10. SHARED AND OTHER EXPERIMENTAL FACILITIES

The shared facilities are operated to encourage both hands-on research by experienced and qualified users, and as educational tools for students and researchers from other disciplines who can benefit from their use. A broad-range of facilities teaches students the skills of nanofabrication, imaging, and synthesis that they will need after graduation, and open new avenues of investigations for all disciplines. The shared experimental facilities play a special role in fostering interdisciplinary exchanges. The facilities are the natural meeting places where students from all parts of the Center learn from one another and share technical expertise.

Figure 10.1. Construction nears completion at Harvard University (*left*) on the new Laboratory for Integrated Science and Engineering (LISE), November 2006. Computer aided design of the completed LISE building (*right*) that will be the new home of the shared experimental facilities.

New Laboratory Construction

Harvard University is supporting the construction of a new, 135,000 sq. ft. Laboratory for Integrated Science and Engineering (LISE). The Faculty Planning Committee viewed the construction of LISE, in close proximity to other science buildings in the north Yard, as a singular opportunity to create a research environment that will centralize major experimental facilities and foster cross-disciplinary research. The principal architect of LISE is Jose Rafael Moneo who served as Chairman of the Architecture Department of the Harvard Graduate School of Design (1985–1990). The building will include extensive vibration-free space to house the shared facilities including major cleanroom and nanofabrication facilities, advanced imaging laboratories, and facilities for materials synthesis. The building will also have space for new faculty (Interdisciplinary Research Laboratories) to advance cross-disciplinary research. A third programmatic element will be common spaces to promote collaborative exchanges. The project is now entering the final construction phase (Fig. 10.1). LISE is scheduled to open in summer of 2007. The University is planning the acquisition of new instrumentation for LISE as well as the relocation of current equipment, from five different buildings where the shared facilities are now located, with the transition occurring through the remainder of the year.

Harvard University supported the construction of a new building in the North Yard at 60 Oxford Street. The top two floors, along with one floor in the adjacent Engineering Sciences Lab (ESL) at 40 Oxford Street are now home to faculty in Bioengineering. Assistant Professor **Parker**'s laboratories have been finished in this space which has been an impetus for collaborative work in the Tools for Integrated Nanobiology Cluster, for example. The University has also recently completed the construction of new laboratory space for undergraduate bioengineering training (Fig. 10.2). These recent buildings and teaching laboratories will continue to pull the science community together, across traditional departmental boundaries and be spaces where researchers can interact in new common experimental and training facilities.

Figure 10.2. New bioengineering undergraduate teaching laboratories in Pierce Hall.

Integrated Management of Facilities and Technical Staff

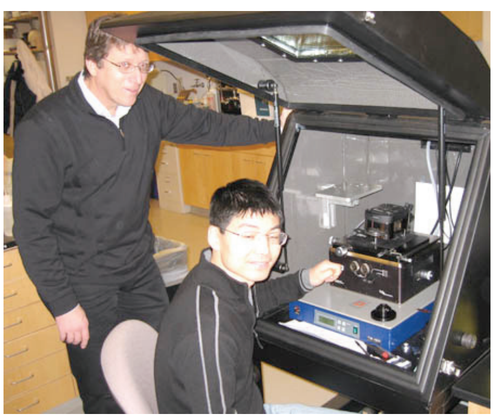


Figure 10.3. Dr. Jiandi Wan uses the new Asylum MFP-3D AFM instrument in Bauer Laboratory, as Dr. Richard Schalek, CNS senior staff, assists.

In January 1999 Harvard announced the commitment to launch several new interdisciplinary research centers in the sciences. The faculty had identified a strong scientific and technological need for the understanding and development of mesoscale materials and structures. This new challenge would require sophisticated facilities for imaging, nanofabrication, synthesis, and growth. The Center for Imaging and Mesoscale Structures (CIMS) was born from this vision. **Halperin**, co-PI of NSEC, was the first Scientific Director of CIMS. Harvard University supports the Center for Imaging and Mesoscale Structures (CIMS) to support research and education in the area of nanotechnology and mesoscale science. A main mission of CIMS is the provision, operation and maintenance of complex facilities for imaging and fabrication. CIMS began to purchase equipment and hire technical staff as well as construct a second cleanroom in the basement of the Gordon McKay Laboratory. The management of the shared facilities at Harvard from CIMS, MRSEC and NSEC were integrated in 2002; the management boards of these Centers work closely together. Importantly, instrumentation for new CIMS facilities are open to all students, research associates, staff and faculty of the NSEC (regardless of institution), and to all NSEC collaborators. This integration made CIMS the main source for centralized user facilities in the Oxford Street science campus. In September 2004, **Marcus** became the Scientific Director of CIMS. In April 2005, CIMS was renamed to the Center for Nanoscale Systems and they launched their new website (www.cns.fas.harvard.edu). In January 2006, Eric Martin joined CNS from Avici Systems (North Billerica, MA) as the Technical Director. CNS presently has

