

*A National  
Nanotechnology  
User Facility for  
Industry  
Academia  
Government*

 **CNST** Center for Nanoscale  
Science & Technology

**NIST**  
National Institute of  
Standards and Technology  
U.S. Department of Commerce

# The Center for Nanoscale Science and Technology

The National Institute of Standards and Technology (NIST) Center for Nanoscale Science and Technology (CNST) is the Department of Commerce's nanotechnology user facility. The CNST enables innovation by providing rapid access to the tools needed to make and measure nanostructures. These tools are provided to anyone who needs them, both inside and outside NIST, with a particular emphasis on helping industry.

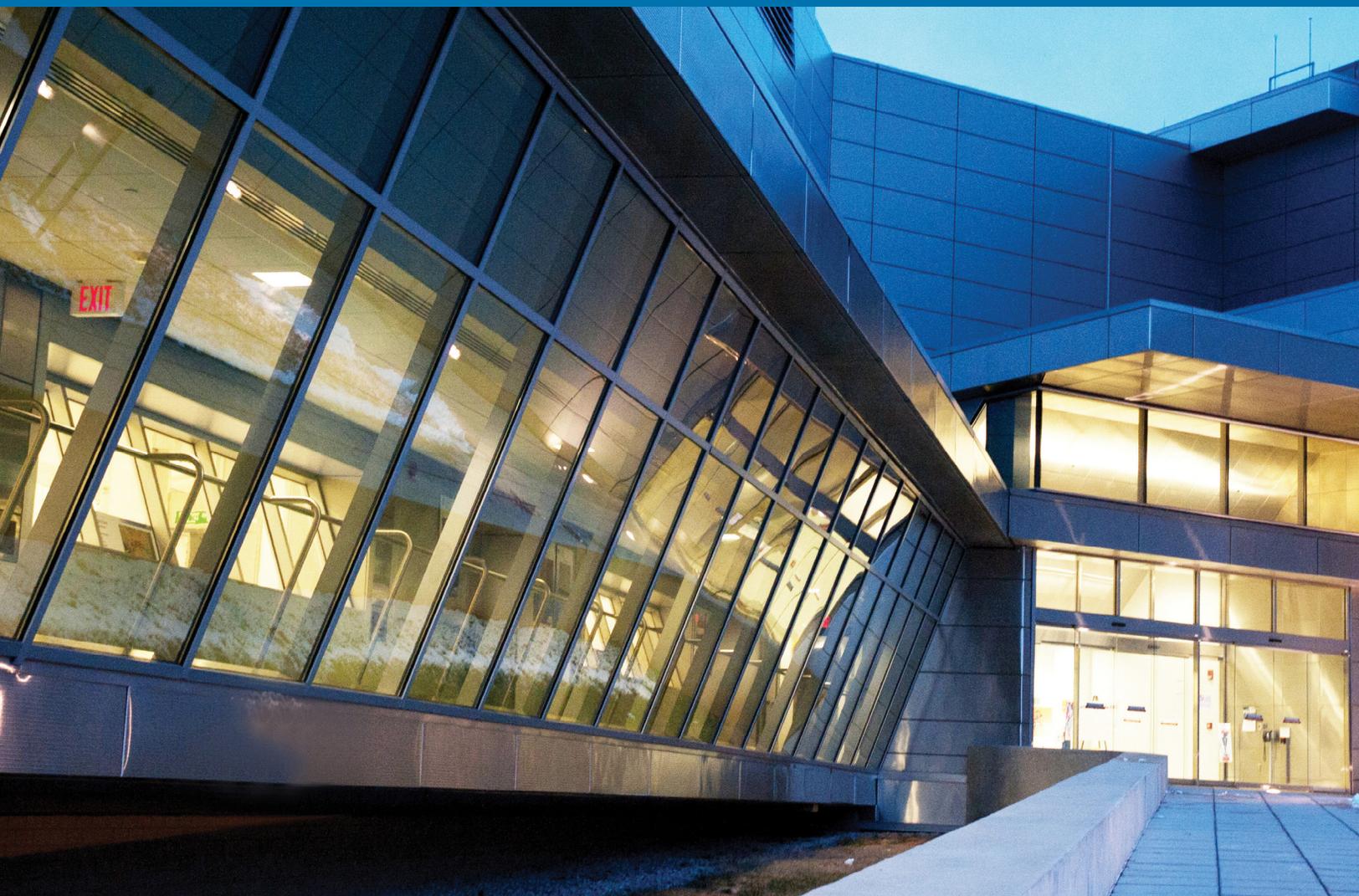
In the **NanoFab**, you can use our commercial state-of-the-art tool set at economical hourly rates, and get help from a dedicated, full-time technical support staff.

