its network-based educational outreach and training:

- Expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering;
- Train 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: 1) developing and distributing activities to encourage K-12 students to enter science and engineering fields; 2) developing resources to inform the public about nanotechnology; 3) developing activities and information for undergraduates regarding careers in nanoscience; 4) developing tools and resources for undergraduates and graduate students that focus on teaching and learning and research; 5) designing programs to ensure the inclusion of underrepresented groups; 6) developing programs for technical workforce development; and 7) 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. The network coordination for these activities occurs at Georgia Tech with specific sites responsible for specific components of our education programs. Summarized below are some of the specific programs for education and human resources and the lead institutions:

1. Web-based open textbook on nanotechnology; University of Minnesota
2. Instructional modules for K-12 teachers; Georgia Institute of Technology
3. Workshops in emerging disciplines to educate established professionals; Harvard University
4. Tools for web-based education and outreach; Stanford University
5. Research Experience for Undergraduates; Network-wide activity coordinated by Cornell University
6. Research Experience for Teachers and Teacher Training programs; Georgia Institute of Technology and the University of California Santa Barbara
7. Workforce Development; Pennsylvania State University
8. Technical support for undergraduate and secondary school laboratories; University of New Mexico
9. Dissemination of education information and resources; Cornell University and Stanford University

The challenges of any large-scale activity center on coordination and communication. The coordination of the education outreach is being undertaken by the education coordinator (Dr. Nancy Healy) who joined the network at the end of July. Her first priority has been to visit each site to establish lines of communication, determine the scope of current and future activities, and to determine network and local needs. To date, she has visited nine sites and has held phone conferences with four sites. 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.

NNIN's coordinated activities have a very significant role to play in enhancing knowledge of this fast growing field for a variety of audiences. We believe that we are uniquely positioned to gather activities, resources, programs, etc. that have been developed at other sites (NSEC, MRSEC, STC, ERC, etc.) and adopt and adapt them for use by the NNIN and distribute these across the network and nation. This is an important objective of the NNIN as an infrastructure - in that we will leverage our network experience and resources to implement programs on a national scale, as well as disseminate information developed by others.

A challenge is keeping accurate records of our activities and resources and their critical assessment. 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.

The education coordinator is in the process of developing a tracking system for education efforts that will be used by each site to provide quantitative data on our efforts.

5.2 NNIN REU Program

NNIN conducts a large network-wide ten-week **Research Experience for Undergraduates** (REU) summer program in nanotechnology. Even though, NNIN officially started in March, NNIN was successful in advertising and attracting an excellent pool for its REU program by pre-award advertising and solicitation to a large group of university faculty. 550 students applied and 72 were chosen for the program.

The biggest challenge of an REU program is in providing a complete and exciting research program in a 10 week period. By leveraging the existing NNIN infrastructure for user support and training, NNIN can provide a very strong nanotechnology experience for new students in even this short period of time. The independent research projects undertaken by the students cover a board range of technical fields involving nanotechnology, enabled by the extensive NNIN equipment resources, with strong expectations, and strong mentoring and faculty involvement built in. The visibility of NNIN within the research community and the visibility of our REU program help assure program diversity. Our unique network-wide convocation provides a powerful conclusion to our program, providing an opportunity for each student to share their results in a public forum with the entire NNIN program.

Each student in this program participates in a real research project as a member of an established research team. For the most part, these are funded research projects at the NNIN sites, with the students working with a graduate student mentor for day-to-day activities and strong faculty involvement for the broader mission, objectives, and conduct of the research. In some cases, students work with facility staff in support of broader process technology. We require that there be a strong intellectual focus to each of the projects, with extensive mentoring by students, faculty, and NNIN staff.

The program is focused on providing realistic research experiences to developing undergraduate scientists. Our previous programs have shown that this experience has a direct positive effect on career choices. Through this program we make a significant contribution to the human resources pool of scientists and engineers trained in nanotechnology. This impact will be apparent by the number of REU students who pursue careers in nanotechnology or related fields, at the BS, MS, or PhD levels. It is our objective to track, as we have done in the past, the path that the students participating in our program take.

In support of these major objectives, major characteristics of our program are:

- We provide a hands-on research experience with state-of-the-art instrumentation and expertise in nanofabrication in an environment well-suited to efficient user training and user support.

- Our program is individual project based, with each student independently responsible for a research project. This provides a quality realistic research experience for those considering future careers in technical careers.

- We have a large pool of available faculty, much larger than that available at any one site, with keen interest and experience in supporting undergraduate research. This enables the program to cover a broad technical area and enables a strong match between student and faculty interests.

- We continue to focus on attracting a broad range of minority/female students to our program. With contacts developed over the past 11 years, we also focus on under-represented non-research institutions.

- Our progam employs a network wide convocation to allow students to share their research results with their peers from other sites. Through the convocation, and other inter-site technical exchanges (videoconferences), we will expose the students to a extremely broad range of nanotechnology fields and research opportunities.

The 2004 REU program at 5 of the NNIN sites was funded by the NNUN REU program; the program at the seven new sites was funded in 2004 through NNIN funds. For 2005, 79 students will be supported through a combination of NSF site funds, NNIN funds, and industrial support.

5.3 Training and Development Activities

Substantial progress has been made on a variety of training and development activities across the network. At this point, much of the work completed has been accomplished at the local level. The education coordinator is compiling this information to develop dissemination plans for the network-developed programs and activities.

The Open Textbook will be a web-based textbook for nanotechnology to be used at the upper undergraduate and beginning graduate student level. The matrix for the textbook has been developed by Dr. Steve Campbell of the University of Minnesota and disseminated to the site directors with lead writing assignments established. Currently the matrix is at the feedback stage and once comments have been received and incorporated, writing assignments will be fully developed and writing schedules will be defined. We have had discussions regarding the development of guidelines to ensure the consistency of the format.

An important component of our education training will be the development of instructional materials for K-12 schools. Discussions at various sites has indicated the need for a continuum of instructional materials ranging from “simple” hands-on presentations to school and community groups to curriculum modules tied to state and national standards. The education coordinator has been collecting the instructional materials developed at NNIN sites and from other resources to develop an on-line resource for teachers and sites to use.

Stanford University in collaboration with the Mid-continent Resource for Education and Learning has received an Nanotechnology Instructional Materials Development award (proof-of- concept) from the NSF entitled “A Nano Leap into New Science.”. Stanford will serve as the content experts on the development of modules aimed at high school physical science and chemistry courses. This project is an outgrowth of NNIN education outreach at Stanford.

In the summer of 2004 Georgia Tech hosted two RET teachers, Stanford University hosted one, and the University of Washington hosted two. Stanford's participant developed a lesson plan to teach students the process of photolithography. The University of Washington participants developed a high school classroom activity on self-assembling hydrophobic/hydrophilic monolayers. The Georgia Tech participants developed implementation plans on how they would present their research experience in their classrooms.

Course development at the post-secondary level is also occurring at NNIN sites. The University of Michigan has developed a web-based course on MEMS that is being utilized by seven graduate students at Howard University in addition to other students across Michigan. They have also developed a Societal Impact of Microsystems course for upper undergraduates and beginning graduate students. Four sites (University of Minnesota, Stanford University, University of California Santa Barbara, University of Texas) are working with Pennsylvania State University's ATE for Nanofabrication Manufacturing Technology Partnership to develop similar programs for two year colleges. The University of Minnesota has a joint grant with Dakota County Technical College that developed a capstone experience for two-year AAS students with students beginning fall 2004. Under the NNIN, this program has been expanded to include Chippewa Valley Community College.

The University of California Santa Barbara has implemented a six month internship program for community college students at Ventura and Santa Barbara Community Colleges entitled Technicians in Nano Technology. One student is currently participating and a second student is in the selection process. The University of New Mexico is working with Southwest Indian Polytechnic Institute to develop a pre-engineering program that will include nanotechnology. In addition they are developing an Introduction to Nanotechnology course for undergraduate engineering majors. They currently provide a lecture on "What is Nanotechnology" for the Introduction to Engineering course. The University of New Mexico has also developed seminars for undergraduates on the society and ethical implications of nanotechnology.

UCSB is currently working with local industry users to build career pathways for students. They are forming a Board of Industries which will provide input on the skills that seek in employers. From this information, UCSB will develop educational short courses for post-secondary students with industry partners providing internships.

Pennsylvania State University has provided outreach and demonstrations to community colleges and their own students to recruit these students into nanotechnology career paths. Howard University is creating a six-week capstone course for its freshmen engineering course that will focus on nanotechnology and it will be ready for the spring 2005 semester.

Pennsylvania State University is developing a new teaching clean room facility which will allow remote access to selected processing tools and characterization equipment. A successful pilot of remote access of AFM and SEM technology was completed in October 2004. The goal is to use such equipment in outreach activities and on site learning experiences.

The NNIN web-site also includes a variety of educational material – nanocourses, mentoring of graduate students, discussions on societal and ethical issues, that have been developed at Cornell University.

5.4 Integration of Research and Education

Two of our most prominent programs for the integration of research and education are the REU and RET programs. The REU program has been described above. The RET program occurred at three sites during the summer 2004 under NNIN funding. Georgia Tech, Stanford, and the University of Washington hosted a total of five teachers. All five teachers completed research projects using the facilities at each site and developed instructional materials/lesson plans to infuse their experiences into their high school classrooms. These materials are being collected by the education coordinator for placement on the NNIN web site.

The University of California Santa Barbara has sponsored two high school students in the Apprentice Researchers Program. This program brings high school students to campus to undertake research activities in nanotechnology. They are also developing with Santa Marcus High School (80% Hispanic) a six week after school program for 11^{th} graders to do laboratory experiments in nanotechnology and assist the participants in designing science fair projects.

The University of New Mexico had two high school students participating in the NASA Sharp program conduct research in nanotechnology during summer 2004. The NNIN supported this effort through facilities and equipment support for the participants.

5.5 User Training

Training of new and continuing users is a major component of NNIN activities. The quality of training is a determining factor in the success of NNIN and what makes the NNIN facilities distinct from other research centers which serve users as a sideline.
Our goals for these programs are to provide practical training to all users at an appropriate level, from novice to expert, efficiently and effectively. Users expect to be in the lab and working within a period of days after arrival. Firstly, all users must receive safety and general laboratory rule training. Depending on the tool and the site, tool specific training can be accomplished individually, in small groups, in small classes, or via multimedia computer based systems. While multimedia computer based training has significant upfront cost of time and dollars, there is significant benefit to be derived. We are developing common instrument training protocols that will be available in multi-media format on our website. The human element — from knowledgeable staff— will, however, remain critical. Because there is significant overlap in tool sets between sites, NNIN will make every effort to share training materials between sites. Instructional training media will be available both via the NNIN web site as well as individual site web sites. By making training openly available on the web sites, we will also help train many

non-users from across the nation. This is an integral part of NNIN's national infrastructure mission.

5.6 Education Program Plans

While much activity has occurred across the network, we have several initiatives planned to continue to meet the NNIN education goals and objectives. The education plans discussed here are the ones for the **near future**. Based on feedback received from the site coordinators, we will be developing our communication structure. Several coordinators have indicated that they would like to meet as a group to discuss issues facing each site, share ideas, and develop joint programs. We will schedule an education coordinators meeting for late winter or early spring 2005. We will also develop a list serve where questions can be posted by coordinators and resources shared. Lastly, we will have phone conferences every other month to address issues and concerns, share activities and resources, and provide updates on meeting goals and objectives.

A high priority is development of the NNIN education web site. We will provide links to undergraduate activities that are occurring at sites, such as a link to the University of Michigan MEMS course, UCSB's internship program, and PSU's Nanofabrication Manufacturing Technology Partnership. All training and development activities sponsored by the NNIN will also be posted at this site. The Education Coordinator will work with the Cornell site to develop the education site on the NNIN web site.

The Education Coordinator will be developing a tracking system to collect information on the outreach activities occurring at all levels. It will be imperative that this system be accessed remotely from each site for logging in of data. The system will be developed to determine the type of activities occurring, the duration, number of participants, target audience, etc. With such a tracking system, we will be able to have quantitative data on the extent of our outreach activities at both the local and national levels.

In terms of workforce development, sites will continue to work with PSU in developing a similar community college program for their regions. We will also disseminate UCSB's internship program to other sites for possible adoption. UCSB will also be developing short courses for undergraduates in nanotechnology. These courses will be used to recruit students into the field of nanotechnology.

6 Outreach and Knowledge Transfer

6.1 Objectives

As noted above, to attain each of the NNIN's education objectives, a variety of innovative activities have been defined. The network coordination for these activities is occurs at Georgia Tech with specific sites responsible for specific components of our education programs. Summarized below are some of the specific programs for outreach and knowledge transfer and the lead institutions:

1. Science magazine for grades 1-5 (6-10 year olds); Cornell University

2. Nano Road Tour, a mobile nanotechnology presentation; University of Texas

3. Videos and Public Service Announcements for K-12; Howard University
4. Guidance Counselor outreach on educational and career opportunities; University of Washington
5. Nano Camps for middle and high school students; Pennsylvania State University
6. Mentoring programs for secondary school students; Howard University
7. Inclusion of underrepresented populations; University of New Mexico

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.

6.2 Marketing NNIN via Conferences, Exhibitions, and Print

Promotion of nanotechnology and of the capabilities NNIN is an important function of NNIN, particularly in this first year. While the former NNUN sites have a continuing user base, we must be proactive in informing the user community of both the new sites and the new capabilities at each site. NNIN has trade show booths on both the east and west coast ready for deployment. Since March 2004, we have displayed at March APS, AVS, MRS Fall and Spring, the Election Ion and Photon beams conference, SPIE Microlithograpy and several specialized nanotechnology showcases. The booths are staffed by knowledgeable staff from various sites who can discuss nanotechnology applications with inquirers. These exhibits are important to raise the profile of NNIN and to recruit new users for all sites.

NNIN Directors and staff have given invited talks and participated in panels at a variety of conferences and institutions. These include the APS March Meeting, Workshops for Physics Teachers, Infocast, colleges in local community, national laboratories, and meetings that focus on commercialization of nanotechnology (Infocast, etc.) to promote awareness of NNIN and its capabilities.

In March of 2004, NNIN created a simple 4- page brochure describing NNIN, the NNIN sites, and the network capabilities. Thousands of copies were distributed to the sites, to NSF, and to potential users at conferences. This was updated in December with a new 12 page glossy color brochure. These have been distributed to the sites, to NSF, and to potential users at various trade shows and conferences. We will also undertake a targeted mailing to NSF and other agency nanoscience grantees, as well as to small businesses through commercial channels.

In addition, individual sites have developed flyers, brochures, and posters for their own site capabilities.

6.3 NNIN Outreach Activity

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

Georgia Tech and Pennsylvania State University had summer Nanocamps for high school students which served 175 students. These camps provided hands-on activities and an introduction into nanotechnology research.

Tours by middle-school and high-school students are a common activity at nearly all the sites of the network. During these tours, the students are presented information on nanotechnology, provided tours and in some cases short experimental experiences, and information on careers in nanotechnology. The Stanford site participated in the University's Community day and had over 500 people visit their nanotechnology exhibit that included demonstrations about nanofabrication and the NNIN. They developed self-guided tours of the SNF facility. In addition, the SNF hosted a two-day open house in April to celebrate its participation in the NNIN which included campus and industry attendees. Cornell utilizes a variety of occasions, its annual meetings and events organized by other Cornell centers, to advertise its capabilities, and to host day-long events focused on usage of facility resources.

The University of New Mexico has developed a brochure for recruitment of undergraduates and high school students into nanotechnology career paths. They are also providing a presentation on nanotechnology to students at a Santa Fe high school (80% underrepresented) and have done a similar presentation at other high schools. The University of New Mexico has a mobile laboratory to reach rural schools. They have under development a component on nanotechnology research that will assist teachers.

The University of Washington is working with Seattle's new science museum to develop an exhibit on nanotechnology.

