The NIST Center for Nanoscale Science and Technology: Supporting US Innovation in Nanotechnology

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*Abstract***— The NIST Center for Nanoscale Science and Technology (CNST) was established in May of 2007 to accelerate innovation in nanotechnology-based commerce. Located in NIST's Advanced Measurement Laboratory Complex on the Gaithersburg, MD campus, the CNST is the only national nanocenter with a focus on commerce. It supports the development of nanotechnology through research on measurement and fabrication methods and technology. The CNST has a unique design which supports the U.S. nanotechnology enterprise through the readily available, shared use NanoFab, as well as providing opportunities for collaboration in multidisciplinary research on new nanoscale measurement instruments and methods. The NanoFab is accessible to industry, academia, NIST, and other government agencies on a cost-reimbursable basis. With a simple application process, the NanoFab provides rapid access to a comprehensive suite of tools and processes for nanofabrication and measurement. While the NanoFab provides a comprehensive suite of commercial tools, the CNST's research scientists and engineers are creating the next generation of nanoscale measurement instruments and fabrication methods, which are made available through collaboration.**

Keywords-component; NIST; CNST; commerce; nanocenter; nanofabrication; nanomeasurement; nanomanufacturing; future electronics; energy

I. INTRODUCTION

Nanocenters are becoming ubiquitous throughout the US and the world, and with good reason. Nanotechnology continues to be a very strong area of scientific focus, its role in commerce is increasing with every day, and the nanocenter paradigm continues to be seen as an optimal way to further both the discovery and application of new nanotechnologies.

Nanocenters come in a variety of forms, but generally have a few similar overarching characteristics. They tend to be multidisciplinary owing to the broad nature of nanotechnology itself. And, they usually have some mechanism to efficiently share the expensive tools that are required. A great many nanocenters exist at universities. They range from small organizations, which may be "virtual" in the sense of having a physically dispersed organization of participants, to major centers occupying a large central physical plant. The National Science Foundation supports both research and education through a variety of university nanocenters under several programs, including fourteen that comprise its National Nanotechnology Infrastructure Network. The Department of Energy supports nanotechnology research projects through five Nanoscale Science Research Centers as part of a program that provides major scientific user facilities for the US.

NIST, as part of the US Department of Commerce, has the mission to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. Thus, the CNST has a unique and markedly different focus from other nanocenters. It emphasizes measurement, i.e., the development of new instruments and methods for nanoscale measurement, and its work spans the range from discovery to production, including nanomanufacturing in addition to nanofabrication. Because of CNST's broad role in removing the measurement barriers encumbering the introduction of new products to the market, it is critical that the structure of the CNST support a rich and energetic interaction with industry.

II. CNST DESIGN CONSIDERATIONS

A. Goals and Implementation

The organizational design of the CNST needs to meet several important goals. Since our central mission is to support the development of nanotechnology from discovery to production by making available, as well as advancing, state-of-the-art nanoscale measurement and fabrication tools and methods, our design must logically support both safe and efficient access to a large tool set and have a significant research capability aimed at furthering the state-of-the-art. We chose to satisfy the first objective by establishing a shared-use facility, the NanoFab, that operates much like an NSF supported NNIN nanofabrication facility. The cost of maintaining and operating the tools is recovered by charging an hourly rate for tool use that varies depending upon the tool. Users doing proprietary research pay the full cost recovery rate. Otherwise, users supporting the mission of the CNST may qualify for a cost shared rate that substantially reduces their expense. No distinction is made between academia, business, or government in determining the applicability for the reduced rate; the rate is determined by what you are doing, not where you are from.

Another goal is to reduce the barriers to using the facility to an absolute minimum. This goal is particularly important because companies, and in particular small companies, frequently need rapid access to tools and expertise. Further, many of their needs would not be ranked highly if held to a standard of cutting edge fundamental science in a peer review process. Hence, our entry process uses very simple applications that are reviewed by CNST staff, on a continuous basis throughout the year, for safety, appropriateness, and merit. Typically, only a week or two is required to obtain access; tool use is then on a first come, first served basis via an on-line reservation system.

Users of the NanoFab possess a broad spectrum of knowledge and experience, ranging from seasoned veterans with 30-years of experience to complete novices. The veterans are granted access relatively quickly following a mandatory safety course and examination, and confirmation by our NanoFab staff that they are fully qualified to operate the tools they need. This option is popular with some companies because, since they are involving no NanoFab staff in the fabrication or measurement process, they can both retain sole ownership of all intellectual properties rights and maintain the data as proprietary as well. At the other extreme, complete novices may choose to be trained on the tools they need to use, have a NanoFab staff member run the process for them, or employ a combination of both alternatives. An initial project discussion with the NanoFab staff and a relevant expert from the research staff helps determine the optimal processing steps. Because many users will depend on the NanoFab staff for extensive consultation and help, we have staffed the NanoFab with highly experienced process engineers drawn largely from the semiconductor industry. Having an experienced staff is also important to maintaining stable and reliable processes in the NanoFab. A small company that has developed a process for making its own structures or device needs to be able to return several months later and be able to duplicate their prior results without having to start a new research project.