In the **NanoLab**, you can access the next generation of tools and processes through collaboration with our multidisciplinary research staff, who are developing new measurement and fabrication methods in response to national nanotechnology needs.

Robert Celotta, Director

J. Alexander Liddle, Deputy Director (Acting)

[www.nist.gov/cnst](http://www.nist.gov/cnst)



# A National Nanotechnology User Facility

The CNST is available to serve researchers from industry, academia, NIST, and other government agencies by providing:

## A state-of-the-art research **NanoFab** offering

- A comprehensive tool set, including advanced capabilities for lithography, thin film deposition, and nanostructure characterization
- Reliable, reproducible processes maintained by a professional staff
- Quick access at economical rates—submit the short application at any time; get started in a few weeks
- Training and advice provided by experts
- Fabrication and characterization support available—let us do the work (at additional cost)

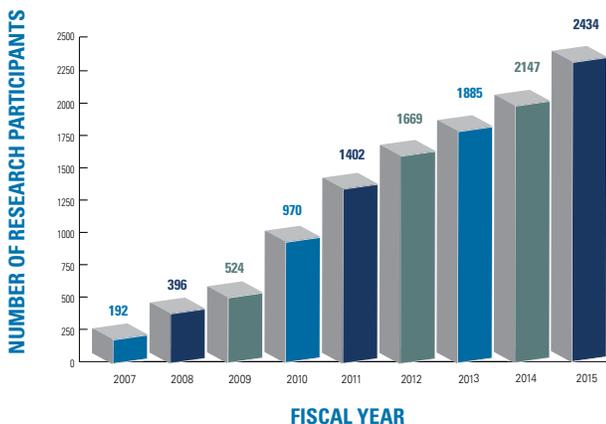
## A **NanoLab** with world-class researchers offering

- Collaborative research with unique instruments and nanofabrication methods
- Exciting opportunities for postdoctoral researchers and visiting scientists and engineers
- A broad research portfolio with emphasis on these thematic areas
  - Nanofabrication and nanomanufacturing
  - Energy storage, transport, and conversion
  - Future electronics

Resources (FY 2015): Budget \$37 million, Staff 142 (132 Technical)

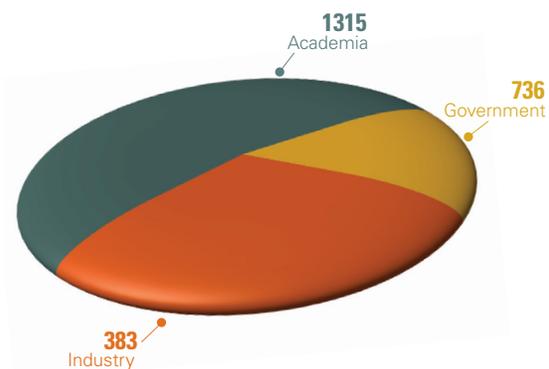
Let us solve your measurement and nanofabrication problems!

