Progress and Plans of National Nanotechnology Initiative (NNI) Agencies

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Summary

Advancing nanoscale measurement science, standards, and technology is an important component of NIST's mission to promote U.S. innovation and industrial competitiveness. From leading cutting-edge research, to providing world-class facilities, to coordinating the development of standards that promote trade, NIST's intramural nanotechnology research program directly impacts the Nation's economy and well-being. The nanotechnology research conducted in NIST's laboratories and user facilities results in measurements, standards, and data crucial to a wide range of industries and Federal agencies, from new measurement and fabrication methods for advanced manufacturing to reference materials and data needed to inform the responsible development and use of nanotechnology. NIST further supports the U.S. nanotechnology enterprise through its user facilities, including the NIST Center for Neutron Research (NCNR) and the nanofabrication facility (NanoFab). The NCNR provides access to a range of world-class neutron scattering tools for characterizing the atomic and nanometer-scale structure and dynamics of materials. The NanoFab provides rapid access to state-of-the-art tools needed to make and measure nanostructures. NIST staff members participate widely and lead in nanotechnology-related standards development and international cooperation activities such as the Organisation for Economic Co-operation and Development (OECD) Working Party on Manufactured Nanomaterials, the International Organization for Standardization (ISO) Technical Committee (TC) 229, the International Electrotechnical Commission (IEC) TC 113, and ASTM International Committee E56. Interagency coordination and information sharing related to these activities is facilitated through the NSET Subcommittee.

Key Technical Accomplishments by NNI Goal

Goal 1. Advance a World-Class Nanotechnology Research and Development Program

NIST has made significant progress toward foundational measurements for a range of nanoscale systems and applications. NIST nanotechnology-related research programs include measurement science for photonic circuits, polymer membranes, energy efficient electronics, and reliability for advanced microelectronics. NIST has continued to perform pioneering quantum opto-mechanics experiments that use quantum correlated phonons as a means of realizing an absolute temperature scale, and is harnessing the unique properties of graphene to develop improved quantum resistance reference standards.

Highlights

- To realize atom-based devices, the frontier for traditional silicon electronics, NIST has a research effort in atomically precise fabrication, atomic-scale device metrology, and fundamental measurement science at the atomic limit. The main focus of the work to date has been to integrate atomic dopant placement, scanning tunneling microscope patterning, and contacts to devices as small as 5 nm. NIST has pioneered new methods to locate the nanometer-scale patterned devices and to connect e-beam patterned contacts, enabling measurement of nanodevices. Portions of this work are done with collaborators in the Department of Energy (DOE) Center for Integrated Nanotechnologies, companies, and universities.

- In collaboration with academic researchers, NIST scientists have now unveiled the long-mysterious inner workings of memristors, semiconductor elements that can act like the short-term memory of nerve cells. The resistance of a memristor depends on the amount of current that recently flowed through it. Moreover, a memristor retains that memory even when electrical power is switched off. Despite the keen interest in memristors, scientists have lacked a detailed understanding of how these devices work and have yet to develop a standard toolset to study them. Now, NIST scientists have identified such a toolset and used it to more deeply probe how memristors operate. Their findings could lead to more efficient operation of the devices and suggest ways to minimize the leakage of current.[1]
- NIST filed a provisional patent application for a microflow measurement system, about the size of a nickel, that can track the movement of extremely tiny amounts of liquids—as small as nanoliters (nL, billionth of a liter) per minute. The invention is designed to fill an urgent need in the rapidly expanding field of microfluidics, in which precisely measuring tiny flow rates is critical.[2]

Goal 2. Foster the Transfer of New Technologies into Products for Commercial and Public Benefit

NIST staff members continue to participate in, and lead, standards development activities in a range of nanotechnology standards development organizations such as ASTM International's Committee E56, ISO TC 229, and IEC TC 113.

Highlights

- NIST staff participates actively in pre-standards protocol validation through work in inter-laboratory testing organized by the Versailles Project on Advanced Materials and Standards (VAMAS). This is a critical step in developing robust standards, and greatly facilitates the process of standards development while also ensuring the fit-for-purpose of the resulting standard.
- NIST staff members are also actively involved in standards development for different aspects of measurement and characterization, including in ISO TC 229, ASTM E56 and IEC TC 113. NIST staff members are also leading the revision of an ISO Technical Specification related to nanomanufacturing processes vocabulary.