The development of measurements and fabrication methods that go well beyond the current commercial state-of-the-art requires a very different approach. For example, since nanotechnology is a young discipline that is rapidly evolving, it is important that our research approach be agile, allowing it to retarget its research and development objectives relatively quickly in response to perceived need. This need is best met by a relatively flat organizational structure, one that utilizes a multidisciplinary team of core researchers supplemented by a much larger cadre of postdoctoral researchers and a dedicated technical support staff. The frequent arrival of new postdoctoral researchers brings with it new knowledge, experience, and ideas as well as allowing much more rapid changes in direction than might otherwise be possible.

Researchers from outside the CNST can access the advanced tools under development through collaboration, either to aid in their development or to make early measurements using a tool or method not yet available elsewhere. Collaborators include visiting professors, industrial researchers, postdoctoral researchers, graduate students, or undergraduates with tenures ranging from several days to several years. Such collaborations are arranged by direct application to the leader of the research project of interest. In addition, formal strategic partnerships have been established. The CNST benefits greatly by the partnerships it has established with other programs

Nanotechnology being such a broad topic, it is necessary to select carefully from a constantly changing list of priorities for new instrument and method development. One must have taken care, however, to assemble a research staff possessing a broad range of technical expertise and experience in order to maximize the number of tractable problems. For this reason, the CNST has selected experts in a several key nanotechnology fields, including nanofabrication; nanomanufacturing; atomic-scale characterization; nanophotonics; nanoplasmonics; nanoscale electronic and ionic transport; nanotribology; theory, modeling and simulation of nanostructures; nanoelectro-mechanical systems; nanoscale modeling and simulation; environmental transmission electron microscopy; control of nanoparticles; nanomagnetic imaging and dynamics; nanomaterials for energy storage and conversion, and nano-scale fluctuations and control. Currently, three priority research areas have emerged, based on a gap analysis of nanotechnology measurement needs: future electronics; nanomanufacturing; and nano-enabled energy conversion, storage, and transport devices.

III. CURRENT STATUS

The Center for Nanoscale Science and Technology was created formally in May of 2007. Since then, the CNST has staffed and equipped its NanoFab shared use facility, and assembled a team of researchers to develop, in collaboration with the user community, the needed instruments and methods of the future.

A. The NanoFab

The NanoFab consists of a large clean room and several more conventional laboratory modules in an adjacent building. The NanoFab cleanroom occupies 1,800 m^2 of floor area, which includes 750 m^2 of class-100 space. The NanoFab cleanroom contains over 65 fabrication and processing tools, providing electron beam-, photo- and nanoimprint-lithography, laser writing and mask generation, field emission scanning electron microscopy, metal deposition, plasma etching, chemical vapor deposition, atomic layer deposition and silicon micro/nano-machining. Additional tools, which are located outside the cleanroom, include a dual beam FIB system and an atomic force microscope. The CNST has a particularly strong capability in electron beam lithography. An ultra high resolution electron beam lithography system provides for direct write nanoscale feature development and mask writing capability from small samples up to 300 mm substrates. A second E-beam lithography tool is designed for direct writing on wafers with a 2 nm spot size on substrates up to 150 mm x 190 mm in size. Additionally, a state-of-the-art nano-imprint lithography system produces nanoscale features in soft materials from a hard mask made using the e-beam writer. The tools are interlocked and controlled using the Coral software system.

B. Instrument and Measurement Resarch

A multidisciplinary staff of approximately 18 project leaders, augmented by about twice that number of postdoctoral researchers, works on the development of new instruments and methods to further nanotechnology. Current disciplines represented include, physics, applied physics, chemistry, chemical engineering, electrical engineering, mechanical engineering, biology, materials science, and aeronautical engineering. Additional groups provide supporting technology in the areas of electronics, mechanical instrument design, and computing.

Examples of current research programs include:

- Development of ultra-low-temperature scanning tunneling spectroscopy methods for measurement of the electron transport in graphene
- Methods to study electron transport in nanoscale organic/inorganic devices
- Techniques for nanoscale optoelectrical characterization of photovoltaic materials and devices
- Imaging methods for nanomagnetics
- An optically operated nanoscale mechanical tool set
- A new super-resolution optical microscopy method
- Ways to position and orient nanoparticles using feedback control
- Methods for nanomanufacturing and directed self assembly
- Nanotribology measurement methods for nanomanufacturing
- Methods to measure light-matter interactions in chip-based optical cavities
- Probes for nanomaterials in electrochemical energy conversion and storage
- Novel ion source development to improve focused ion beam nanofabrication and imaging

Such projects are carried out through collaboration using a variety of mechanisms. Many involve collaborations with resesarchers in other NIST Laboratories, making use of their deep disciplinary skills and knowledge. Others involve collaborations with universities, other government laboratories, or industry. Some are joint exploratory development programs with a manufacturer of a scientific instrument or fabrication tool. Many have benefitted by the existence of a NIST-University of Maryland Cooperative Program which links the CNST and University of Maryland Nanocenter.

Since being established in May 2007, the CNST has grown rapidly, with over 500 scientists now participating in CNST-supported research. Current research participants come from more than two dozen companies, a dozen national laboratories, 70 universities, and from institutions in 30 States and 15 countries.