## CNST Research Participants

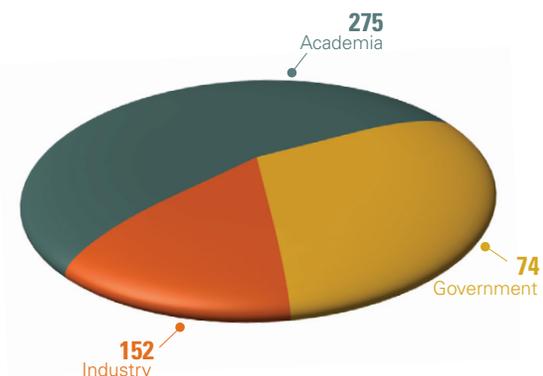


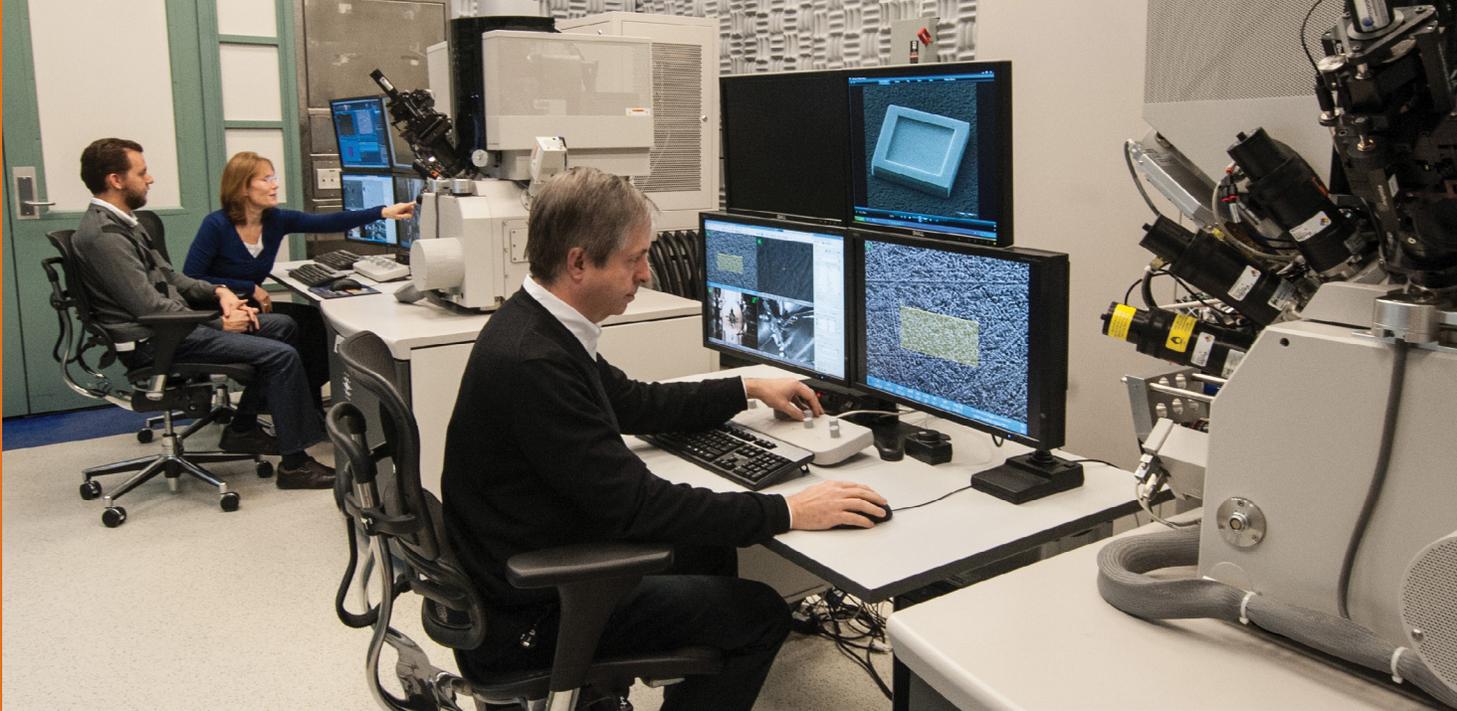
CNST “research participants” are those who directly participate in a CNST project. Research participants include those who use the facility onsite or remotely, and their collaborators on the project.

## 2434 Research Participants in FY 2015



## 501 Institutions Represented in FY 2015





# NanoFab

## The NanoFab: A Shared National Resource

The NanoFab provides researchers with rapid access to state-of-the-art, commercial nanoscale measurement and fabrication tools and methods, along with associated technical expertise, at economical hourly rates. It is well equipped to process and characterize a wide range of nanoscale materials, structures, and devices. Through its shared operating environment and close coupling with experts in the NanoLab, the NanoFab also promotes collaboration in nanotechnology both across NIST's laboratories and with and between other researchers.

To get started, contact the NanoFab Manager, **Vincent Luciani**, [nanofab@nist.gov](mailto:nanofab@nist.gov)

- **Rapid access** – Applications are accepted continuously, with a streamlined application process designed to get projects started in a few weeks.
- **Shared-use operation** – Economical hourly rates are charged *a la carte*, based on operating costs, with tools reserved through an on-line system.
- **Researchers may apply for reduced rates** – If a non-proprietary project advances the CNST mission, rates may be reduced by up to 50 %.
- **Flexible hours** – The NanoFab is open and staffed weekdays from 7 am to midnight, with access possible 24 hours a day, 7 days a week. We coordinate with each researcher to ensure that work can be scheduled during permitted access times.
- **Training** – The NanoFab will train researchers in tool use (tool and training charges apply).
- **Expert staff dedicated to technical support and process development** – The NanoFab is operated by a dedicated support staff of process engineers and technicians who train and assist users, operate and maintain the tools, and develop and control the processes. The support staff is available for expert consultation for all tools and processes.
- **Remote jobs** – Researchers can specify the work they need done and have it performed by the NanoFab staff at additional cost.
- **Intellectual property rights are protected** – NIST does not claim any rights to intellectual property used or developed in the NanoFab unless a NIST federal employee is a co-inventor.