The University of California Santa Barbara hosted a "Day in Nanoscale Science" that reached 120 13 year olds, 120 parents, and 50 volunteers (done in conjunction with John Hopkins University's Center for Talented Youth). A variety of activities were done by the students and their parents. Fifty students from Santa Maria High School (90% Hispanic) visited campus and did a lithography wet etch lab. Plans have also been made to provide similar activities when several of UCSB's student organization (including the Hispanic Organization) host approximately 1,200 high school students from Santa Barbara and Ventura counties (predominantly Hispanic students) in March 2005. UCSB has developed 11 new hands-on labs and worksheets for middle and high school students with teacher preparatory lab sheets with answer keys. These have been tested with students and are ready for full scale implementation. UCSB hosted seven public seminars in the summer which reached approximately 250. To inform the public they included parents in the student activity they held in conjunction with the Center for Talented Youth. Brochures have also been developed to seek industry support for internships and student clean room support.

Georgia Tech will be hosting approximately 300 eight graders in April 2005. The site will be providing tours and hands-on activities for the students. Georgia Tech has also met with the Georgia Alliance of Science Educators to receive recommendations on nanotechnology education. Georgia Tech is also working with NSTA on its proposed Virtual Learning Community link. They have also established a relationship with science and mathematics teaches at a metro Atlanta middle school who have agreed to help develop and pilot instructional materials.

The University of Michigan had 150 11th and 12th graders visit their facility for a tour and demonstration. They have had preliminary discussions with Holy Redeemer High School in Detroit (majority underrepresented) and Forsythe Middle School (Ann Arbor) for piloting NNIN-developed instructional materials. A public outreach brochure on nanotechnology is also being developed.

Pennsylvania State University has established the Center for Nanotechnology Education and Utilization which houses the Nanofabrication Manufacturing Technology Partnership the ATE Center for nanofabrication manufacturing education, and the NNIN education outreach office. By housing several of its efforts in one center, PSU seeks to leverage its various outreach programs to address incorporation of nanotechnology in K-gray education.

PSU has developed activities for grades 9-12 including kits that demonstrate the practical applications of nanotechnology with everyday products. They are currently revising and aligning these activities to meet state standards. PSU has also been active in providing seminars, workshops, and conferences on nanotechnology that have reached approximately 1,400 participants. They have run a Hands-on Nanofabrication Workshop for Educators (65 teachers) and a Nanotechnology Learning Tools Development Workshops for Educators (19 teachers). Several of their outreach activities have been in conjunction with PSU's ATE for Nanofabrication Manufacturing Technology and support NNIN's workforce development goals.

During the summer of 2004, NNIN organized a workshop together with Indian Institute of Science focused on educational and interdisciplinary research issues of nanotechnology. The workshop brought together researchers and educators from USA and India, as well as a broad contingent of Indian educators and students, to discuss the key needs and suggestions for possible approaches for incorporating the interdisciplinary nanotechnology advances in undergraduate and graduate curriculum.

The workshop identified the guiding principles that should determine the changes:

- an undergraduate education should provide a broad and rigorous core education that prepares the student to be analytical and rapidly trainable for active technical contributions in design and manufacturing based on the science and engineering areas

- a graduate education should have a rigorous, complete and advanced technical focus, drawing on the current knowledge and that makes the student an independent thinker and problem solver. Research is the central thrust in graduate education in order to provide the student with the capability to ask the appropriate questions and find the answers for theoretical and experimental directions.

The principal observations and recommendations of the workshop were:

- Undergraduate education should remain focused on the breadth and rigorousness of a core curriculum that emphasizes the underlying knowledge of physics, chemistry, mathematics, and increasingly in biology, followed by a selection of courses that lead to a more rigorous technical direction. Exposing students to the methods and key ideas of the scientific process are critical. This broad education, with a technical focus, is critical to their becoming successful practitioners who may not necessarily pursue advanced degrees.
    - Biology is increasingly connected to the physical sciences and engineering. The ability for a student to take at least one course in biology as an option would provide a more complete education than is currently provided.
    - Nanotechnology is not a discipline; it is an inter-disciplinary area with significant underpinnings in engineering disciplines, physics, chemistry, biology, materials sciences, etc. Undergraduate students need exposure to this area, both for the knowledge of the major current technical questions and directions and on how it connects to the core education. Furthermore, nanotechnology can be used as a vehicle to excite and motivate students to purse careers in science and engineering. At least two mechanisms for incorporating this idea are:
        - an evolutionary change of course content for a variety of the classes so that they reflect problems and approaches of the nano-scale, and
        - offering of elective courses – such as introductory-level freshman courses that excite and motivate the students to want to take related advanced courses in subsequent years.
    - The participants were unanimous in their opinion that nanotechnology is not an area for a new department, nor yet an area where a degree needs to be granted.
- Graduate education, with its advanced technical focus and goal of making the student an independent thinker and problem solver, poses an interesting challenge for the interdisciplinary nanotechnology area since the strength of the underlying disciplines must be maintained.
    - Quantum mechanics, thermodynamics/statistical mechanics (i.e., molecular thermodynamics), materials science, biology, chemistry, systems engineering, and engineering as dictated by design, are all key elements of an education that the student must be able to draw on. It is critical that the students receive education in the related areas through approaches and instruction by faculty that connect to the science and engineering of the condensed state.

- Nanotechnology-oriented course offerings should draw on this knowledge to provide strong inter-disciplinary strength. Individual faculty members are not likely to be able to provide this inter-disciplinary breadth due to their discipline-specific focus.
    - A team approach (multiple faculty members across departments) to interdisciplinary teaching can provide a balanced method towards a more complete inter-disciplinary student education in nanotechnology that still assures that the underlying discipline-specific strengths are imparted.

New textbooks that can draw on modern computing and web-based resources that help connect the disciplines, are needed for effective instruction of a large group. Most universities are not likely to be able to draw on the multiple faculty members from different disciplines that are needed for effective teaching.

NNIN's effort in the open textbook will draw on many of the thoughts developed in this workshop.

6.4 Web

NNIN has developed an extensive web site to act as a portal for users and the public to NNIN activities, located at http://www.nnin.org. In addition to general information on NNIN and each site, the web site contains searchable network process database, and a variety of multimedia education and outreach resources. During the coming year, additions to the site will include additional educational resources, multimedia training, a current events calendar and the NNIN archive of SEI resources. The site is database driven to allow easy updating and permission based editing of selected sections by each site. The full features of the web site are still under development.

6.5 Outreach Plans

The Education Coordinator has been compiling K-12 outreach materials and links to resources that will be placed on the NNIN education website in the near future. These resources have come from NNIN sites and other NSF-sponsored sites such as NSEC and MRSEC sponsored programs. Georgia Tech has also been compiling web sites that would be useful for teacher who are seeking information on nanotechnology. These sites will be added to the NNIN web site.

While it is useful to compile instructional materials and demonstrations, it is critical that we link these materials to state and national standards. Penn State has a Ph.D. candidate in science education who is currently linking their outreach materials to state standards. The NNIN education coordinators will need to devise a plan on how to best link our resources currently available to national and state standards.

Georgia Tech has had preliminary discussions with three additional sites in planning an Instructional Materials Development proposal for the NSF. The possible partners are the University of Michigan, Pennsylvania State University, and the University of California Santa Barbara. We will also seek industry support to develop instructional materials for nanotechnology lessons in K-12 schools.

We will continue to organize focused workshops on key issues related to nanotechnology. A safety-related workshop has been organized for the day just before the annual meeting. In the coming year, our workshops will focus on hands-on usage, on attracting new users, developing usage in geology, and other issues as they are identified.

7 Social and Ethical Issues in Nanotechnology

The NNIN social and ethical issues (SEI) component is designed to provide an infrastructure for education, research, and outreach on social and ethical issues associated with nanoscience and technology. The infrastructure includes regular lectures and panels on social and ethical issues, creation of case studies and scholarly analyses, creation of educational modules, and development of an "SEI portal" within the NNIN website to provide easy access to SEI resources. The SEI component also includes research projects using the NNIN as a base for exploring ethical issues, organizational and workforce change, innovation and industrial change, and public understanding of nanotechnology.

7.1 SEI Infrastructure

To ensure that social and ethical issues are addressed throughout the network, each NNIN site appointed a local "SEI coordinator." The coordinators held their first annual meeting on 26 April 2004 at the University of Washington, to explore both the range of issues to be covered under the "SEI" label and to plan specific activities of the SEI infrastructure. Key outcomes of the meeting included:

- Planning for course on social and ethical issues (see below)
- Outline for the SEI portal
    - SEI Intro
    - Direct contact
        - Ethics consult
        - Public engagement
    - Suggested readings
        - Basic
        - News (about SEI)
    - Teaching resources
        - Educational modules
        - Sample syllabi (Engineering ethics, Nano ethics)
        - Tutorials on SEI (for both NNIN users and for public)
        - Case studies
        - Guidance for users: How do I identify SEI in my project?
    - Archived talks/panels
        - Speakers bureau
    - Statistics/data (e.g., NanoBank, workforce data)
    - Links
        - International nano projects (SEI)
        - Related links
    - INTERNAL SITE
        - SEI user data
            - SEI research users (demographics)

        - Event counter (speakers, panels)
    - For NNIN site managers
        - Safety and environmental issues
    - Research tools
        - Interview protocols
        - Intake/exit interviews

Tim Lenoir at Stanford has directed a team implementing the technical infrastructure to manage this portal. They have established the database, which is ready to be populated with documents, videos, and other materials. They have also created a video annotation tool that will allow viewers of live or taped discussions among nanoscientists and ethicists to be commented up on a blog-style commentary, thus extending the ways in which contemporary nanoscientists can be engaged in discussions about social and ethical issues.

After an international search initiated in February 2004, the NNIN SEI coordinator, Dr. Ana Viseu, began work on 5 December 2004 at Cornell. Dr. Viseu, a Portuguese citizen completed her PhD at Univ. of Toronto on social issues in nanotechnology. She will be responsible for working with the Stanford team to implement the SEI portal, including scheduling and taping of regular lectures and panels on social and ethical issues, drafting the educational modules, and compiling the bibliographies and case studies, as well as regular coordination with all NNIN SEI site coordinators.

7.2 SEI Events

Many NNIN sites hosted lectures or panels to explore social and ethical issues. Among the talks were:

- 8 April 2004, Cornell: "Social and ethical issues in nanotechnology" panel discussion (Bruce Lewenstein, Steve Hilgartner, Ron Kline, Cyrus Mody, all from Cornell) (videotape available on NNIN website)(co-sponsored by NNIN and Cornell Center for Nanoscale Systems)
- 13 November 2004, University of Washington: Thomas Stroebe (Univ. Washington), "Ethics in Science and Technology" (sponsored by UW Nanotechnology Students Association)
- 17 November 2004, Cornell: Steve Hilgartner (Cornell, "Ethics of Nanotechnology? What are Studies of Emerging Technologies Used For?" (sponsored by Bovay Program in History and Ethics of Engineering)
- 18 November 2004, Cornell: Davis Baird (Univ. South Carolina), "On the Mythology of Nanotechnology" (co-sponsored by NNIN and Cornell Center for Nanoscale Systems)

With the arrival of the NNIN SEI coordinator, we expect the number and frequency of panels and lectures to increase. They will be taped regularly and made available on the SEI portal.

Planning has also begun for several meetings on social and ethical issues to be held with NNIN support. Our activities in 2005 and 2006 include:

- February 2005, "Nanotechnology and the Public," session at American Association for Advancement of Science, Washington DC
- April 2005, "Science for Sale? Public Communication of Science in a Corporate World," 3-day conference to be held at Cornell
- 2006, "Science and Technology in Contemporary Society: Ethical Issues in Nanotechnology," jointly organized by Stanford and École Polytechnique (Paris)

7.3 SEI Education

A major goal of the NNIN SEI component is to integrate social and ethical issues into the education of all students (both undergraduate and graduate) pursuing nanoscale science and engineering. Significant progress was made toward this goal during 2004. Among the activities:

- Discussion among SEI site coordinators, both in person at the April 2004 annual meeting and in subsequent conference calls and e-mail exchanges, about content and design of ethics courses.
- Development of draft ethics curriculum, led by Dr. Kirsty Mills (Univ. New Mexico). Among the potential topics are:
    - Ethical systems
    - Molecular engineering (reality vs. hype)
    - Health and safety issues (for researchers, users, manufacturers, publics)
    - Human enhancement issues
    - Legal and regulatory issues
    - Stakeholders (general public, nano workforce, legislatures, judiciary, media)
    - Environmental effects
    - Cultural and religious issues
    - Privacy issues
    - Economic impacts (industrial change, nano-divide)
    - Education and workforce changes
    - International issues (including research distribution, technology export, military applications)
    - Best practices
- Implementation of ethics curriculum in Fall 2004 semester at Univ. of New Mexico (ENGR N-322, "Societal and Ethical Implications of Nanotechnology") (in progress)
- Continuing development of existing course at Univ. of Michigan in Fall 2004 (EECS 598, "Societal Impact of Microsystems") (in progress)
- Integration of nanoscience and technology issues into existing course at Stanford on "Ethical Issues in Engineering" (STS 115/ENGR 131) (Spring 2005)
- Development of website at Cornell on social and ethical issues for use in undergraduate courses (Comm/MSE 498, "Nanotechnology SEI website") (Spring 2004)

- Initial development of course on "Social study of emerging technologies" at Cornell (S&TS 720, to be offered Spring 2005)
- Initial development of course on "Bodyworks" (including implications of nanotechnology for medicine and human enhancement) by Prof. Tim Lenoir of Stanford (to be offered in Spring 2005 at Duke University)
- Guest lectures by NNIN SEI site coordinators in undergraduate courses and for visiting schoolteachers, including
    - September 2004, Stanford: Robert McGinn spoke to high school teachers
    - November 2004, Cornell: Bruce Lewenstein spoke to freshmen in AEP 102, "Introduction to Nanotechnology"

In addition to the integration of SEI into formal education, the NNIN contributed to broader public education about social and ethical issues by participating in the Kavli Institute Workshop for Journalists on "Nanoscale Science under the Microscope," 3-5 October 2004, at Cornell University. The workshop introduced journalists from major organizations, including the *Nature*, the *New York Times*, and the Associated Press, to key issues in nanotechnology, including both research frontiers and social and ethical issues.

In the coming year, the NNIN SEI coordinator will work with the NNIN Education coordinator to integrate SEI into the online training materials available through the NNIN website. In addition, further collaboration among sites will continue, to make the initial ethics curriculum and course materials more widely available.

7.4 SEI Research

Researchers associated with the NNIN have particular interests in ethical issues arising in the context of nanoscience and technology; public and researcher understanding, awareness, and responsiveness to social and ethical issues associated with nanoscience and technology; work processes and structures within the nanoscience and technology community; technology transfer/diffusion between the research community and industry; and social and historical analysis of the growth of nanoscience and technology. The following projects were supported by NNIN in 2004:

- **Identifying ethical issues perceived by NNIN users** (PI: Robert McGinn, Stanford). This project is designed to identify ethical issues in nanoscale science and technology that emerge from NNIN users. McGinn (who specializes in engineering ethics) has participated in NNIN training at Stanford and engaged NNIN administrators in discussions about ethical concerns. He also helped lead the discussion on ethical issues at the NNIN site coordinators' meeting in April 2004. From that background, he has developed a survey on ethical issues to be distributed to NNIN users. The survey covers areas such as interest in ethical issues; education in ethics (particularly science and engineering ethics); perceived ethical issues in science and engineering generally; perceived ethical issues in nanoscale science and engineering; and existing ethical beliefs. In December 2004 he will be contacting NNIN site directors to plan for distribution of the surveys, with field study to begin early in 2005.