thirteen full-time technical staff members and the available instrumentation is organized in three areas: Imaging and Analysis; Nanofabrication (including cleanroom operation); and Materials Synthesis. The complete list of instrumentation and equipment is listed on the facilities web page (www.cns.fas.harvard.edu/facilities/). CNS makes a direct, cost-sharing contribution to the NSEC through annual equipment acquisitions. The support and operation of the shared experimental facilities are the responsibility of CNS, with the only recharge to CNS from the NSEC in the form of user fees.

National Nanotechnology Infrastructure Network (NNIN)

UC Santa Barbara and Harvard University are two of the thirteen members of the National Nanotechnology Infrastructure Network (NNIN) began in March 2004. CNS is also responsible for managing the Harvard portion of the NNIN activity (www.nnin.org) that further reaches out to a national user base. The areas of focus at Harvard are soft lithography and the assembly of nanoparticle and molecular electronics; theoretical simulations of electron states and transport in nanoscale systems. These areas have significant overlap with research in the NSEC.

Michael Stopa leads the coordination of the computational initiative in NNIN (Fig. 10.4). Stopa was previously at NTT in Japan and gave several seminars as part of the international exchange programs of the NSEC. Like the NNIN experimental program, NNIN/C is a multi-university initiative, the object of which is to establish a national computing resource that provides hardware resources and simulation tools dedicated to nanoscience research for the academic and industrial research communities. The software tools include commercial software packages for design and analysis, of nanometer scale devices as well as some of the latest academic advances in nanoscale modeling and simulation software. A workshop Synergy Between Experiment and Computation in Nanoscale Science was held from May 31–June 3, 2006 (Fig. 10.5) that attracted over 100 participants, from other NNIN computational sites, across the nation, and from 12 countries. NSEC speakers at the workshop included **Heller**, **Kaxiras**, **Marcus**, and **Whitesides**.

Figure 10.4. Michael Stopa speaking at a NISE-net Forum at the Museum of Science, Boston.