Goal 3. Develop and Sustain Educational Resources, a Skilled Workforce, and a Dynamic Infrastructure and Toolset to Advance Nanotechnology

NIST has several facilities that support the national infrastructure for nanotechnology research and development, including the NanoFab and NCNR user facilities serving industry, academic, and government researchers on NIST's Gaithersburg campus, and the MicroFabrication Facility located at NIST's Boulder campus, which houses nanofabrication tools for electronics and other applications. The reallocation of

[1] https://www.nist.gov/news-events/news/2018/01/thanks-memory-nist-takes-deep-look-memristors

[2] https://www.nist.gov/news-events/news/2018/01/stopwatch-nanofluids-nist-files-provisional-patent-measuring-nanoliter-flow

equipment funds from NIST's nanotechnology facility to other higher-priority shared equipment resources is reflected in the decrease in NIST contributions in PCA 4 from fiscal year (FY) 2017 to FY 2018.

Highlights

- In January 2018, NIST released the NanoFab Equipment and Operations (NEMO) web application as open-source and free software.[3] Making reservations, accessing tools, and maintaining equipment at the NIST NanoFab got a lot easier five years ago when NIST developed a customized laboratory management web application. Now other nanotechnology fabrication facilities and laboratories across the Nation can reap the same benefits. Users can customize NEMO for their own laboratories, enabling any customer with a desktop or mobile device to reserve tools, view the operating status of instruments, and seek assistance from laboratory staff. The web application is written in the Python programming language and uses the Django web framework. It is system-independent (can run on Linux, Windows, or Mac) and does not require special hardware to operate.
- NIST used a focused ion-beam machining technique to fabricate devices that allow precise measurement of the size of nanoparticles in a liquid. The nanofluidic devices, which have the potential for mass production, could become a new laboratory standard for determining nanoparticle size. Such measurements could expedite quality control in industrial applications of nanoparticles. Several customers of NIST's nanotechnology user facility, where the work was conducted, have expressed interest in adapting the technology for measuring both the size and brightness of nanoparticles in their products.[4]
- In 2018, three NIST beamlines will come online at the National Synchrotron Light Source (NSLS)-II, located at Brookhaven National Laboratory (BNL). Nine end-stations will take advantage of the unique broad and brilliant spectrum at NSLS-II to provide a world-leading suite of measurements of the atomic, molecular, and electronic structure of materials. The beamlines feature different parts of the x-ray spectrum, and hence the different types of materials and properties they can measure. A unique aspect of the NIST beamlines is the ability to measure samples with multiple beams, enabling the measurement of more diverse and complex structures such as in polymer-metal composites.
    1. All beamlines are still in the construction phase, however the "hard" x-ray beamline is in the final stages of commissioning, with scientific operations anticipated to start in the March/April 2018 timeframe. This beamline will feature a NIST-operated x-ray spectroscopy line—used to look at solid/solid interfaces such as in semiconductors, glasses, and advanced metal alloys—as well as an x-ray diffraction station being built and operated in collaboration with IBM.
    2. The other two beamlines feature longer wavelengths, called "soft" and "tender" x-rays. These lines (SST-I and SST-II) will feature measurement capabilities for materials across the entire periodic table, including microscopes that can probe molecular composition and orientation, which are both critical factors in many plastics, organic materials, and electronics. These are in the final stages of construction, with commissioning anticipated during the summer of 2018 and scientific operations beginning in the fall of 2018.
    3. Centered on the NIST synchrotron science group, NIST is developing a new collaborative model with DOE and BNL to streamline technology development, data management, scientific impact, and transfer to stakeholders.

[3] https://github.com/usnistgov/NEMO

[4] https://www.nist.gov/news-events/news/2017/12/atomic-blasting-creates-new-devices-measure-nanoparticles

Goal 4. Support Responsible Development of Nanotechnology

NIST develops validated methods for physico-chemical and biological measurements, and makes reference materials available to academic, industry, and government stakeholders. For example, NIST is developing methods to simultaneously measure nanoparticle size, mass, number concentration, and apparent density; methods to investigate transformations of silver nanoparticles released from textile materials; and is evaluating the applicability of an ISO standard method for *C. elegans* growth and reproduction inhibition using a broad range of nanoparticles.