- **<u>Organization and workforce change</u>** (PI: Suzanne Brainard, Univ. of Washington). This project is designed to document the processes shaping, the progress in, and the changes associated with the nanotechnology workforce. In year 1, databases have been established to document changes associated with four objectives:
  - <u>Longitudinal study assessing diversity and opportunity in nanotechnology workforce.</u>
    - Growth of professional nanotechnology associations
    - Number of certificates, 2-year degrees, 4-year degrees, and graduate degrees in nanotechnology (in collaboration with NNIN personnel at Penn State)
    - Post-NNIN experience of users at NNIN facilities (in collaboration with NNIN personnel at Georgia Tech and Cornell)
    - Surveying nanotechnology firms regarding type of industry, available jobs, skills and education necessary, and demographics of those hired
    - Identifying nanotechnology regional hubs
  - <u>Growth of nanotechnology as a field and discipline</u>
    - Growth of academic journals specializing in nanotechnology
    - Growth of academic literature on nanotechnology (currently complete for 1975-2003)
    - Growth of patents (both applied for and granted) in nanotechnology (currently complete for 1981-2003) (in collaboration with Georgia Tech)
    - Public perceptions
  - <u>Patterns of communication within SEI management team and Univ. of Washington user facility</u>
    - Currently designing research protocol for exploring multi-disciplinary, cross-site collaboration and work within NNIN (in collaboration with Univ. of New Mexico)
    - Conducting case study of work practices in multidisciplinary nanotechnology research team at Univ. Washington.
  - In addition, the Univ. of Washington team is collaborating with Cornell and University of New Mexico in more general explorations of social and ethical implications of nanotechnology research, including historical research on past industrial and technological revolutions and assessing curricular models for addressing ethical issues in nanotechnology.
- **<u>Innovation and industrial change</u>** (PI: Marie Thursby, Georgia Tech). This project is exploring the effects on development and diffusion of technological discoveries of a variety of factors, including business organization and

economic, regulatory, and legal mechanisms. In year 1, the research protocol has been developed for surveying NNIN users on the diffusion of nanotechnology from research site to implemented technologies. Links have been built between the data to be collected through these surveys and the quantitative data on publications and patents being collated at the Univ. of Washington and in the NanoBank project linked to NNIN through the California Nanosystems Institute at UC-Santa Barbara. The survey has been tested at Georgia Tech, and work is in progress to develop the links with other NNIN sites.

In addition, the researchers have conducted interviews to develop a case study of collaboration between a major U.S. multinational conducting leading edge research in nanotechnology and a university research center. Recent Congressional testimony suggests that negotiations regarding intellectual property ownership have become a significant impediment to business and university collaboration. The goal of this project is to write a case that can be used in multidisciplinary classes on commercialization of university research.

- **Public understanding of nanotechnology** (PI: Bruce Lewenstein, Cornell). This project is documenting the rise of nanotechnology as a public issue, including references to nanotechnology in mass media reports and public opinion about nanotechnology. Using an NNIN REU student (from UC Santa Barbara) at Cornell in summer 2004, the project completed gathering data on media references to nanotechnology, 1986-2004. Analyses are in process exploring the different topics covered in those reports and comparing coverage to other emerging technologies, such as biotechnology. In fall 2004, the project also coordinated a national public opinion survey on nanotechnology (in collaboration with Penn State); preliminary data are now being analyzed.

7.5 Other Activities

Many of the SEI site coordinators also participated in the planning for the NSF-funded Center for Nanotechnology and Society NSEC competition and are part of the teams that submitted preproposals in mid-November 2004. The NNIN SEI coordinator established that the NNIN SEI infrastructure would provide a distribution network for any of NSEC competitors who requested that it serve in that role, thus ensuring that the NNIN is available to all users throughout the country.

7.6 Plans for Year 2

With the hiring of the SEI Coordinator, the SEI component expects to be substantially more active during Year 2. Key issues for attention include:

- Continuing support for ongoing research projects
- Continuing development of curriculum models for integrating social and ethical issues in nanotechnology education
- Implementing the "seed grant" system for small research projects
- Identifying mechanisms for "counting" SEI users of NNIN

- Designing and implementing the SEI portal, including both distribution of information and archiving of NNIN history
- Scheduling regular SEI talks and panels at NNIN sites, with tapes/videos made and put on the SEI portal
- Establishing stronger mechanisms for sharing of SEI information among the SEI site coordinators, including providing for data needs for individual research projects on SEI across the NNIN.
- Establishing stronger links with the education component of NNIN
- Developing new programs in areas such as policy training and ethics consultations

8 Safety, Health and Environment

Mary Tang, Ph.D., staff member at the Stanford Nanofabrication Facility, is coordinating the Safety, Health, and Environment activities of the network. As its first activity in this area, NNIN is holding a workshop on the Health and Safety Aspects of Nanotechnology, organized by Mary Tang and Mandy Esch, Cornell, at Georgia Tech on Dec. 2. Program information is available via the NNIN web site or at http://snf.stanford.edu/Links/Nanosafety.html.

9 Diversity

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 small colleges.” 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.

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.

The University of New Mexico has created brochures to recruit undergraduate and high school students into nanotechnology career paths. They have distributed these brochures at several major conferences that they have recently attended which include: The Society of Mexican American Engineers and Scientists, the American Indian Science and Engineering Society, the Hispanic Engineer National Achievement Awards Corporation, the Society of Hispanic Professional Engineers, and the National Society of Black Engineers.

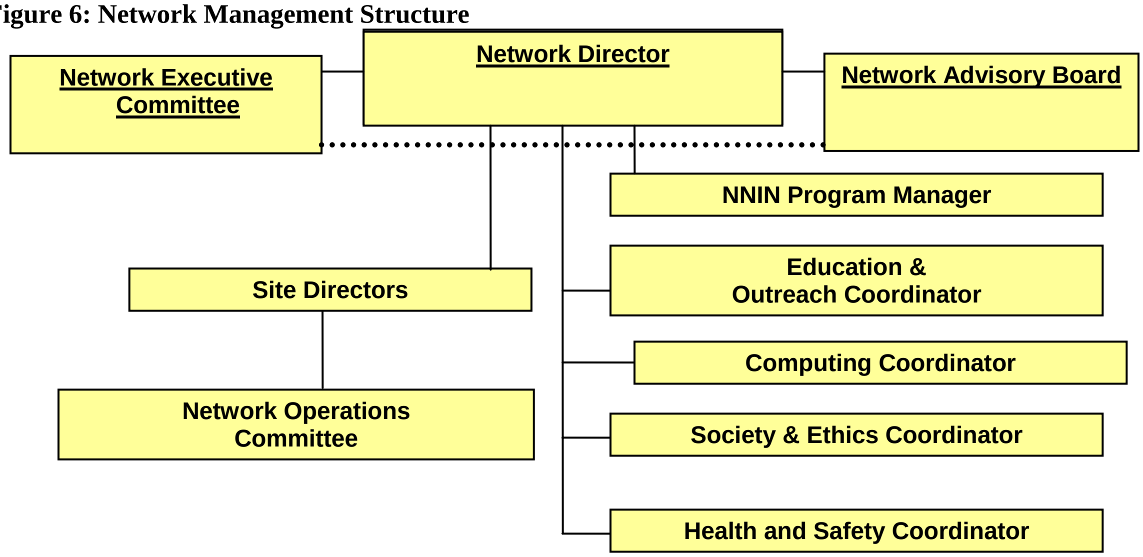
The University of California Santa Barbara is working with the on-campus Hispanic organization to participate in its Hispanic Day for southern California high school students. They have been working with a high minority high school (80% Hispanic) and will offer a six week after school program for 11^{th} graders in spring 2005. UCSB had a strong focus on recruiting minority participants in the high school field trips to campus with one session having 71% Hispanic students and another session having 29% minority students.

Howard University has several activities that focus on underrepresented populations. Currently, Howard has a video contest for the public service announcements that it is developing to reach minority middle and high school students. The NanoVan (traveling nano exhibit) will focus on touring Washington, DC inner city schools to provide enrichment activities focused on nanotechnology. Howard is also adopting high schools with high minority student populations for mentoring programs. Dr. Harris, site director at Howard, is organizing an NNIN session at the upcoming meeting of the National Society of Black Engineers.

10 Management

A cohesive management for the NNIN is essential to the coordination and operation of the various facilities that researchers will find easy to access and easy to use. 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. 6.

Figure 6: Network Management Structure



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 2 permanent members – Cornell and Stanford, 3 members elected from the other sites (currently Georgia Tech, Michigan and Harvard), and the

Coordinators of special thrust areas of the network. The NEC meets monthly by conference call, or more often, if necessary.

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 advise 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. Dan Kevles; Stanley Woodward Professor of History, Yale University
- Prof. Harold Kroto; Royal Society Research Professor, Chemistry, U. Sussex
- Dr. Carl Kukkonen; CEO, ViaSpace Technologies
- Prof. George Langford; Professor of Biology, Dartmouth
- Dr. Jim McGroddy; Retired Senior VP, Research, IBM
- 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

The appendix includes brief biography of the network advisory board members.

The Network Director is the point of contact with NSF, and has the day-to-day responsibility for implementation of network policies and program. To assist the Network Director, Dr. Lynn Rathbun (Cornell) has assumed duties of NNIN Program Manager to coordinate the daily activities and the long term goals of the network.

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:

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

The site directors are responsible for the operation of individual sites and will also provide feedback to the NEC to help frame the vision, policies, procedures, evolution, and management of resources. The site directors hold a conference call at lease once every two months.

Research-user support services – user scheduling, on-site and remote research service, etc. – are coordinated by the Network Operations Committee (NOC) which consists of the Laboratory Managers/Associate Directors/ or equivalent personnel that have day-to-day laboratory responsibilities.

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.

11 Advisory Board and Review Meeting

The first annual NNIN Advisory Board meeting was held at Georgia Tech on Dec.3-4, 2004. In addition to the NNIN Advisory Board, the meeting was attended by NSF program offices and six selected NSF reviewers. The combined meeting consisted of technical presentations, Network overview, site presentations, and feedback from the Advisory Board and Reviewers. A brief discussion of the major points follows. The comments by these groups have been taken under advisement and will help guide management activity in the upcoming year.

11.1 Advisory Board Report

The Advisory Board strongly praised NNIN for the good start on an ambitious mission. The commended the increase in support of network infrastructure by NSF and remarked on the expanded scope on the network to encompass new areas on nanotechnology. The Advisory Board was particularly positive about the role the NNIN has played and will continue to plan in supporting innovation in the small business community.

The Board commended the efforts of NNIN to promote itself in the technical community but suggested that this should emphasize promotion of small and newer sites as the capabilities of the prior NNUN sites are widely know.

The resourcefulness of NNIN in supporting an extensive infrastructure on limited budget was commended. Maintaining the capital equipment base at an adequate level was highlighted a significant challenge and they recommended more planning in this area.

While commending the expanded scope of NNIN, they cautioned against further growth (geographical or technical) without expansion of financial support.

The advisory board cautioned on the complexity of managing and coordinating a 13 site network and emphasized that additional resources and structure may be needed in this area.

11.2 Review Panel Report

NNIN received written comments from the Review Panel in January 2005. A response to the review panel has been submitted to NSF.

The review panel commended NNIN for the initial progress of the network and establishment of its culture. Several cautionary notes were common to several of the reviews. Amongst these concerns were

- Uneven initial progress of some of the sites.
- NNIN Web site organization
- Long term planning and goals management

NNIN is responding to these concerns through a detailed plan that the NNIN Program Manager is charged to implement. The efforts encompass attracting users to the newer sites, measurements and timely execution of network's efforts, and the development of the second generation of the NNIN website. The NNIN website is data driven and has incorporated in its organization. This provides all sites of the network to appropriately modify and input information for general dissemination.

11.3 Future meetings

Both the Review Panel and the Advisory Board remarked on the added value of interaction brought by bringing together the review panel and the advisory board. They also commented on the difficulty of such a meeting with mixed purpose and on the general format and length of the meeting. In response to these comments and concerns from NNIN itself, NNIN is in discussion with NSF on the timing and format of future meetings.

Appendix 1 Site Reports

A1.1 Cornell University Site Report

CNF's technical site focus and responsibilities are in the variety of the areas of nanotechnology with a strong focus on providing the complex integration capabilities as well as the support of the SEI, Safety, Computation and other thrust areas. The mission of CNF mission encompasses includes fabrication, characterization, synthesis, education, computation, and SEI.

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

CNF user base is 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 of 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.

In late 2003, CNF moved its entire operation to a new laboratory space, abandoning Knight Laboratory which had served it for 23 years. 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 during April, 2003 onwards, during the period Aug-Nov 2004, each piece of older equipment was deinstalled, decontaminated, moved and reinstalled, while the laboratory remained, for the most part, operational to the user community. The move presented CNF with an opportunity to renew and expand CNF equipment base in selected areas, and CNF has been able to take advantage of this opportunity.

Among the new facilities available:

- **JEOL 9300 FS E-beam Lithography Tool:** CNF has one of only two of these 100 KeV instruments at a US university. It is capable of writing 20 nm features at a speed of 50 MHz. Our tool became fully operational in Feb. 2004 and has received significant use which continues to expand as experience with its reproducibility and large-scale capability grows.
- A **Heidelberg DWL66 Scanning laser pattern generator:**. This tool can make masks or direct write on wafer to feature size 0.5 um. CNF recently obtained the first upgrade to "grey scale" exposure capability, another new capability within NNIN.
- Five **Silicon Processing Furnace Stacks with 20 individual tubes:** CNF acquired via donation and prudent purchase, and subsequently modified, rebuilt, and installed, five recent vintage 6" horizontal MRL furnaces. As retrofitted, they provide 10 atmospheric tubes and 10 CVD tubes for annealing, oxidation, CVD oxide, CVD nitride, and CVD Polysilicon where the properties of films can be

individually tailored to the various disciplines' needs. Ten total tubes are currently operational. When fully operational, this installation will allow proper separation of MEMS and Electronics process flow for optimum process capability. CNF was able to provide this advance resource for an investment of less than $650 K.

- **Hamatech/Steag HMR/HMP900 automated single wafer chemical processors:** These tools allow programmable spray chemical processing of single wafers; for etching, cleaning, or development. CNF has deployed six of these to improve reproducibility and minimize chemical waste.
- **Oxford 100 ICP Oxide etch:** In order to provide fast and high aspect ratio etching of silicon dioxide required for MEMS and microfluidic applications, CNF has acquired this ICP etch tool.
- **FEI 611 Focused ion beam:** CNF obtained by trade an FEI 611 focused ion beam system, with both cutting and deposition capability. It is now used for sample preparation for characterization (e.g. TEM, SEM) as well as for direct fabrication.
- **Woolam V-VASE Spectroscopic Ellipsometer:** This powerful and versatile tool measures the optical response of thin film stacks and by modeling can easily extract the thickness and optical properties of each individual layer. For many of nanoscale experiments dependent on complex structure, this is an indispensable tool for non-destructive characterization.
- **Wyko:** CNF has acquired a Wyko optical interferometer for height profiling of structures.
- **Applied Microstructures MVD100:** The MVD100 is a molecular vapor deposition tool with integrated plasma cleaning/activation. Organic self assembled monolayers can be adsorbed to change the surface chemical properties, useful for both MEMS and Life Sciences applications. This purchase was made possible by a grant from Intel and a cooperative arrangement with Applied Microstructures.
- Outfitting the new lab included a full new complement of **Gas Cabinets, Spinners, Hotplates, RCA wet Decks, Stripper wet decks, and resist stations.**
- **Xenon Difluoride Etch System:** CNF recently ordered an **Xactix XeF_2** dry etch release system for MEMS and biology applications. We expect this to be delivered in February 2005 and contribute significantly to our MEMS process base.
- **Computation:** See below

The value of these new tools alone is approximately $45M. 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 labs will enable expansion of CNF's chemistry and biology support facilities. In particular, on of the first efforts will be to set up a set of furnace tubes for full wafer CVD carbon nanotubes.

Among the new NNIN mandates for CNF is to be one of the network centers for computational nanotechnology. In preparation for this role, CNF obtained a Dell cluster of thirty-two dual processor Xeon as a donation from Intel in early 2004. Sixteen additional nodes have been promised for 2005. CNF has set a portion of the cluster as a Linux cluster for scientific computation, in particular for computational materials science and computational chemistry for nanostructures. After an extensive search, CNF recently hired **Derek Stewart, Ph.D.** from Sandia National Laboratory as a Scientific Computational Liaison. Dr. Stewart joined CNF on Dec. 1. Within the NNIN, the Technical Liaisons are experienced scientists with responsibility for helping users in highly specialized areas. Derek Stewart is working closely with other Computational Liaisons and Dr. Mike Stopa (Computation Coordinator, Harvard) to establish a coherent scientific computation resource spanning device and process simulation, computational materials science, and computational chemistry.

