Grand Challenge Area

Nanoscale Instrumentation and Metrology: A New Age of Measurement Standards and Tools

Challenge

Nanotechnology-based industry requires the development of highly capable, low-cost, reliable instrumentation and internationally accepted standards for the measurement of nanoscale phenomena and for the characterization and manipulation of nanostructures. Improvement in measurement and manipulation capabilities is critical to the progress of nanotechnology.

Vision

Improved measurement methods to better characterize nanoscale processes and structures are needed. Additionally, present nanoscale measurements have little metrological underpinning and few standards to ensure their reliability and repeatability. Standard reference materials need to be developed and calibrated to establish the accuracy and reproducibility of a given nanoscale measurement tool. Standardized instruments with nanoscale resolution will accelerate scientific discovery and provide quality control in the fabrication and assembly of manufactured nanostructures. These research tools also will be adapted into miniaturized sensor and actuator technologies.

The complexity and breadth of nanotechnology provides a wealth of opportunities for innovation in instrumentation and metrology. Analytical instrumentation with increased resolution and sensitivity is needed to characterize the chemical composition and structure of materials at the nanoscale. Quantitative models for interpretation of scanned probe images are lacking. New analytical approaches are needed to characterize soft materials—materials otherwise deformed by the proximity of tips used in scanning probe microscopes. Progress in understanding biological systems is severely hampered by inadequate capability for probing cellular and subcellular nanoscale phenomena. Instrumentation for precise nanometer-position control across samples of centimeter dimensions will be required to realize commercial nanoscale device fabrication.

The creation of atomically controlled and measured structures may lead to the establishment of new fundamental standards. For example, quantized electron devices may provide improved electrical current standards.

Agency Participation

(leads in bold)

DOE	Centers to exploit unique national laboratory measurement capabilities
NIH	*In situ* diagnostics and therapeutics, medical imaging
NIST	Nanoscale measurement science, instrument calibration, standard reference materials, and nanoscale physical and chemical properties standard reference data
NSF	Broad based science as a source of new instrumentation concepts

In addition, DOD, DOE, EPA, IA, FDA, NASA, and DHS are developing measurement instrumentation with improved signal-to-noise for more sensitive detectors for each agency's mission-related needs.

Research Example: State-of-the-Art Nanoscale Measurement and Manipulation (supported by NIST)

Propelled by the constant need for increased speed and density and reduced cost, electronic and magnetic devices continue to get smaller. Integrated circuits in present day electronic devices have dimensions of less than 100 nanometers. Measurement of such nanostructures demands novel fabrication and characterization systems, such as illustrated in Figure 10. The facility shown here enables the atom-by-atom assembly of complex nanostructures under completely autonomous computer control. The facility is designed with the goal of atomic-resolution imaging and the ability to probe electronic properties of nanostructures with high-electron energy resolution. Cryogenic temperatures are required to achieve electron energy measurements sufficient to resolve the variation of quantum energy states in nanostructures. *In situ* fabrication and transfer of samples is essential to the study of well-designed and characterized nanostructures.

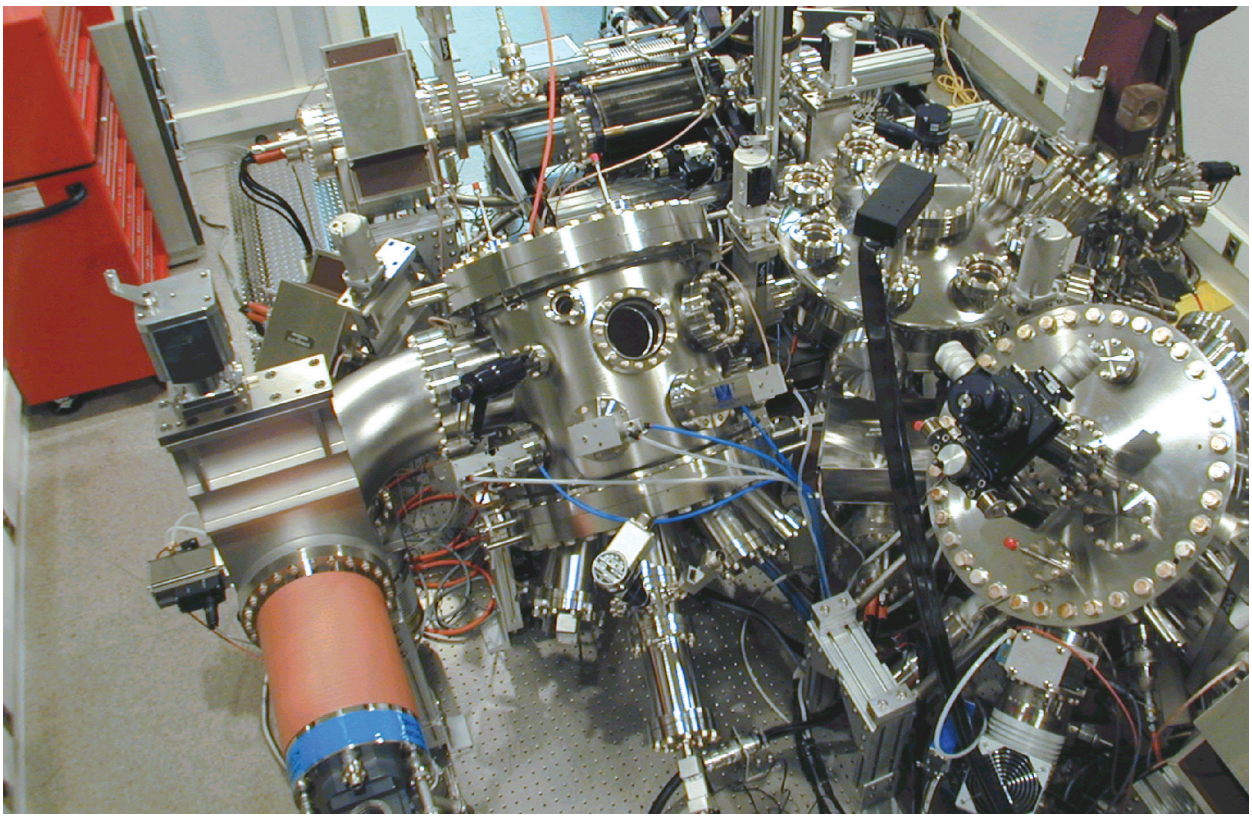

Figure 10. The NIST Nanoscale Physics Facility is a unique state-of-the-art instrument for the fabrication, characterization, and manipulation of novel nanostructures, with the following specific capabilities:

- Scanning tunneling microscope operating at ultra-high vacuum and controlled temperatures from about -270˚C to -150˚C
- Superconducting magnet system with 1.5 Tesla vector magnetic fields at the microscope position and 10 Tesla vertical magnetic fields at the microscope position
- Molecular beam epitaxy system to deposit semiconductors and metals with *in-situ* transfer of samples to the scanning tunneling microscope system
- Tip preparation system to image the atomic structure of tips with *in-situ* transfer of tips to the scanning tunneling microscope system
- Acoustically and electrically shielded measurement environment with extraordinarily high attenuation of external environmental disturbances

Courtesy J.A. Stroscio and R.J. Celotta, NIST Physics Laboratory