Highlight

- NIST is reissuing gold nanoparticle reference materials (RMs), due to the tremendously high demand for them. RM 8012 gold nanoparticles are nominally 30 nm diameter, and RM 8013 gold nanoparticles are nominally 60 nm diameter. The RMs are extensively analyzed by NIST scientists to assess particle size and size distribution by multiple techniques for dry-deposited, aerosol, and liquid-borne forms of the material. Dimensions are measured using multiple independent methods—including atomic force microscopy (AFM), transmission electron microscopy (TEM), scanning electron microscopy (SEM), dynamic light scattering (DLS), and small-angle x-ray scattering (SAXS). Currently listed as out of stock, these are slated to be available again by the end of FY 2018.

Plans and Priorities by Program Component Area (PCA)

PCA 1. Nanotechnology Signature Initiatives and Grand Challenges

The President's budget request for the NIST laboratories preserves NIST's core measurement science research activities. NIST's proposed funding for the five Nanotechnology Signature Initiatives is held constant from FY 2018 to FY 2019. A reduction in FY 2019 of NIST's contribution for the Nanotechnology Grand Challenge reflects the elimination of a grant to the Semiconductor Research Corporation supporting a public-private partnership with industry and university partners to identify breakthrough materials and technology solutions for next-generation computing and information processing.

Research Highlight

- NIST is now positioned to begin measurements of atom-scale devices, which will allow measurement and manipulation of individual electrons, a key to scalable quantum computing. Currently, reliability of the contacts to buried structures constitutes the highest risk to measurement integrity and device yield. NIST will pursue several promising solutions to this problem. Additionally, NIST is exploring complementary dopants that would enable novel, atomically abrupt bipolar devices that may reveal classes of artificial two-dimensional materials that enable researchers to explore new science and novel technology.

PCA 2. Foundational Research

NIST's foundational nanotechnology research portfolio includes research to measure and advance the understanding of functional nanostructured materials, nanoscale imaging, and nanomechanical properties of materials.

Research Highlight

- An interdisciplinary team of NIST researchers is partnering with industry collaborators in an exploratory research project to use atom probe tomography for sub-nanometer-resolved three-dimensional chemical mapping.

PCA 3. Nanotechnology-Enabled Applications, Devices, and Systems

NIST measurement science programs to support PCA 3 include efforts for photonic circuits, polymer membranes, and energy-efficient electronics. NIST will continue to develop new methods to measure functional nanostructured materials, advance the development of single-photon detectors, and continue to harness the unique properties of graphene to develop improved quantum resistance reference standards. NIST will also continue its research efforts to advance the use of scanning probe microscopies to evaluate nanoscale properties of materials.

PCA 4. Research Infrastructure and Instrumentation

Consistent with the administration's priorities to redirect domestic discretionary resources, NIST is requesting reduced funding in FY 2019 for its user facilities, which provide U.S. scientists with access to world-class neutron measurement capabilities and state-of-the-art nanofabrication facilities. NIST will prudently reduce user support and defer upgrades for these facilities, while continuing to provide access to instruments that are of the greatest benefit to the user community.

PCA 5. Environment, Health, and Safety

The President's FY 2019 budget request eliminates the majority of NIST's nanomaterial environment, health, and safety (nanoEHS) program, ending the research and development efforts needed to develop new and continue providing existing standard reference materials. Projects included in NIST's request for PCA 5 in FY 2019 include research to understand and measure the reduced flammability of upholstered materials incorporating nanomaterials, and the analysis of nanomaterials in complex matrices.

Highlight

- NIST staff members, in collaboration with other U.S. Government agencies, academic institutions, and the private sector, are leading efforts in ISO TC 229 to develop methods for assessing the release of manufactured nanomaterials from commercial, manufactured nanomaterial-containing polymer composites. This work will help fill an important gap in understanding of how manufactured nanomaterials may be released from a range of commercially available products, many of which are often used for consumer purposes.