In early 2004, CNF hired **Michael Guillorn, Ph.D**, from Oak Ridge National Laboratory. Michael had previously been a CNF user and has extensive experience in nanofabrication and characterization. Michael serves as a user resource for materials and characterization, including liaison to the advanced materials characterization facilities of the Cornell Center for Materials Science.

In addition to operation, as the site of the director of NNIN and the prime contractor for NNIN, a significant amount of administrative tasks fell to CNF to get the network started. Not the least of these were executing twelve major subcontracts and establishing the NNIN use data reporting scheme.

The move to Duffield was a big time commitment for CNF, however, CNF stayed operational continuously during the period. The move did affect user productivity to some extent but the extent of disruption was managed and minimized. The move, however, did have significant effect on user fee stream with a significant drop between Oct. 2003 and March 2004. Since the beginning of summer, CNF laboratory activity has returned to normal, and is now taking advantage of the improvements in the laboratory's resources. Currently, CNF is operating at a steady stream of new academic and industrial projects with training of 5-10 new users nearly every week. In addition to these users, CNF is also beginning to serve a large remote user community that wants to take advantage of the specialized resources – high resolution (10's of nm) feature definition to specialized capabilities such as membranes and other structures used in biology and physical sciences.

Cornell hosts a number of education-oriented activities. These include the traditional activities such as hosting of high-school students with introductory lectures, laboratory tours, hands-on activities (nearly one visit a month), hosting of groups from activities organized by other Cornell-based centers (Physics Teachers Workshops of Center of Nanoscale Systems, Biology-oriented activities of NanoBioTechnology Center, Teacher programs of Cornell Center of Materials Research and Journalist oriented program of Kavli Institute), as well as CNF's own organized activities geared towards local community outreach and small colleges. CNF also teaches a Nanocourse over a period of 3 weeks during the summer that is attended by REU students, and academic and industrial users of CNF.

A1.2 SNF Site Report

Technical and Staffing Highlights

During this past year, SNF hired Dr. Paul Rissman to the newly created position of Director of Research Operations. Dr. Rissman has assumed overall responsibility for the operations of SNF to insure that our efforts and service best meet the needs of our wide-ranging research community. Dr. Rissman has previously run research operations at LSI Logic and the Hewlett-Packard research facility on Deer Creek Road in Palo Alto. As a result of this experience, he brings a new level of managerial professionalism to our operation and is already impacting our operation in significant ways.

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 expect to increase the monthly equipment charge cap for both academic and industrial users on January 1, 2005. The hourly rate charged to users will not be increased at this time 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.

We are encouraged, however, that this downward trend in industrial usage of SNF has finally stopped and that we are beginning to see a rise in industrial usage. This is based both on the number of industrial users that have been in the lab the past three months and on an increase in the number of industrial users in our initial biweekly safety training. We expect that our rate increases coupled with even modest increases in industrial usage will return us to a financial condition that is balanced over the long haul.

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

Two new Laurell resist spinners that will be used primarily by researchers interested in coating their wafers with resists and polymers that are not offered on our more automated systems.

A Nikon Body 9 stepper that should allow the development of patterns as small as 0.35 – 0.40 μm. This instrument is still undergoing initial characterization but should be released for general usage by January, 2005.

A SCT sputtering tool that will broaden the range of metals that can be sputtered in our laboratory. Engineering development and characterization of this tool has just concluded ant it has been released for usage by our user community.

A second STS deep silicon etcher has been acquired. 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 existing STS tool is the most heavily used piece of equipment in our laboratory so the completion of engineering characterization will have a significant impact on many users of our facility.

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.

Education/Outreach Activities

New Education Director. SNF hired a new Education Director, Marni Goldman, who is also Education Director of CPIMA (Center on Polymer Interfaces and Macromolecular Assemblies). She is also Associate Director of Stanford's Office of Science Outreach. She will report to SNF's Director of Special Programs, Mike Deal, and will help coordinate SNF's education programs and integrate some of them into CPIMA's and Stanford's local education/outreach programs.

REU. SNF participated in the NNIN Research Experience for Undergraduates program, involving the 12 NNIN sites. This year we took advantage of some of the REU activities of CPIMA, including their Career Day and Graduate School Workshop. Mike Deal helped Lynn Rathbun and Nancy Healy write the proposal to NSF for 5 years of NNIN REU funding. The three of them will make up the NNIN REU executive board.

RET. SNF initiated its Research Experience for Teachers (RET) program this past summer. We leveraged resources with CPIMA which has had an RET program for five years. One high school physics teacher spent 8 weeks working on a research project to develop force probes for studying touch sensation. He met weekly with the CPIMA RET teachers. These meetings were led by an education consultant retained by SNF. At the end of the summer, the teacher produced an education transfer plan which included lesson plans to teach his students the process of photolithography.

Community Day. 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 nanofab 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.

Nanoscience K-12 Curriculum Development. "A Nano Leap into New Science" curriculum development project was started this year. SNF collaborated with the Mid-continent Research for Education on Learning (McREL) to obtain an NSF Nanoscience Instructional Materials Development (NIMD) grant. This four year grant will result in the creation of a high school science module on nanoscience and technology. The project was kicked-off with a two day meeting hosted by SNF for those associated with the project from McREL and the external evaluators to learn about current topics in nanoscience.

Remote Users/Access

Number of remote users for last 9 months: 31 (7 industrial, 1 government, 18 other academic, 5 local). Of those, 10 were through MEMS-Exchange.

2. SNF staff did a remote demo for McREL visit (see #5 in Education report). We webcast a live, remote lab tour from inside the cleanroom to McREL personnel. Then we webcast a live demo of SNF's atomic force microscope (AFM) from inside the cleanroom. Shown were live images of setting up and operating the AFM, and then live screen shots of images acquired from the AFM, including AFM surface images of gold layers and DNA samples. 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 developed an extensive table of common furnace processes and recipes that remote users at SNF can have processed for them.

Societal and Ethical Implications of Nanotechnology

Professor Robert McGinn has begun his activities at SNF. In particular, he has personally completed our laboratory safety training so that he can enter the laboratory and interview SNF lab members to discuss their views and perceptions related to ethical implications of nanotechnology. Professor McGinn is also working on the development of a survey that will be distributed to a broader range of our community to assess their views related to ethical implications of nanotechnology.

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

Technical Progress and Accomplishments

The Georgia Tech Microelectronics Research Center (MiRC) acquired a JEOL JBX 9300FS electron beam lithography (EBL) tool in March 2004 and became operational and open to users on June 7th, 2004. The tool features 100kV accelerating voltage, 4nm Gaussian spot beam diameter, a thermal field emission source, can handle 300mm wafers with 248mm x 248mm of writing area, and can pattern sub-20nm line widths. Since that time there have been 21 unique research projects which have utilized the facility. These users include Georgia Tech researchers and scientists from the University at Albany and SEMATECH. Dr. Lee from Auburn University has used the Ebeam Lithography Facility to do experimental verification of his proximity correction software, "PYRAMID".The facility has successfully offered electron beam lithography baseline processing know-how and training to all of these users. Current state of the art capability includes 18nm line widths in positive resist and 12nm line widths in negative resist.

A collaboration has been established with Dr. Jud Ready of Georgia Tech Research Institute (GTRI) to research controlled placement and growth of carbon nanotubes for advanced interconnect applications. This research makes use of the capabilities of the Electron Beam Facility to control placement and patterning of nanometer scale catalysts islands in order to subsequently control the growth of carbon nanotubes.

The MiRC has ordered 2 RIE tools from STS that will be installed in December 2004. These will be individually dedicated to chlorine and fluorine based etching chemistries. The MiRC has upgraded its Astex/Plasmaquest ECR-PECVD system to deposit SiO_x, SiN_x and silicon oxy-nitride films. The MiRC has received from Intel a $50,000 donation equipment donation (computers, wireless PDAs, and wireless tablet computers) for support of NNIN and cleanrooom activities. In addition, the MiRC has submitted an equipment donation request to Intel for another $100,000 in equipment and software. The MiRC is in the final stages of selecting and purchasing a nanoimprint tool and thermal field emission SEM.

The MiRC has expanded its portfolio of online user training videos for user education before they come into the Cleanroom. The MiRC has advised other NNIN sites (e.g. the U. of Minn.) on the creation of their own training videos.

Besides assisting 26 outside users in the MiRC Cleanroom we have assisted over 30 remote users since March, 2004 on topics ranging from safety practices, process expertise, equipment troubleshooting and maintenance, user training, and cleanroom management software.

NNIN Personnel Hiring

The MiRC has hired Dr. Nancy Healy (previously with the South Carolina University System) as the NNIN Education Coordinator, Diana Palma as assistant educational coordinator, Dr. Greg Book (previously with Intel and Sematech) as a NNIN process domain expert and lead user outreach coordinator, Dr. James Joyner for part-time user outreach activities and a programmer for NNIN web and database development. The MiRC is currently interviewing a final group of candidates for another process domain expert and a bio-domain expert. Using Georgia Tech funding, the MiRC has also hired 2 equipment engineers to support cleanroom operations and Dr. Raghunath Murali to support the electron beam lithography facility.

Safety and Health

Course curriculum and training developed for Chemical Safety training in a lecture setting and Fume Hood training in a lab setting have to date trained well over 100 users. The Chemical Safety training has leveraged the help and expertise of Georgia Tech's Environmental Health and Safety personnel. A cleanroom accident response procedure has been developed that instructs users how to contact MiRC staff and emergency personnel, and how to respond to an incident (e.g. what steps to immediately take at the point of the incident, where to go for medical treatment, and what information to bring with them). A standard procedure for gathering a complete account of any safety incident has also been implemented so that a careful post-incident analysis can be made and lessons drawn from it. Georgia Tech will host the NNIN "NanoSafe - A Workshop on Enviromental Health and Safety in Nanotechnology Research" on December 2, 2004.

Computing

Georgia Tech is part of the Southern Light Rail project which is now operable as a part of the National Lambda Rail project. Connections came be made to most locations in the east, west and northern areas as well as some locations in Europe. Connections to Texas and Louisiana will be available after January 2005. The point-to-point connections can be made available with almost any variation in the amount of bandwidth desired. Data and video collaboration can include multiple sites if desired. Testing is scheduled here at Georgia Tech within the next month to review connectivity and equipment requirements for video conferencing and video transfer with data rates sufficient to cover HDTV quality transmission.

REU Summer Experience

Georgia Tech (Microelectronics Research Center (MiRC)) participated in the NNIN/NNUN network-wide REU program during summer 2004. 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) sponsored in collaboration with the Center for Education Integrating Science, Math, and Computing (CEISMC) Outreach Program at Georgia Tech. Both teachers worked on problems related to the e-beam lithography tool in the MiRC cleanroom. Their focus was to solve issues related to significant improvement in resolution of images produced at nanometer scale.

Other Education Outreach Efforts

Diana Palma, the Assistant Education Coordinator attended the Georgia Association of Science Educators (GASE) and National Science Teachers Association (NSTA) conventions to gather information and explain the NNIN program goals. Contact was established within Georgia Tech with Center for Education Integrating Science, Math, and Computing (CEISMC) Outreach Program at Georgia Tech, the math and science education outreach office on campus.

In June 2004, a 4-Day Activity/Tour/Speaker NANOCAMP (in collaboration with CEISMC) introduced 22 rising juniors and seniors from a wide range of Georgia high schools to nanotechnology. The diverse multi-cultural and socio-economic group with interest in math and science careers participated in interactive activities with professors and graduate students in discussion and demonstration settings. A follow-up activity day is planned for alumni participants in winter 2005.

In October 2004, 33 students and 6 chaperones and teachers from Renfroe Middle School Advanced Math and Science Program visited MiRC. The students toured the cleanroom and participated in a scale and measurement activity as well as watched a demonstration and explanation of wave-guide equipment by MiRC engineers.

Since late July 2004 Dr. Nancy Healy, the NNIN Education Coordinator at Georgia Tech, began to create links with the efforts already underway with all of the NNIN sites collect all information pertinent to programs already underway. She has visited nine of the sites and held phone conferences with the other four. Trips are planned for the other sites in early 2005.

Nancy Healy and Diana Palma met with CEISMC specialists in August to begin developing the RET and Nanocamp programs for summer 2005. They also attended a workshop sponsored by the Center for Assistive Technology & Environmental Access (CATEA) at Georgia Tech to learn how distance learning is becoming available to visually and hearing impaired students. CATEA expressed an interest in working with MiRC and NNIN as we develop web-based materials to make these materials accessible to impaired individuals. This advanced technology will be accessible to NNIN users.

In September Diana Palma visited the Math, Science and Technology teachers at Austin Road Middle School (Metro Atlanta) who have committed to piloting and promoting instructional programs developed by MiRC. Arrangements have been made to bring their entire 8^{th} grade to Georgia Tech on March 8 & 9, 2005 for the first ever NanoInfusion Day. This event will be coordinated by MiRC and will include campus-wide tours, speakers, and lab experiences for 150 students each day.

Dr. Janet Kolodner (College of Computing at Georgia Tech), a nationally recognized leader in the field of curriculum development, visited the MiRC and a collaborative relationship for the development of formal and informal teaching models and virtual instructional tool development has been established.

In August, Dr. Healy visited and established a relationship with the University of South Carolina's NanoCenter. Discussions centered on sharing of educational and public outreach resources and materials. In addition, the NanoCenter is proposing to NSF an NSEC and discussed ways that the proposed center could collaborate with the NNIN.

Nancy Healy attended a Conference at Pennsylvania State University highlighting the NanoManufacturing Technical Program (NMT), which is a 2-year community college technical training program with a culminating semester at PSU. PSU has as one of its NNIN education goals serving as a model for development of similar programs at other NNIN sites. They also shared an Interactive Learning Kit for teachers and students that they developed for summer NanoCamps and teacher workshops.

During Dr. Healy's visit at the Cornell Nanofabrication Facility, she met with Anna Waldron and Carl Batt the education director and co-director of Cornell's Nanobiotechnology Center. NBTC personnel have agreed to come to Georgia Tech in February to present a one day Microfluidics Lab they have created for high school students. This is part of our goal to adopt and adapt instructional programs developed at other sites for NNIN's use. We will recruit participants from Georgia high schools and also include teachers who are currently working with us on other endeavors.

A web-based resources and LISTSERVE for teachers who have expressed and interest in Nanotechnology information is being developed. This resource is updating them on links to information and resources on nanotechnology and will eventually become available to the NNIN website.

Nancy Healy and Diana Palma attended the Frontiers in Engineering Education Conference in October 2004 and the NASA Techbriefs NANO2004 Conference in November 2004 to enhanced their collection of instructional materials, ideas for new programs and developed further contacts for program development.

Workshops and Outreach

The MiRC provided a booth at the 5th Annual Nanotechnology Conference hosted by Z.L. Wang, Director of the Center for Nanoscience and Nanotechnology and the Center for Nanostructure Characterization in the College of Engineering at Georgia Tech. The booth provided potential users of the MiRC facility information about the NNIN user program, educational opportunities, and clean room user opportunities. The director of the MiRC, Dr. James Meindl along with Dr. Azad Naeemi, an MiRC research staff member, were featured speakers at this workshop.

The MiRC along with the Georgia Research Alliance (GRA) held a 1-day workshop on electron beam lithography in August 2004. The workshop included presentations on electron beam lithography, a panel discussions with panel members from Georgia Tech, other universities (Emory, Clark-Atlanta) and industry (Orthonics) and a tour of the MiRC facilities. Attendees included members of the Georgia Tech community, outside academic researchers, industrial researchers and the GRA.

The MiRC has hosted visits with Oak Ridge National Lab (ORNL) researchers to discuss opportunities for ORNL personnel to use MiRC facilities. The MiRC has also advised ORNL personnel on facility requirements, installation procedures and operational procedures for their EBL tool (a JBX 9300FS to be delivered in 2005).