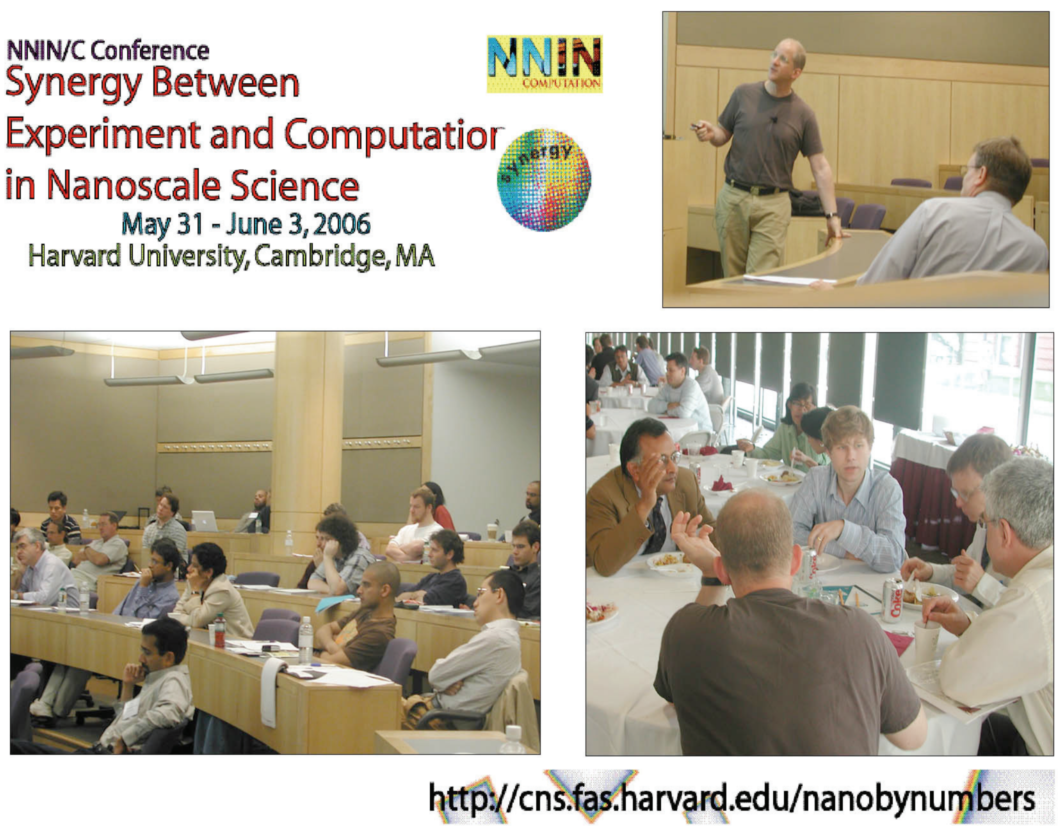


Figure 10.5. NNIN/C Conference activities, 2006.

In August 2006, Fettah Kosar joined the CNS/NNIN team as a senior staff scientist (Fig. 10.6) to oversee the operation of the Soft Lithography Foundry (SLF), support academic and industrial researchers on projects, and train users on master fabrication and soft lithography. Fettah completed his Ph.D. in Bioengineering and Nanotechnology from the University of Washington in 2005. Before joining CNS, Fettah was a senior fellow in Paul Yager's group at UW, working on the design and development of a microfluidic point-of-care system for the rapid and on-the-field diagnosis of life-threatening infectious diseases in third-world countries.

Inline with the NNIN mission, CNS organized a Soft Lithography Technical Forum, which was held on Harvard University campus in Cambridge on October 31st and November 1st, 2006. This event was the second in a series of Technical Forums organized by individual NNIN sites. The main goal of the Forum was to disseminate and share technical knowledge and practical information on soft lithography across NNIN sites, as well as to educate and train NNIN personnel on some basic soft lithography techniques. Subject matter included overviews from participating sites, expert presentations, hands-on training sessions, laboratory demos, and tours of functional facilities.

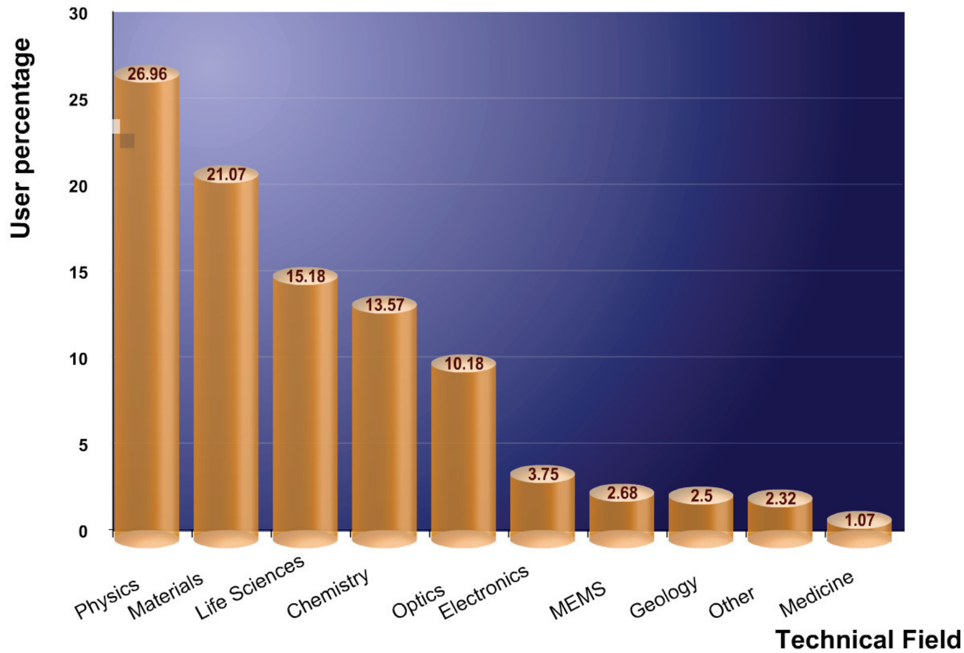
Fourteen participants from ten NNIN sites attended this forum, excluding the CNS staff members. After opening remarks by **Charles Marcus** and Eric Martin, the forum took off with a stimulating keynote presentation from **George Whitesides**, who addressed a full house about his vision of the NNIN Soft Lithography Network. After the keynote, it