The MiRC has provided speakers to local civic groups (Kiwanas and Key Club, the high school counterpart to Kiwanas) to described nanotechnology, the NNIN and research opportunities and programs at Georgia Tech.

Societal and Ethical Implications

The MiRC along with Prof. Marie Thursby has developed a voluntary online user survery/profile instrument that will be used to build a database of user information that can be used by the societal and ethical research portion of the NNIN. This survey instrument has been approved by the Georgia Tech Internal Review Board and will be shared with any other NNIN school.

A1.4 Michigan Site Report

Technical Focus

The principal focus of the University of Michigan **Solid-State Electronics Laboratory** (SSEL) under the NNIN program is to provide facilities and processes for the integration of Si integrated circuits and MEMS with nanotechnology, with applications in biology, medical systems, 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 nano-scale, practical realization of nanotechnology-based systems will require this type of micro/nano integration. SSEL 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. In addition, as one of the major university fabrication facilities in the middle part of the country, SSEL will also provide access to users to a variety of technologies and materials covering all aspects of the nanosciences. The University of Michigan is also home to the MGRID, a networked computational resource that could be used by users to attack complex computational problems facing the nanoscience community.

Activities During The First Year

As one of the new sites in the NNIN, Michigan has focused its efforts during the past few on hiring personnel, developing the infrastructure needed to support users, on user outreach and training, and on education and establishing the framework for SEI studies.

Personnel Hiring

After the start of NNIN, Michigan has hired or reassigned a number of staff positions to carry out the goals of the NNIN. First and foremost, Dr. Sandrine Martin was hired as the technical manager and the person in charge of conducting many of the day-to-day activities of the NNIN and its users. Dr. Martin was an accomplished researcher in the area of thin-film displays and solid-state devices and technologies and brings with her a rich technical knowledge and background as well as commitment to users' needs. Dr. Gerry Roston has been hired as a computer programming specialist who is in charge of automating all of the operations of the SSEL as well as installing user data collection and monitoring software to provide the necessary statistical data needed by the NNIN. He and his two assistants have installed a new on-line web-based tool reservation and tracking system that can be expanded to the whole network if needed. Several of existing SSEL technical staff, including process and equipment engineers have been reassigned to the tasks of supporting the users and maintaining the equipment that is used by them.

User Outreach

One of the most important tasks of the Michigan site has been to recruit and reach out to new users. While we are not yet in an ideal situation in this regard, following staff hiring and reassignment, we have made several efforts on behalf of either the NNIN or the Michigan site to inform users about our capabilities or publicize the objectives of the NNIN as a whole. Some of these efforts are summarized below:

Nano Event, June 9th, 2004 Organized by Small World Expo at the Renaissance Center, Detroit, MI Attendance: about 30-40 people. Informal meeting, networking reception

August 2004. Feature article on SSEL and NNIN in Michigan Small Tech Association Journal

Hitachi High Technologies America – Nanotech Seminar September 22nd, 2004 Organized by Hitachi HTA at the Michigan League, Ann Arbor, MI Attendance: about 40 people. Series of presentations on nanotechnologies and materials science

NanoCommerce 2004, October 5-7th, 2004 Organized by: Small Times at the McCormick Place, Chicago, IL. Nanotechnology business conference and trade show. Not personally attended by SSEL, but SSEL provided some informational material (brochures, business cards) presented on MEDC booth. Attendance of ~400 people

Interfaced with several external users and discussed their needs and the ways they could use the SSEL and the NNIN services. Several of these users are considering using the SSEL but are now limited by their available funds.

While the number of external users of SSEL is still limited since we have just started, we have a very diverse user base, both in terms of academic discipline and based on the research areas of interest. The following two pie charts provide a summary of research groups using the SSEL, based on data collected in the past few months using our automated system.

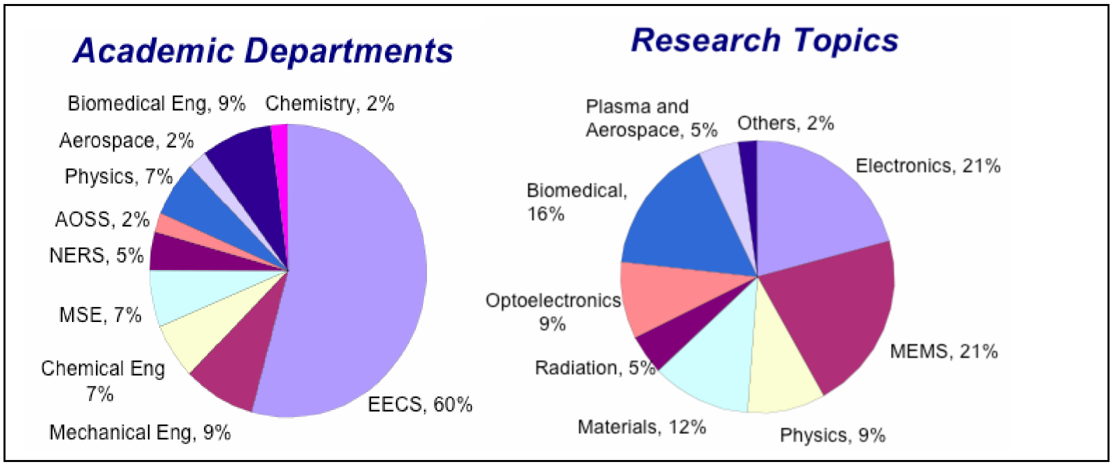


Figure 7: Michigan distribution.

Most of our current users are on-site users. However, the SSEL also serves a limited number of remote users, through the MEMS-Exchange program. Over the last 7 months, 15 remote users made use of the SSEL for about 100 hours of lab time.

User Training

In order to accommodate users and facilitate their training, SSEL has undertaken several efforts. These are summarized below:

- Online safety training for faster access to the lab
- Online lab orientation and equipment training in progress
- Equipment training:
- provided by staff for improved consistency and quality
- available for both new and existing users
- no charge for training
- lab access fees waived during training period for new users (up to 1 month)
- documentation available online, to be reviewed by users before hands-on training

These activities will continue in some areas and will be completed in others and others will be started based on user feedback.

New Equipment and Lab Automation:

As mentioned above, one of the primary activities for the SSEL has been installation of a fully automated online system for lab access, equipment training, user data tracking, accounting and charging. This system is critical to both the success of the NNIN at Michigan and to the easy access to this facility for our users. All users use this system to provide their demographic information and the system collects and compiles all of the relevant information about our users. As the system is finalized we will also automate the billing and charging of fees. Currently users can use the web to reserve and track various equipment, to monitor their usage of the facility, to obtain forms and other training material, and to interact and communicate with other users.

During the past few months several new equipment have been installed and are available to users. These are summarized below:

- Tempress LPCVD furnaces: A stack of furnaces for LPCVD deposition of low-stress silicon nitride, low-temperature and high-temperature oxide and doped polysilicon have been brought online. These add to existing LPCVD capability and double or enhance our capacity in film deposition
- EVG Mask aligner 620: A new contact mask aligner has been installed and in use to expand the lithography capability and increase throughput.

Additional equipment will be added wherever necessary to facilitate access and use by our external users, to address the areas of critical need where bottlenecks may develop as the number of users increases, and to broaden the user base and address the needs of new disciplines.

Education and Outreach

The Michigan site has conducted several activities in the area of Education and Outreach. During the summer of 2003, Michigan supported three undergraduate students through the REU program. These 3 students worked with two faculty PI's on ZnO nanostructures, new materials for nanoimprint lithography, and nanofluidic channels for biological applications. The feedback from these students was quite positive and we will host 8 REU students for summer 2005. A meeting was held with Dr. Nancy Healey where plans for future educational programs were discussed. The Michigan site will leverage its background and work in its NSF WIMS ERC to the NNIN program. Several shared educational programs have been planned with Michigan ERC and will be reported in the future.

Outreach to underrepresented pre-college students has a high priority and will expand as we enter our second year. Since the start, we have conducted the following outreach activities:

Holy Redeemer high school – 5668 Baker St, Detroit, MI 48209 – large percentage of minority students (60% Hispanics, 20% African-American, 20% Caucasian), 95% graduation rate, 92% of graduating seniors go to 2- and 4yr colleges. Discussions initiated with Joseph Reican, CSB (school president), and educational programs aimed at these students in the areas of micro and nano technologies will be developed.

Tech Day, November 6th, 2004 at the University of Michigan, Ann Arbor, MI. Tours of the SSEL given to about 150 high-school students (grades 11-12).

Social-Ethical Issues

As stated in the original proposal, Michigan was to contribute to the SEI aspects of the NNIN through a special topics courses offered to students here at Michigan and available through the web to others. This course was originally developed as part of the NSF WIMS ERC, but expanded to include topics related to nanotechnology. The title of the course is Societal Impact of Microsystems (EECS 598) taught by Prof. K. D. Wise. It reviews the challenges the global society will face during the next fifty years and how microsystems can help meet them. Classes consist of lectures by invited speakers followed by a panel discussion. The course examines issues such as the population explosion and its expected impacts on energy consumption, pollution, and global warming. Developments in transportation, health care, space exploration, information technology, nanotechnology, and homeland security are also considered along with engineering ethics.

A1.5 University of Washington Site Report

Mission and Instrumental Capabilities

The mission of the University of Washington (UW) Nanotechnology User Facility (NTUF) within the NNIN network is to attract and serve industrial and academic users from biology and life sciences that stand to benefit from advances in nanotechnology. As of October 2004, NTUF had provided service to 126 cumulative users, 30% of which work in the fields of life sciences and medicine. Since the start of NNIN in March 2004, our number of users has increased by about 40% and facility usage time has increased by 55%. Our equipment includes an optical fluorescence microscope, two AFMs, and a SEM with E-beam lithography capability. These tools are well suited to characterize cellular structure and morphology of biological samples under dry or aqueous condition. NTUF provides critical support to many research areas including catalysis, nanostructured materials, biomaterials, motor proteins, microfludics, and bio-nanosystems.

New instruments and services

To accommodate the increasing demand from the biological community for living cell imaging, NTUF is in the process of acquiring a $350K Zeiss LSM510 two-photon ready confocal microscope. NNIN contributed $100K towards this purchase with the balance of the funds coming from other federal and university funds. UW and the Washington Technology Center (WTC) have committed space and renovation moneys for a climate-controlled room adjacent to NTUF that will house the microscope. The instrument is expected to become available to users early 2005.

Over the past 7 months, NTUF has developed a contract nano- and micro-fabrication service to support nanobiotechnology research. Our staff fabricates nano- and micro-patterned substrates for the study of cell adhesion and patterns proteins using electron beam lithography and microcontact printing. Users requiring complex nanostructured substrates are directed towards other NNIN nodes. We believe that this new service, together with the confocal microscope, will lead to a significant increase in new bioscience users from the NNIN network.

New hires

The NTUF staff was expanded in May 2004 through the hiring a lab manager (Lara Touryan, PhD. BioE), a research engineer (Sravani Pakala,M.S. ME), and an education/outreach manager (Ethan Allen, Ph.D. Neuroscience). Our highly motivated team draws upon its collective expertise to offer a superior learning, working and problem-solving environment in support of NNIN users.

Website

NTUF has developed a database-driven website (http://www.ntuf.washington.edu) that will go live in November 2004. The site will serve as an initial portal for inquiries, new user registration, equipment scheduling, and account management for registered users. This resource will be connected to the Cornell NNIN mother site and serve to promote the NNIN-UW facility and foster interactions between staff and users/public. Our system is capable of generating monthly user/usage reports effortlessly, allowing staff to concentrate on user needs.

Workshops and open house

NTUF has promoted NNIN and the UW user facility by hosting two open houses in April and September 2004 (170 visitors), sponsoring the annual UW Nanoscale Science and Technology Workshop (116 attendees), participating in exhibitions at the MRS Spring and Fall (planned) meetings, and giving presentations at workshops and meetings. NTUF has also established a synergistic partnership with WTC through the Washington State Nanotechnology Initiative that seeks to position Washington as a pole for nanotechnology. The experienced WTC marketing team has promoted NTUF in their publications, tradeshows, and conferences.

Education and outreach

Dual Ph.D. program: NTUF operates under the umbrella of the UW Center for Nanotechnology (CNT) which established the nation's first Dual Degree Ph.D. Program in Nanotechnology. To date 16 students have completed this dual degree, earning Ph.D.s in both their home department discipline and nanotechnology. Most have gained hands-on experience on the tools available in NTUF.

RET program: The NTUF Research Experience for Teachers (RET) program enables high school science teachers to explore cutting-edge advances in nanoscience and nanotechnology through a 10-days long laboratory immersion. This summer, two teachers collaborated with UW scientists to develop classroom activities in order to engage and excite high school students about nanotechnology. The teachers also gained direct experience on the nanotechnology characterization tools housed in NTUF.

REU program: NTUF participated in the network-wide NNIN Research Experience for Undergraduates (REU) program by offering four 10-week-long summer research project to undergraduate students. These were: "Integrated Biologically Active Microsystems

Lab-on-a-Chip"; "Hybrid Nano-Scale Pattern Formation through Nanocrystal Self-Assembly"; "Molecular Substrates for Nanobiotechnology"; and "Synthesis of Diluted Magnetic Semiconductor Quantum Dots".

SFS program: NTUF joined forces with UWEB (a NSF-ERC) in the 2004 offering of Science for Success (SFS), a summer science outreach program that seeks to encourage economically disadvantaged and underrepresented high school students towards careers in science/engineering. Seven of the18 participating students (10 African-American, 5 Asian females, 1 Pacific islander and 2 Hispanics) were supported by NNIN.

Community college collaboration: NTUF is working with leaders from Community Colleges across Washington and Oregon to build new programs that will enable the rapid creation of a technically-trained workforce to meet the rising needs of nanotechnology. NTUF is envisioned as a key component of such programs, providing a forum for hands-on experiences in a wide variety of nano techniques to ensure sufficient breadth of training and background.

Science fiction museum exhibit: Faculty from the CNT and NTUF staff are collaborating with science educators from the UW College of Education, leaders of the new Science Fiction Museum in Seattle, and other museum professionals to create a traveling exhibit focused on nanotechnology. The overall aim of this project is to use this fascinating subject matter as a gateway to intrigue and engage students in science.

Societal and ethical implications of nanotechnology

The SEI team at UW uses quantitative and qualitative methods to document and observe the processes, progress, and changes that occur in the NNIN multidisciplinary, multi-site and multi-PIs collaboration. Four major projects are being tackled.

Diversity and opportunity in the nanotechnology workforce. This project involves (1) observing and documenting the history of the growth and changes in the workforce and careers in nanotechnology at the national level, and (2) assessing the impact of nanotechnology on student career outcomes. The first subproject involves:

- Tracking the number of professional nanotechnology associations.
- Tracking 2-year technical degrees, certificates, 4-year and graduate degrees in nanotechnology (with Penn State).
- Tracking users at NNIN facilities (in collaboration with Cornell and Georgia Tech).
- Surveying nanotechnology firms with respect to jobs available, type of industry, skills and education desired by employers, and who is being hired.
- Identify nanotechnology regional hubs.

  Databases have been or are in the process of being created. They will be made available to the public via NNIN mother and sub-sites and updated on an annual basis.

The second subproject involves:

- Extending the existing tracking of UW-IGERT Nanotechnology fellows to all UW Nanotechnology students
- Utilizing UW mentoring database information from the IGERT program
- Conducting interviews with graduates from the UW Dual Ph.D. Program in Nanotechnology.

Growth of nanotechnology as a field and discipline and its impact on society. This project involves:

(1) evaluating the maturity of the discipline by:

- Tracking the number of academic journals specializing in nanotechnology. We have set up a database of journals and will add to it on an annual basis.
- Tracking the number of academic articles published on nanotechnology each year. The database is complete with articles published from 1975-2003 entered and will be updated annually.

(2) assessing the nature of the advances resulting from the research by compiling a database of U.S. patents in nanotechnology from 1981 to present (in collaboration with Marie Thursby, Georgia Tech)., and

(3), documenting popular public perceptions of nanotechnology in mass media (e.g., news, movies, popular fiction) in collaboration with Bruce Lewenstein (Cornell).

Patterns of communication within the SEI management team and NTUF. This project involves identifying strategies for multi-disciplinary, cross-site collaboration and work across NNIN (with Kirsty Mills, UNM) and within NTUF.

Social and ethical implications of nanotechnology research. This project involves: (1) assessing current and future implications of nanotechnology using historical research on past industrial and technological revolutions (in collaboration with Cornell, UNM and Stanford) and (2) build a database of curricular modules available at the NNIN institutions that address ethical issues in nanotechnology (in collaboration with UNM).

A1.6 Penn State Site Report

Technical Focus

The technical focus of the Penn State site of NNIN is general nanofabrication with an emphasis on chemical and molecular scale technologies and other strengths in novel materials. To continue enabling fundamental advances in these and all areas of nanotechnology, the Penn State Nanofabrication Facility (the Nanofab) is constantly adding new equipment and capabilities. Some recent additions which are now up and in use include an Applied Materials multi chamber RIE and PECVD cluster tool which has been modified to allow liquid precursors to be used for deposition. Applications of this tool include the deposition of novel low-k dielectrics and barrier materials for advanced electronic interconnects. A TekVac single target sputtering tool and Tegal RIE have also been installed in addition to an EV Group embosser/anodic bonder which is being used to pattern ceramic materials and create nanostructured surfaces. A Heidelberg Instruments laser writer is also currently under installation. Additional equipment that will be coming on-line includes 2 LPCVDs, an additional APCVD, a Thermawave Optiprobe, and an expanded wet chemical area to help further support chemical nanofabrication users.

The Nanofab has also added John McIntosh, Senior Process Engineer, to its staff. John comes to the Nanofab with nearly 20 years of experience in electron microscopy, metrology, photolithography and focused ion beam instrumentation. He has worked for Lucent, FEI and Aristotle University in Thessaloniki, Greece.

The Nanofab supports the research of many external users both on site and via remote access. External on-site users include University of Pittsburgh, LCM Technologies, SpectraMedix LLC, Nanohorizons and Membrane Assays, among others. Remote access users include UCLA, Brown University, New Jersey Institute of Technology, Rosemont College, Duquesne University, Case Western University, Purdue University, Lehigh University, Drexel University, University of Texas, Naval Research Laboratory, TRS Technologies, Applied Research in Photonics, Brandywine Optics, Air Products, Solid State Measurements, Lake Shore Cryotronics, Microfab Technologies, Particle Measuring Systems, Verimetra, Photonami, and Hanson Technologies, among others.

Education, outreach, and workshops.

The Penn State site has extensive education, outreach, and workshop activities. Included among these are the regularly offered three-day professional development workshops for secondary and post-secondary educators. Approximately 70 educators attended these workshops in 2004 alone. The workshops entail lectures on the fundamentals of nanotechnology and nanofabrication, combined with laboratory work in the Nanofab clean rooms where these fundamentals are practiced. In addition, workshop participants discover the growing applications of nanotechnology in many industries including the biotechnology, MEMs, optoelectronics, chemical and electronics industries.

The Penn State NNIN site, through its Center for Nanotechnology Education and Utilization (CNEU), also offers *Nanotech Camps* for secondary students. These three-day camps are offered in the summer and provide secondary school students with an orientation to, and opportunity to use, basic nanofabrication processes such as physical and chemical vapor deposition, lithography, plasma etching, self-assembly, and SEM, AFM, and STM characterization techniques. Applications of these nanofabrication processes to diverse fields such as microelectronics and biotechnology, as well as educational and career opportunities in nanofabrication, are explored and discussed in these Camps. In addition, one-day camps are held throughout the year. More than 625 students (plus chaperones) have attended three-day summer *Nanotech Camps* to date, and many more have attended one-day camps. Ten three-day *Nanotech Camps* were held in the summer of 2004. Nine of these Nanotech Camps targeted first time campers; the final camp was held for participants who have been to a previous camp and requested to return for a “next level” experience. The *Nanotech Camp* agenda is designed to be interactive and fun, while still maintaining a high level of introductory nanotechnology and nanofabrication basics. The PSU NNIN site supports a focused effort aimed at attracting students came from disadvantaged minority communities to these camps. In 2004, 82 students who attended *Nanotech Camps* were from disadvantaged minority communities.

The Penn State NNIN site, through CNEU`s Nanofabrication Manufacturing Technology (NMT) Partnership institutions (all the community colleges and numerous small colleges and universities in Pa.), also conducts extensive student nanotechnology-awareness efforts at secondary schools. To support these efforts, a student recruitment video on nanotechnology and the educational programs of the NMT Partnership has been produced, and duplicated for mass distribution in various formats. In addition, a portable tabletop display has been produced for each of the 14 Pa. community colleges, the Pa state-system colleges and universities, and Penn State campuses, along with brochures and other recruitment materials, to support these efforts.

In an effort to continuously improve the outreach effectiveness of the PSU NNIN site, an outreach presentation entitled “An Introduction to Nanotechnology – Career Opportunities and Educational Pathways” was created by CNEU personnel, during the third quarter of 2004. This presentation is currently being utilized by CNEU outreach personnel and is also being offered to other organizations for use in their continuing outreach initiatives.

In addition, the Penn State NNIN site is presently in the final design stages of the creation of a new Teaching Clean Room. A highlight of this academic-use clean room will be its ability to support remote access to processing tools and characterization equipment.

Further PSU NNIN site outreach efforts also include numerous meetings with administrators, faculty, staff, and researchers from other universities, government labs, companies and economic development organizations. Included in these activities have been meetings with the University of Wisconsin, North Carolina State University, West Virginia University, North Dakota State University, USDA, University of Helsinki (Finland), School of Bioresources and Technology (Thailand), Korea Institute of Industrial Technology, Pai Chai University (Korea), Korea Institute of Energy Research, McKesson, Project Genesis, Penn United Technologies, Micron Technology, Carbone of America, the Industrial Modernization Center, the PA Industrial Resource Center Network and many others. The PSU NNIN site also participated in a National Workshop on Nanotechnology in the Forest Products Industry where the role of the NNIN and the focus on enabling chemical and molecular scale research at the Penn State Nanofab was presented. The PSU site also held a workshop: “Micro and Nanotechnologies: Success Stories from Companies using the Penn State Nanofabrication Facility” in conjunction with the Technology Council of Central PA on October 13, 2004.

A1.7 UCSB Site Report

Facility Move/Equipment Additions

After 15 years in its present ~3000 ft^2 location, the UCSB Nanofabrication facility is moving into a new 12,000 ft^2 cleanroom in the new Engineering Sciences Building. We anticipate the move completion to be in Q1 of 2005. We now have sputtering, etching, and deposition systems fully operational in the new facility. The 15 new wet benches (of which NNIN equipment funds of ~$125K were used) for increased user capacity are due for delivery in December. Unlike the wet benches in our present facility, the new facilities' wet benches will support full-wafer processing of 200 nm substrates, a feature critical for MEMs. In December, we also take delivery and installation of a new Karl-

Suss MA-BA6 aligner. This tool will integrate with our Suss wafer bonder for doing aligned wafer bonding using various substrates and processes. We have also receive a Nanonex 2000 nanoimprint tool and alignment option that interfaces with the Karl-Suss aligner. We expect this tool to assist in the low-cost implementation of nanostructure formation for scientific experiments in the non-traditional areas of chemistry and biology. The Nanonex imprinter was made available through CNSI funds. We have also ordered refurbishment of a Motorola-donated i-line GCA Autostep200 wafer stepper. This will overcome one of our bottlenecks in lithography for 400-500nm optical lithography, providing two systems that can be used by users for these critical process steps. Furnace systems for oxidation and general annealing have been donated by Intel and by Raytheon. We have also received donation of an ion-beam deposition tool from Intel for enhancement of our optics-based research. Finally, through CNSI-related funds, a new 100kV JEOL e-beam lithography tool has been ordered. Delivery is ~ 1 year away. The addition of these facility resources enables us to push the research envelope in the nanoscale for a larger number of researchers.

One additional user and process support engineer has been hired both to facilitate our move into the new facility and to accommodate an increased number of users.

Users: Inside & Outside, both industrial and academic

During 2004, there have been approximately 33 hours/month average remote usage. There have been 210 internal academic users and 62 external users, hence the external users represent 23% external users of the total. Of these external users, 16 are of academic affiliation. 6 users in the research facility have been undergraduates (educational).

We have tracked technical e-mail inquiries from 14 academic institutions this year. Three have turned into external user jobs. Two were given support letters for research proposals stating that we can do the work. Six received direct technical advice (process related) to assist them in their research at no charge. Three are still possible active jobs, waiting on user response. E-mail inquiries from 11 companies have been tracked. Two of these have turned into remote jobs.

Under NNIN-staff direction 50 Santa-Maria High School Students and 40 middle-school students gained teaching cleanroom access and experience. These numbers are not normally reported in the spreadsheets.

We are aware of the need to increase our outside academic uses. We are fully committed to increasing the external the external users. Positive steps taken toward this goal are

1) <u>Improved facilities</u>: with the move into the new 10,000 ft^2 facility, severe space pressure is relieved. Users are more easily accommodated. An aggressive expansion of the tool set is feasible and is being pursued to support better in particular better process capability for Silicon & MEMs.

2) <u>Outside user outreach:</u> We have published a site brochure highlighting our capabilities, with a strong focus on how the UCSB NNIN site can serve outside users. This brochure has been mailed to ~110 professors in engineering, physics, chemistry, and

bio-engineering at all of the southern California universities. The brochure is the precursor and first edition of a UCSB Nanotech newsletter which will be regularly distributed to southern California universities. The brochure and the newsletter highlight the capabilities of the facility available to the outside users and addresses our educational outreach efforts.

The brochure serves as an initial introduction, to be followed up by visits and seminar presentations at targeted institutions. The presentation highlights the NNIN capabilities that we can offer as a supplement to their local resources in nanotechnology. Presently, the presentation date at UC Santa Cruz has been confirmed (January), and we are arranging to give talks at other institutions, with a particular emphasis on nearby institutions.

To ease facility use by outside users, we have added a processing section to our web-site. This site will give standard and advanced process information more quickly to the outside users. Our three Ph.D. engineers are working to document and release this information for a wide variety of processes. The first area of focus has been optical lithography, and is nearing completion.

NNIN Funded Educational Activiteis

UCSB Nanofab has committed to a major expansion of it educational outreach efforts. We have hired a full-time academic coordinator, Angela Berenstien, for our educational programs. She is off to a rapid start.

Educational Activities to Encourage K-12 students to enter science and engineering fields

Summer camps: In the summer of 2004, NNIN funds were used to support 2 students in the "APPRENTICE RESEARCHERS PROGRAM, (ARP)", an REU program for students who would be high school seniors in fall of 2004. One student that NNIN supported (50%) is Hispanic. ARP students built resistors in the student clean room using the photolithography/liftoff process.

Short term weekend and summertime "chip camps" are in the planning stages and will be implemented in 2005. Santa Maria High School will be the first school to participate.

School field trips On October 9th, 2004, NNIN partnered with the EPSEM program (Expanding Pathways for Science, Engineering, and Mathematics) to host a field trip of 50 students (10th and 11th grade) from Santa Maria High School. All students conducted experiments. Specifically, NNIN brought many of these students into the clean room, so that these students would pattern silicon wafers using photolithography.

Development of Hands-on activities or demos for K-12 students: Since June 2004, 11 new hands-on labs and worksheets targeted toward middle- and high-school students were developed and tested. In addition, separate teacher's preparatory lab sheets with answer keys were created.

Other K-12 outreach programs: On October 16th, 2004, UCSB hosted 120 middle-school students (13 years old) in a "Day in Nanoscale Science and Engineering". This program was done as a partnership between UCSB and Johns Hopkins University's Center for Talented Youth (CTY). On this day, every student got hands-on experience in nanotechnology by doing labs in one of the following subjects: Nanofabrication, Crystallography, Nanoscale properties of Light, and Surface Science. In addition, students attended demonstrations and had a creative component, where they had to make a commercial for a nanotechnology product. Commercials had to explain how the product used nanotechnology, and how using nanotechnology makes this product better than other products on the market.

Plans are already underway for NNIN participation in an event on March 5, 2005, very similar to the CTY event described above, but this time, it targets 1200 high school students within Santa Barbara and Ventura Counties. This event is in partnership with many student organizations around UCSB. The focus is to increase interest in STEM by providing hands-on activities and demonstrations, and to encourage pursuit of higher education in STEM. NNIN is providing the nanotechnology component for this event.

NNIN Funded Activities and Resources to Inform the Public

Public Seminars Held: 7 seminars during the summer of 2004; about 40 people attended each seminar (this is a reasonable estimate)

On October 16th, 2004, UCSB hosted 120 middle-school PARENTS (in addition to the 120 13 years old students) in a "Day in Nanoscale Science and Engineering". On this day, every PARENT attended the following seminars:

What's so great about being small? Life at the Nanometer…
How to prepare your students for higher education
Nanotechnology on Trial: The Social & Ethical Implications of Nanotechnology
How Crystal Structure Helps Nanotechnology

Development of nano exhibits for general public: On October 16th, 2004, UCSB hosted 120 middle-school PARENTS (in addition to the 120 13 years old students) in a "Day in Nanoscale Science and Engineering". In addition, parents attended exhibits of various nanotechnology products.

Public Service announcement/brochures. NNIN funds were used to develop 3 brochures:
-One brochure, titled "Interns in Industry", used outreach funds to target industry users in order to encourage partnerships with UCSB that would create sponsorships and internship opportunities (at these industries) for students participating in NNIN education outreach programs.
-One brochure used Outreach funds to target Industry users to advertise the needs of the student clean room, in hopes to get equipment donations.
-One brochure used NNIN funds to advertise the facility to outside academic users in an effort to increase these numbers.

Activities/Information for undergrads regarding careers in nanotech

We are in the process of building career pathways with industry users of our NNIN facility. In 2005 we plan to:

- Form a board of industries

- Ask the board what skills they would like the students to learn
- Develop educational short courses for college students to develop hands-on skill sets on clean room equipment.
- Industry partners provide internships/permanent job opportunities for graduates of this program.

Teaching and Learning tools and resources for undergrads and grad students;

Technicians In NanoTechnology (TINT) is a 6-month internship program for college students to get experience in the clean room. Currently UCSB has one student from Germany, but a local student will begin in January 2005. Internships are 40-hours per week, and the internship includes training and use of clean room equipment as well as an introduction to the business end of running a clean room.

Research Experience for Undergraduates

The UCSB NNIN site participated in the NNIN-wide REU program. We will expand the number of summer REU students in 2005. We are also exploring, whether with the network or independently, operating a significant REU program in the fall, winter and spring terms. This is motivated by our desire to further expand the REU program, which is a highly effective educational program.

Research Experience for Teachers

UCSB has worked with GaTech and other institutions in developing and submitting a proposal to the NSF for a NNIN RET program. We are highly committed to this effort.

Inclusion and Diversity:

UCSB has been involved in the following efforts;

- ARP (listed above): this has 50% Hispanic support.
- REU 2004: 40% female students, 40% under-represented or minority students (Asian: 1 female, 1 male; African-American: 1 male; American Indian-Latino mix: 1 male)
- Santa Maria High School's "Day in Nanotechnology" Oct 9th: 71% of students in the clean room are Hispanic
- "Day in Nanoscale Science & Engineering" with CTY Oct 16th: (28.5% minority/underrepresented populations, 37.56% unspecified, 33.94% Caucasian)

In progress: An after-school program for high school students (grades 11-12) for San Marcos High School. (Over 850 Hispanic students attend there.) Students will spend 2-3 hours after school twice/week for 6 weeks in the laboratory doing hands-on nanotechnology projects. Students will also be paired with mentors from Hispanic/Chicano UCSB student science organizations that will serve as role models, give these students a feel for university life, and encourage them to pursue higher education in STEM. Students will present their work in the science fair in May. This program will begin in the spring of 2005.

Technical Workforce Development:

We are in the process of building career pathways with industry users of our NNIN facility. Our plan for 2005 is as follows:

- Form a board of industries.