Figure 10.6. Dr. Fettah Kosar (*left)*; **George Whitesides** (*right*) giving keynote presentation at Soft Lithography Technical Forum on Halloween, 2006.

was time for the NNIN site presentations, which promoted sharing soft lithography-related experience and knowledge among the NNIN sites. Overall, the Soft Lithography Technical Forum was received and rated very favorably by the attendees. Whereas this forum was an internal NNIN event, CNS is currently considering a much larger Soft Lithography Workshop at Harvard University for the Fall of 2007. Unlike the NNIN Soft Lithography Technical Forum, this workshop will be open to anyone interested in soft lithography, not just the NNIN sites.

User Statistics

The shared facilities are heavily subscribed with more than 560 users from March 2006 through February 2007. Users came from many different institutions and varied technical fields. Below (Fig. 10.7) is statistical information of the shared facility users. Note that the Other category in the Institution Type chart includes small and large corporations, state and federal agencies, and international institutions. Also, most projects cut across many technical fields. In fact, it is part of the mission of CNS and NNIN to promote such interdisciplinary research. However, for the sake of tracking trends, users must select only one technical field when applying to the CNS/NNIN User Program.



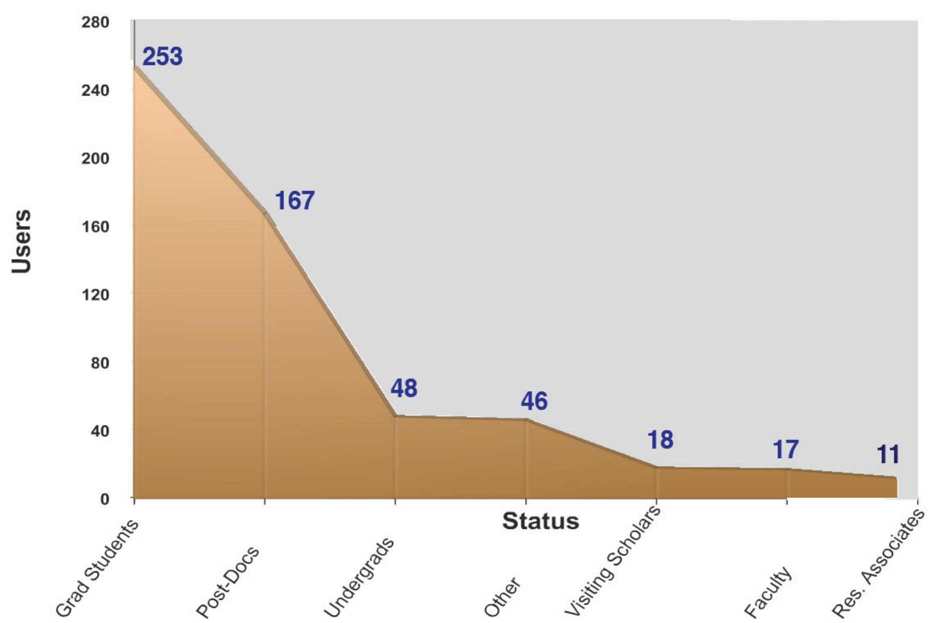


Figure 10.7. Shared Facilities user statistics from March 2006 to February 2007.

Student Training and Safety

Equally important to the acquisition of state-of-the-art instrumentation in the pursuit of our research program, is the availability of talented technical staff that provides training through regularly scheduled courses and hands-on laboratory instruction. The technical staff ensures that environmental health and safety procedures are followed and guidance is provided until researchers are certified as self-users. The staff also helps researchers develop new fabrication processes and measurements techniques, and upgrade equipment in response to changing research needs.