- Ask the board what skills they would like the students to learn.
- Develop educational short courses for college students to develop hands-on skill sets on clean room equipment.
- Industry partners provide internships/permanent job opportunities for graduates of this program.

Activities/Resources for K-12 teachers and guidance counselors:

UCSB has just joined the NNIN in submitting an RET proposal.

A1.8 University of Texas-Austin Site Report

The technical leadership assignment for University of Texas is the support of chemistry and chemical nanotechnology, and tool development including manufacturing research support through development of techniques such as imprint lithography. The development of Step and Flash Imprint Lithography (SFIL) process for sub-100nm device fabrication is an important area of focus for MRC. Towards this goal, we have acquired an SFIL-IMPRIO100 imprint tool from Molecular Imprints, which is scheduled for delivery by the end of November, 2004. It can handle 4- 8in wafers.

A critical part of the SFIL process is the fabrication of the templates for imprinting. The tool uses 6025 UV-Silica templates of size 65mm x 65mm x 0.635mm. The templates can be fabricated at MRC with our JEOL EB/X 6000, 50keV electron beam lithography tool. Our target is to ultimately reach well under 100nm resolution on these templates. We will also identify commercial vendors for templates. The post imprint process, involving different dry etches, can be done on our RIE tools: Oxford Plasmalab-80 and Plasma Therm 790. The template available with the tool at MRC has the following layout (scale in nm). We will design a set of standard templates in consultation with other NNIN sites to hopefully handle the vast majority of applications.

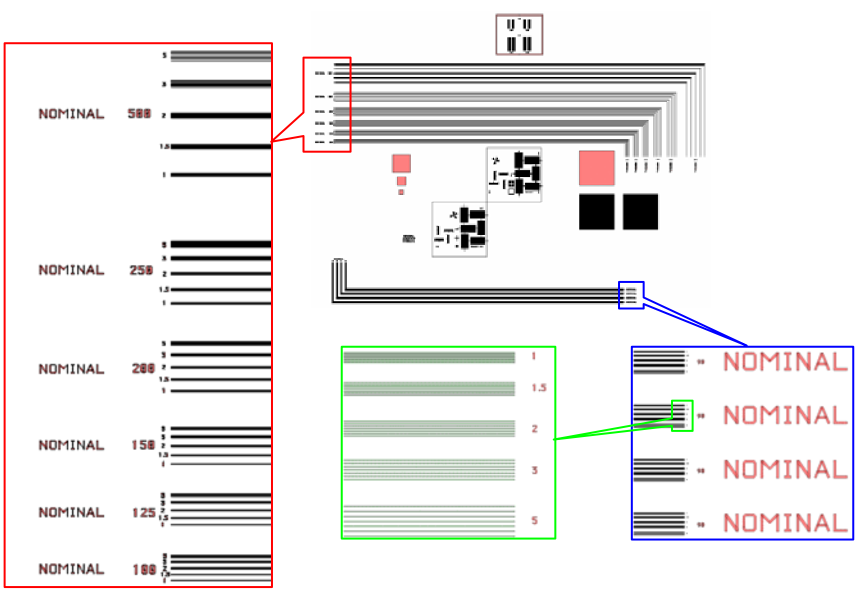


Figure 8:

The NNIN team at MRC-UT Austin, during its first year set up protocols to ease access to the facilities to users outside UT Austin. This included the construction of a dedicated page on the MRC web site with information regarding

- **procedures to gain access to the facilities** (project description, MoU, safety training, equipment training…)
- **list of all equipment** (with pictures) in the facilities, accessible by qualified users
- information regarding location, accommodation, fees etc..

Prior to joining NNIN, MRC-UT did not have a formal fee structure. The LabAccess server, a simple PC-based system using National Instruments Labview, already, installed since 1999 1) assists the facility's staff to maintain the equipment , and 2) enables and disables access tools for users . In addition, since March 2004, the LabAccess server **generates automatically data** both for **monthly** reports required by NSF with all mandatory **metrics,** and **for billing purposes.** Actual charging of outside users has started from Fall 2004, after going through internal UT financial review procedures. We will soon install a **reservation system** linked to the MRC-UT LabAccess system. We will be able to have more flexibility for outside users to work in our lab and generate more coherent data regarding the "Lab time usage." Currently, our internal student users sometimes forget to log out from the tools after they are done. *This has skewed the internal usage hours somewhat*, and we plan to address that by modifying the protocols.

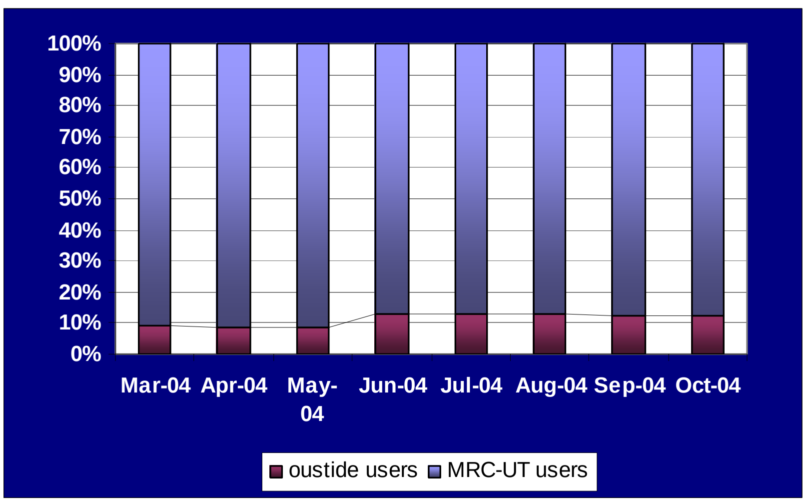


Figure 9: Usage at Texas.

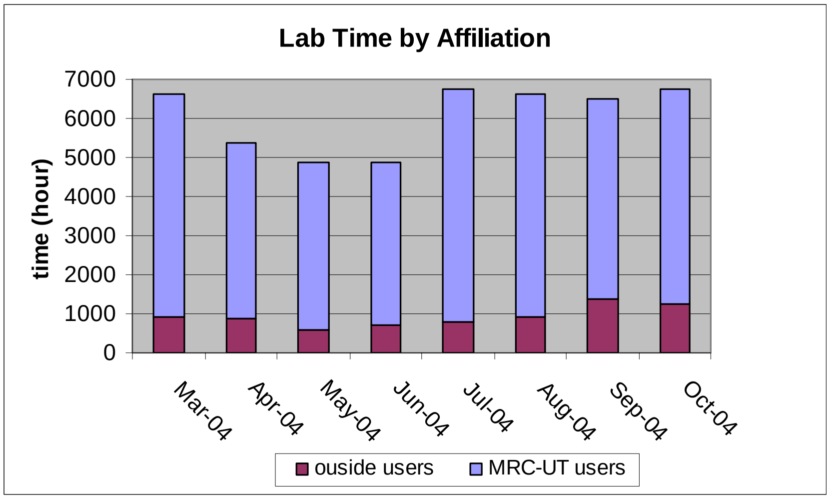


Figure 10: Usage at Texas.

The University of Texas at Austin Microelectronics Research Center (MRC) hosted 3 undergraduate students from other institutes during the summer 2004 Research Experience for Undergraduates (REU) program funded through the National Nanotechnology Infrastructure Network (NNIN) by the National Science Foundation (NSF). The program ran from June 4 through Aug. 14, 2004 and concluded with a convocation where all students presented their research at Pennsylvania State University. This was the first time the MRC hosted such a program and it was very successful, as measured by the results of the undergraduate experience.

The three students involved with the 2004 program were Neha Bagga, Brian Goodfellow and Jessica Huang.

Ms. Neha Bagga, currently a senior at Oklahoma State University, worked under the supervision of Dr. Archie Holmes, Jr., Associate Professor in the Electrical and Computer Engineering Department. Her project was entitled, Anion Exchange of GaAsSb/GaInAs Interfaces. The objective of this project is to investigate and study the anion exchange process at the interfaces of GaAsSb/GaInAs heterostructures. These super-lattices were grown using Molecular Beam Epitaxy (MBE) and characterized using High Resolution X-Ray Diffraction (HRXRD).

Mr. Brian Goodfellow, currently a junior at Cornell University, worked with Dr. Kenneth Liechti in the Department of Aerospace Engineering. His project was entitled, Modeling Controlled Interphases in Fiber Reinforced Polymer. Mr. Goodfellow was responsible for designing, implementing and testing his own device.

Ms. Jessica Huang, currently a junior at Harvard University, worked in the Chemical Engineering Department under the supervision of Dr. Brian Korgel. Her project was entitled, Semiconductor Nanowire Synthesis and she worked with Graduate Research Assistants in a clean room environment.

All of the students were housed together in a University dormitory and spent 40 hours/week working during the 10-week program. We tried to combine a good work-life balance for the students to emphasize that graduate school and graduate research programs are not the same as attending undergraduate classes, but are more of a full-time job and should be approached in that manner. The cost to the MRC for all 3 students to be a part of this program was approximately $30,000.

A1.9 Minnesota Site Report

Mission and Scope

The Minnesota node consists of two primary labs: the Nano Fabrication Center (NFC) and the Characterization Facility (CharFac). In addition, the Particle Technology Lab has begun working toward opening up its capabilities to external users. Toward that end, a lab manager was hired and partially funded by NNIN. He has developed a rate structure for the lab and has begun looking for external users. A significant problem is that the area is fairly narrow (few potential users). The Characterization facility took delivery on a new Technai 300 keV TEM with ~ 0.1 nm resolution, along with a new Technai TEM to be used primarily for teaching and education. These were purchased through an NSF MRI with substantial University funding. NFC upgraded its mask making capabilities and ordered upgrades to it LPCVD capabilities, both through internal funding generated by charge-back fees.

Three new NNIN-supported staffers were added this year. The first is our NNIN administrator. This position handles collection and dissemination of usage statistics for all labs, collecting user publication statistics, organizing workshops, and soliciting new users, and editing and publishing the new NNIN quarterly newsletter. A second staff member added has responsibility for supporting the web and programming needs for the three laboratories. NNIN provides approximately 20% of his support. Both of these two positions are also expected to assist with the open textbook project. Finally, CharFac has added an NNIN-supported staff position for the preparation of samples for high resolution microscopy, TEM samples in particular.

Education

The Minnesota NNIN node has three initiatives. The first is an outreach to AAS students. The node is currently working under an NSF-sponsored grant with a local technical college to develop a one-semester capstone experience. 28 students have been admitted for fall 2004. They are expected to begin the capstone in January 2006. Under NNIN sponsorship, this project has been replicated with a group of Wisconsin 2-year colleges. The first offering to these students in expected in summer of 2006. The second major effort, the web-based open text book, is getting underway. An initial outline of the material has been developed, tentative writing assignments have been made, and a schedule developed.

Outreach

The NNIN node has made two massive mailings in at attempt to attract more external users. These mailings included copies of our new NNIN funded newsletter as well as a description of Lab capabilities. The first mailing went out to over 100 local high technology companies working in similar fields. The second went out to the chairs of chemistry, physics, electrical engineering, mechanical engineering, and chemical engineering departments at every school in Wisconsin, Iowa, Minnesota, and North and

South Dakota. The cover letter explained the NNIN program and encouraged them to distribute the information to their faculty.

Safety & Health

NNIN support is being used to update safety training for the Nano Fabrication Center.

Remote Usage

Remote usage upgrade of a new JEOL SEM has been quoted. We expect that a purchase will be made in late 2004 so that the equipment is available in early 2004. We expect that this capability will be used as part of the AAS programs.

Workshops

NNIN was responsible for organizing two workshops this year. The first, held in May, 2004, was in the general area of nanotechnology. This one-day symposium attracted approximately 500 attendees and included technical talks, posters, and panel discussions. A more specialized workshop in the area of Nanomedicine was held in November, 2004. A collaborative effort with the Medical School, the workshop covers both top-down (i.e. MEMS) approaches and bottom-up (i.e. chemical self assembly and transposon research) approaches. At this writing the workshop has not yet occurred, but we are expecting ~150 attendees. In addition, NNIN promotional materials were distributed at several national and international conferences.

A1.10 University of New Mexico Site Report

Nanoscience at the University of New Mexico is a 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. 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

Technical Focus

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 an important capability of the UNM NNIN site. Quantum dot laser diodes operating in the 1.0- to 2.0- m range possess the lowest threshold current density and largest tuning range demonstrated in any semiconductor laser system.

Nanoscale optical lithography is an important capability offered by the UNM NNIN node. Several systems are available, with a 355-nm (tripled YAG laser) system offering periods to ~ 200 nm and linewidths as small as 50 nm.

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.

The current research at UNM's Department of Earth and Planetary Sciences (EPS) covers a broad range of important nanophase geological materials. Specific research areas in EPS include: 1) mesoporous natural materials and their potential for environmental remediation; 2) geomicrobiology/biogeochemistry: investigation of the interactions of microbes and minerals in extreme biological environments (Lechuguilla Cave, NM). 3) mineralogy and geochemistry of low temperature nanophase materials, 4) volcanic aerosols; and 5) early solar system processes including gas-solid condensation and catalytic reactions involving nanophase materials. 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.

Work in the first period of the program has focused on moving the facilities from an academic culture to a user-facility culture. In order to achieve this we have concentrated on minimizing equipment downtime, instituting regular maintenance schedules, building a spare parts inventory, and training users in operational procedures, as well as technicians in maintenance procedures. New operational procedures have been instituted to track equipment usage time, and usage of supplies, in particular of precious metals.

In order to establish the user program, an UNM NNIN user agreement was created and moved through university legal approval. Each user now completes this agreement, as well as the work proposal. A data base of users and user metrics has been established and is being regularly maintained. A uniform system of calculating user time has been adopted, and is being regularly reviewed. A monthly invoicing cycle ensures timely payment schedules, and allows long-term users to monitor activities.

To meet the demands of the NNIN program, personnel hires include an NNIN Lab Manager, a TEM technician to facilitate remote usage, a computer support engineer, and a cleanroom maintenance technician.

The NNIN program funded the purchase of a PGT Energy Dispersive Spectrometer for use with our Hitachi S-5200 SEM. This extends our nano-characterization facilities by allowing elemental analysis of samples.

Education

The University of New Mexico is creating a new Nanotechnology Curriculum to prepare a highly trained nanotechnology workforce. As part of this a new course, **Societal and Ethical Implications of Nanotechnology**, 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. Rather than the students being 'taught' the issues, they will be required to be active participants defining these issues. Since the interaction between society and technology will determine the extent to which nanotechnology will maximize its potential, team outreach projects - with local media, schools, and similar organizations - will prepare students' ability to interact effectively with the public at large. They will gauge understanding of and reactions to nanotechnology among colleagues, students, faculty, and the broader community, analyze responses, and develop their ability to engage in fruitful debate. The course curriculum and materials will be made nationally available through the NSF NNIN Societal and Ethical Implications (SEI) website.

Related activities include presentations on nanotechnology to the MESA (Math Engineering and Science Achievement) students at Santa Fe Capitol High School, and seminars on the Societal and Ethical Implications of Nanotechnology given at the UNM Law School, to electrical engineering students, and at the MST Course 2003: The Physics and Chemistry of Nanomaterials, sponsored for teachers by the NSF EPSCoR program.

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. UNM is one of only eight universities that are both a Carnegie Doctoral/Research Extensive University and a Minority Serving Institution. 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 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

Mission and Scope

NNIN users have access to the full capabilities of the Harvard University Center for Imaging and Mesoscale Structures (CIMS) which include the following areas:

- Two Fully Instrumented 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
- New Equipment Development

The Harvard NNIN technical focus is on chemical nanotechnology and computation. Broadly, these activities encompass the areas:

- 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 dedicated staff to assist users in the understanding and visualization of next generation electronic structures, and access to these programs over the web.

Technical Focus Areas Progress and Accomplishments

NNIN Technical Focus Area; Soft Lithography and Molecular Electronics.