These cutting-edge instruments also are used in many of the Research Experience for Undergraduate (REU) and Teacher (RET) projects and, in many cases, are resources that are not available to many participants in these summer research programs back at their

Figure 10.8. (*Left*) Dr. Steve Cronin and Sasha Stolyarov (REU, Univ. Texas Dallas) working in one of the cleanrooms; (*right*) Joseph Cox (REU, Eastern Nazarene College) and Visiting Professor John Free, during the summer research experience program, 2006.

home institutions (Fig. 10.8). This is an important illustration how the NSEC brings together talented researchers, who serve as mentors for undergraduates and teachers, technical staff with expertise, and essential (and often sophisticated) experimental facilities. Sasha Stolyarov (above) returned to Harvard after finishing his undergraduate degree at the Univ. of Texas at Dallas and entered Harvard as a graduate student in the Department of Physics. Sasha was awarded an NSF Graduate Fellowship this past year.

Other Facilities

Center participants have access to other imaging, clean room, and synthesis facilities at MIT and UC Santa Barbara. With the installation of three new systems (Fig. 10.9), there are now a total of eight different MBE machines available for sample growth at UC Santa Barbara (www.materials.ucsb.edu/~mbe/lablayout.html). The NSEC has supported exchanges through the travel program by students who are expert in materials growth (UC Santa Barbara) to meet with students working in transport measurement (Cambridge). It is been very valuable in moving research forward for these different groups to gain an understanding of each others' approaches and capabilities. The

National Laboratories have excellent capabilities that also help NSEC researchers, particularly those in micro-electromechanical structure (MEMS) fabrication facilities at Sandia (www.cint.lanl.gov). **Westervelt** serves on the Advisory Board of CINT.

Figure 10.9. (*Left*) The new Engineering Sciences Laboratory which is home to the Nanofabrication Facilities (*right*) at UC Santa Barbara (*right*).

Center participants also benefit strongly from international collaborations with Delft University of Technology in The Netherlands, and the University of Tokyo, the Institute for Industrial Research and NTT in Japan. These institutions are world leaders in mesoscopic science and engineering. Leo Kouwenhoven has created a visiting program with Delft to exchange students and share facilities for collaborative research. Hiroyuki Sakaki and Seigo Tarucha are also coordinating visits with the University of Tokyo, the Institute for Industrial Research, and NTT for the design and fabrication, and testing of nanoscale structures (see also NSEC International Workshops in *9. Outreach and Knowledge Transfer*, above). Our international collaborators have contributed to the travel support for student exchanges and to support joint workshops.

11. NSEC PUBLICATIONS and PATENTS

Note: [a] signifies research principally supported by the NSEC
[b] signifies research partially supported by the NSEC
[c] signifies research where NSEC Facilities were utilized
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12. HONORS AND AWARDS, 2006–2007

Arthur C. Gossard

Newcombe Cleveland Prize, American Association for the Advancement of Science, Best paper of the year in Science Magazine, 2006

Eric J. Heller

Elected Member, National Academy of Science, 2006

Jennifer Hoffman

Presidential Early Career Award in Science and Engineering, AFOSR, 2006

Joseph P. Mizgerd

Invited to become member of Faculty of 1000 Medicine, Faculty of 1000, 2006

Venkatesh Narayanamurti

Member, National Research Council's MRSEC Assessment Committee, 2005–2007
Member, Engineering Dean's Council, Cornell University 2003–2008
Member, Engineering Dean's Council, Brown University, 2004–2006
Member, Engineering Dean's Council, Public Policy Com., 2005–2006
Member, Center for Integrated Nanotechnologies Board, Sandia National Laboratories, 2005–2006
Chair, Yale University Engineering Visiting Committee, 2006
Member, Mork Family Dept. of Chemical Eng. and Materials Science Advisory Com., Univ. of Southern California, 2006
President's Council, Olin College, 2006–

Hongkun Park

Teacher-Scholar Award, Camille and Henry Dreyfus Foundation, 2003–2008
David and Lucile Packard Fellowship, Packard Foundation, 2001–2006

Howard A. Stone

Chair, APS Division of Fluid Dynamics 11/2006–11/2007
Invited speaker for Leaders in Engineering Series, University of Western Ontario, Sept. 2006

Robert M. Westervelt

Director, Board of Advisors NISE Network of Museums, NISE Network, 2006
Board of Advisors, CINT Sandia National Lab., 2003–present

George M. Whitesides

Lifetime Achievement Award, India National Science Academy, 2006

Xiaowei Zhuang

Pure Chemistry Award, American Chemical Society, 2006