The research groups of Harvard Professors George Whitesides, David Weitz, Hongkun Park, Robert Westervelt, Charles Marcus, and Venky Narayanamurti have lead responsibility for soft lithography and molecular electronics.

Dr. Jiangdong Deng and Dr. Ling Xie were hired as NNIN technical liaisons to facilitate use of CIMS facilities by NNIN users. Both have education and extensive experience in soft lithography and molecular electronics processing.

Harvard's two cleanroom facilities were renovated to focus one on soft lithography and the second on nanofabrication. This included purchasing additional equipment and lab facilities.

Technical Focus Area; Computing

The research groups of Harvard Professors Efthimios Kaxiras and Eric Heller have lead responsibility for the Harvard computational task. Dr. Michael Stopa. a senior Computational Materials Scientist, has been hired to manage the Harvard computational task.

The Division of Engineering and Applied Sciences (DEAS) assigned resources and personnel within their Information Technology (IT) section to establish additional computing resources within the framework of a "grid computing" fabric—the Crimson Grid —a computing cluster that will be used in the NNIN computing task. The implementation of this task involves close collaboration with the research groups and IBM.

> The core **Crimson Grid** Computing fabric consists of 90 dual processor IAD32 bit nodes, one 4-way, and two 8-way Power 4+ 64-bit nodes, all on the IBM hardware line. We are benchmarking other architectures (4-way 32 bit Intel Xeon, Opteron 64 bit, Itanium, and Power 5) and memory configurations for the suite of codes that will be supported initially. In the near future, we plan to enhance the Grid with a combination of additional 32-bit and 64-bit nodes, specifically targeted for use by the NNIN users on the Crimson Grid. The Crimson Grid also looks forward to joining other grid fabrics within the NNIN community fabric.

Mr Vincenzo DiBernardo was hired as IT Manager for CIMS to implement the web interactions for NNIN users for both facility use and access to theoretical programs on the computing cluster.

Harvard maintains, within CIMS and related departments, a variety of nanostructure simulation tools which will form the core group of the computing initiative. Current work involves the following programs:

- HARES - a first principles, real-space density-functional calculation package for determining the energies and forces in molecules and solids.
- SETE - an effective mass Kohn-Sham solver optimized for calculating the electronic structure of two dimensional electron gas, semiconductor heterostructures.
- EDIP - A molecular dynamics tool for modelling covalently bonded solids.
- ANEBA - Software for locating the saddle points in free energy space for generic transitions in complex systems.

In addition, Harvard is developing software for simulating microfluidic behavior, and the cluster will serve as a platform for standard numerical tools such as Matlab.

Education

Dr. Kathryn Hollar was hired by DEAS to jointly coordinate the education, society and ethics programs for the Harvard NNIN program as well as two major research centers, NSEC and MRSEC. Dr. Hollar coordinated the NNIN REU program and has participated in all NNIN planning for other educational and SEI programs.

Harvard participated in the NNIN REU program this past summer and will expand its participation for the coming year.

Outreach

Harvard has presented posters on NNIN at several scientific conferences such as Nanotech 2004 (2004 NSTI Nanotechnology Conference and Trade Show), 2004; and the Fall Meeting of the Materials Research Society.

Harvard faculty have presented national and international seminars and given talks on NNIN technical capabilities at over forty universities, research institutions, and conferences in the areas of micro-and-nano fabrication and soft lithography (details available on request).

Presentations on CIMS capabilities have also been presented by CIMS staff at six universities, the DEAS Industrial Outreach Program Workshop, the semiconductor industry's Nanotechnology Research Initiative, the National Academy of Sciences Committee on Facilities, and at two internal NSF program reviews.

Dean Venky Narayanamurti participated in a panel discussion of outreach activities at the 25th anniversary celebration of the Cornell Nanoscale Facility and inauguration of Duffield Hall, October 6, 2004

Safety and Health

CIMS has worked with Harvard Environmental Health and Safety department to develop required safety training courses specifically for users of CIMS nanofabrication facilities. Visits have been made to two labs so far to benchmark operating procedures at other facilities, and CIMS staff will attend one international conference and two workshops on nanosafety in the coming year.

Harvard will send several senior staff to participate in the NNIN Nanosafety Workshop to be held at Georgia Tech in December.

Workshops

CIMS jointly sponsored with ITAMP a workshop on *Mesoscopic Physics, Quantum Optics, and Quantum Information* May 10-12 at the Harvard-Smithsonian Center for Astrophysics.

A1.12 Howard University Site Report

Expanding HNF User Base

In 2004, the NNUN user base at Howard was well over 100. The HNF goal for Spring 2005 was to increase this number to over 175; this includes both external and internal users. The internal user component has been addressed by expanding the research capabilities in the area of medical applications of MEMS, biomaterial characteristization tools (i.e. Confocal and Fluorescence microscopes, MALDI mass spectrometer sponsorship) and increased sponsored research in the area of nanotechnology university-wide. The external users recruitment has taken on two components: one for industry users both large and small companies and special users sponsorships for universities with gap funding needs like smaller Historically Black Colleges and Universities (which will be discussed later).

To increase our industrial are industry users, we have been working with several local business organizations. They include North Virginia Technology Council Nanotechnology Committee, Washington DC Technology Council, Inc, Maryland Department of Business and Economic Development, Montgomery Country Office of Economic Development, GrayCary Patent Law Office, the newly formed DC-Maryland-Virginia Regional Nanotechnology Initiative, NSF Office on SBRIs and several incubator programs in surrounding areas.

This strategy has yielded several new users and we believe we will reach our goal. We have listed five recent examples:

1. Blue-Wave Semiconductor	ZnO/MgO UV detectors (small company)
2. Zin Technologies	SiC-based Piezoresistive sensors (small company)
3. Rohm and Haas	Bryce Photoresist Characterization
4. GWU (F. Hassani)	Multi/Single Layer SAW Sensors
5. Laurence Burley	SEM characterization of special concrete

Outreach Activities

We categorically stated that one of the fundamental goals of the NNIN is to develop integrated and innovative education and outreach programs based on nanotechnology. This short section reports on some education and outreach programs at Howard. They are as follows:

1. Development of a **NanoBackPac** of experiments for teachers- (will be handed out in March at the Howard Nanotechnology workshop for teachers)
2. **Nano Video Contest** (short educational videos on Nanotechnology-December 3, 2004)

3. **NanoVan** (final design December 2004, includes SEM, AFM, etc. late summer 2005 operational)
4. **NanoBoot Camp** (July 2005, co-sponsored by Georgetown University, ASME)
5. **NNIN-RET** (proposal submitted in October 2004)
6. **NanoBoot Camp** (proposed –National Society of Black Engineers National Conference, March 2005, Boston Mass)
7. **NanoBoot Camp** (National Black Family Technology Awareness Week, February 2005)
8. **NanoViliage** (each one teach one, graduate students talk to undergraduates and so on)

Equipment

We have seeked to acquire major equipment that will continue to expand the interdisciplinary nature of nanotechnology. In particular this year the Bio/Nano Interface attracting more users and researchers. We are expanding our growth capabilities in the III-V nitrides are our specialty within NNIN. This interface has only recently been recognized as an important sub discipline of the chemical, materials and biomedical sciences. The new research equipment and the timetable for additional equipment to be purchase shortly is as follows:

1. MOCVD Thomas Swann Reactor (final parts by 12/04)
2. Ellipsometer (operational)
3. Low Pressure CVD system for AlON, SiO_2, and SiN_4 under construction
4. Olympus BX61 Fluorescence Microscope with Biology (6/05 delivery)
5. Olympus FV 300 confocal Laser Scanning Microscope with Biology (6/05 delivery)
6. Transmission Electron Microscope JEOL 1011 (6/05 delivery)

Proposed New Equipment 2005-2006 timeframe

1. Washington Area Regional e-Beam Lithography System Lecia-GB-Flex (3/06)
2. NanoImprinting – NanoNex 2000 (5/06)
3. ICP Deep Plasma Etcher (12/06)

Summer Faculty-in-Residence program at Smaller HBCUs/Course Offers

We plan to jointly establish a nanotechnology technology education program with South Carolina State University (SCSU). This program has been designed to facilitate the maximum use of resources and to reach a diverse group of students. At least one faculty member from SCSU and maybe Virginia Union University will serve in a summer Faculty-in-Residence program at the HNF, conducting research and helping supervise the visiting students. We hope that preliminary research data will be collected so the faculty member can develop a research proposal and get funding for students, equipment, etc. The goal is to produce at least one such faculty person per year.

An undergraduate/graduate course on Introduction to Nano/Microfabrication will be made available to several HBCUs at no cost. This course will be open to all students via the web (much like the Introduction to MEMs course being taught at Michigan with students at Howard). It will be co-developed and co-taught and graded according to the local standards. All the video and web-based tools needed to administer such a course already exist and South Carolina State University along with other HBCUs institutions will offer this course in the fall of 2005.

Gap Funding

We have also allowed several users from the academic community to use the HNF that may need gap funding (in between grant or contracts or trying to obtain preliminary research for full funding). This program is working out very nicely and we hope it can be implemented across the network.

A1.13 Triangle National Lithography Center (NC State University & UNC-Chapel Hill) Site Report (Affiliate Site)

During the last year, state-of-the-art nano-lithography capabilities were established at the Triangle National Lithography Center (TNLC) and provided to the NNIN community of users. The centerpiece of this capability is an ASML 5500/950B production 193 nm scanner, shown in Fig. 11, whose characteristics are summarized in Table 2. Two of these characteristics are of particular importance within the NNIN suite of nano-patterning capabilities. First, the 193 nm exposure wavelength is used in leading-edge production and is expected to be used for many more years; thus this system allows users to test new resist materials and processes, for example, users from the NSF Science and Technology Center on Environmentally Responsible Solvents are currently using the scanner to test CO_2-based resist formulations and processes. Second the high throughput of the tool, e.g., compared to e-beam lithography, is expected to allow small companies to start small-scale pilot production beyond proof-of-concept demonstrations on single devices. This capability then allows those users to address nanomanufacturing issues such as yield and reliability.

Table 2: Specifications of ASML 5500/950B Scanner

Characteristic	Value
Exposure Wavelength	193 nm
Numerical Aperture of Lens	0.63
Resolution	130 nm half-pitch 80 nm isolated lines demonstrated
Field Size	26 mm x 33 mm
Alignment Accuracy	40 nm
Throughput	~ 60 wafers/hr

The scanner was delivered to the cleanroom of the NCSU Nanofabrication Facility (NNF) in October 2003. The tool was dedicated in January in a ceremony that included talks from the chancellors of both NC State and UNC-Chapel Hill and the science advisor to the Governor of North Carolina. The dedication was attended by executives from ASML, government labs, industry, economic development officials, faculty and students.

To meet the starting date of the NNIN, the TNLC was staffed to support on-site and remote users, test reticles were designed and obtained, and resist processes were developed for the scanner during the first quarter of 2004. In March 2004, the TNLC accepted its first user.

Since the start of the NNIN, the user base of the TNLC has grown, see Fig. 11, 12 and Table 3. To keep up with the expanding user base, the TNLC staff continues to address a broader range of needs, e.g., different substrate materials and sizes and different critical pattern geometries. We are continuing to push the resolution limits of the tool. Figure 31 shows 80 nm isolated lines in resist, and we are currently working on photoresist-trimming techniques which hopefully will shrink those lines to 20 nm and allow this tool to address the dimensional regime heretofore only accessible by e-beam and other more-

Figure 11

restrictive techniques. As the TNLC capabilities increase and become more widely known we expect the number of users to continue to grow. Already inquiries regarding multi-hundred wafers per month have been fielded.

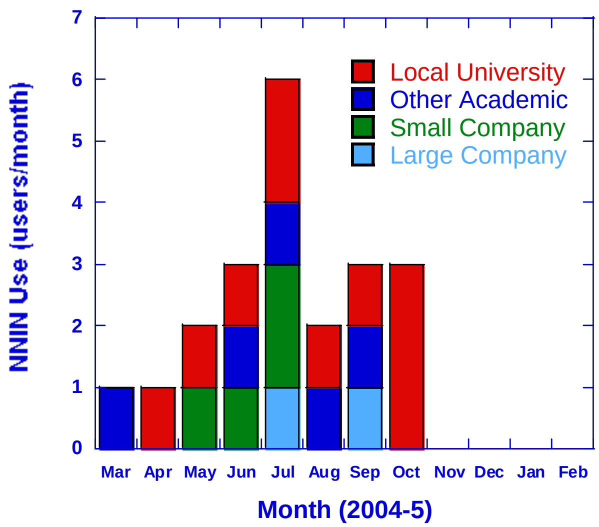


Figure 12 Use of the Triangle National Lithography Center

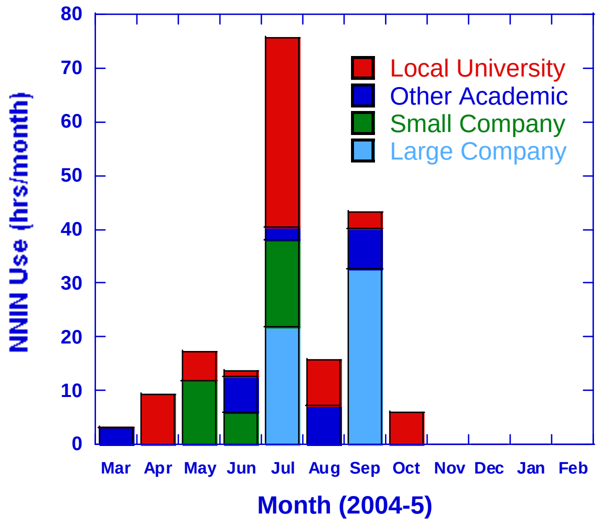


Figure 13 Use of the Triangle National Lithography Center

Table 3 NNIN-TNLC Projects

Project	Institution
Enhancement of Lithographic Processes Using CO_2: CO_2 Modified PAB, PEB & Direct Development	NC State University
Photoresist Synthesis for Microlithography Using CO_2	UNC-Chapel Hill
Corning Grating	Corning
Patterning High Aspect Ratio Features in EUV Resist	Micell
Strained Silicon MOSFETs with SiGe Source/Drain Functions	NC State University
Phase II 193 nm Photoresist	Meng Technologies
Direct Metal Pattern Writing by VLIV Photodissociation	Old Dominion University

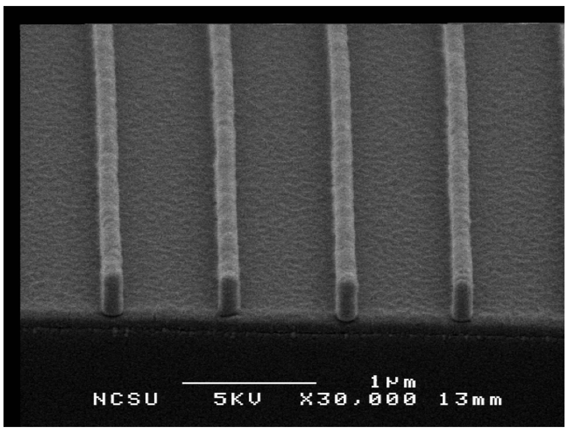


Figure 14: 80 nm patterned lines in resist using the 193 nm scanner

Future plans for the TNLC include: a) extension of the technical capabilities, b) expansion of the user base, and c) broader participation in other NNIN programs. We seek to enhance the "tool box" of capabilities and are working to develop a broader range of processes to meet the needs of a wider community. In particular, we plan to examine: a) photoresist trimming processes to reduce the size of printed features; b) dry etching processes using 193 nm resist masking as well as other “hard masks”, c) substrate holders to accommodate a range of substrate sizes, and d) funding opportunities to install the wafer coat and develop tracks which were delivered earlier this year. To expand the NNIN user base, our approach is twofold: first is emphasis on providing exceptional service for companies with sustained and growing use; second is increasing emphasis on publicizing the TNLC capabilities through its web site, NNIN promotional activities, new brochures, and contacts with economic development programs. We plan to participate in the NNIN REU program in the summer of 2005 for the first time, and we are working to couple NNIN programs on education, society and ethics, as well as safety and health.

Appendix 2: NNIN Sites and Principal Contacts

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