# Tools and Processes

Over 100 commercial tools are available within the NanoFab's 5600 m<sup>2</sup> (60,000 ft<sup>2</sup>) of advanced laboratory space, which includes 1800 m<sup>2</sup> (19,000 ft<sup>2</sup>) of cleanroom. Most tools are located in the 750 m<sup>2</sup> (8,000 ft<sup>2</sup>) class 100 cleanroom. Our key capabilities, tools, and processes are summarized below. Visit [www.nist.gov/cnst](http://www.nist.gov/cnst) for a complete list and the associated rates.

**Lithography** – Pattern features from < 10 nm to micrometers in size on wafers up to 200 mm in diameter using electron beam, nanoimprint, laser, and optical lithography; create masks on-site for features as small as 700 nm; step-and-repeat across wafers with reduction lithography.

- Two Direct Write Electron Beam Lithography Systems (JEOL JBX 6300-FS)
- Laser Pattern Generator (Heidelberg DWL 2000)
- Nanoimprint Lithography Tool (Nanonex NX-2000)
- Contact Aligners (Suss Microtec MA6 and MA8)
- I-Line 5x Reduction Stepper (ASML PAS 5500/275)
- Automated Resist Spin/Spray Coater (Suss Microtec ASC200 Gen 3)

## Focused Ion Beam (FIB) Nanofabrication and

**Characterization** – Perform nanoscale machining and structural and chemical characterization with one of our three dual-beam FIBs, each combining a focused ion beam with a scanning electron microscope and gas injection system.

- Dual Beam SEM and FIB (FEI Helios NanoLab 650), includes a multi-chemical gas injection system and a Kleindiek *in-situ* probe system for nanopositioning and electrical measurements
- Dual Beam SEM and FIB (FEI Helios NanoLab 650), with energy dispersive x-ray spectroscopy (XEDS) for chemical analysis and an electron backscatter diffraction (EBSD) system for advanced materials characterization and crystallographic studies
- Cross Beam SEM and FIB (Zeiss NVision 40), includes an electron beam lithography system

**Metrology** – Characterize materials using a wide range of techniques.

- Scanning/Transmission Electron Microscope (FEI Titan), with 80 to 300 keV acceleration range allows both x-ray and electron energy loss analytical capabilities for chemical analysis
- Field Emission Scanning Electron Microscope (Zeiss Ultra-60), with XEDS for chemical analysis
- Wafer-scale Atomic Force Microscope (AFM) and research-grade AFM
- Tools for ellipsometry, profilometry, reflectometry, contact angle goniometry, and film stress measurements
- X-Ray Diffraction System (Rigaku SmartLab XRD), with a 9 kW rotating anode x-ray generator

**Thin Film Deposition and Processing** – Reliably deposit and anneal a wide variety of metal, semiconductor, and insulator films using thermal, sputter, electron beam, chemical vapor, and atomic layer sources with sub-nanometer precision.

- Cluster Sputter Deposition System (4Wave)
- Two Dual Electron Gun/Thermal Evaporator Systems (Denton Infinity 22)
- Two Sputter Deposition Systems (Denton Discovery 550)
- Furnaces for low pressure chemical vapor deposition, thermal oxidation, and diffusion processes
- Rapid Thermal Annealer (AnnealSys AS-Master 2000 HT)
- Plasma-Enhanced Chemical Vapor Deposition System (Plasma-Therm Versaline), using inductively coupled plasma (ICP)
- Atomic Layer Deposition System (Oxford FlexALRPT)
- Parylene Deposition System (Specialty Coating Systems PDS-2010)

**Dry Etch** – Reactive ion etching, ion milling, and chemical vapor etching for processing silicon, oxides, nitrides, polymers, metals, III-V compounds, alloys, ceramics, and multilayer structures.

- Two ICP Etchers (Oxford Plasmalab 100), with sample heating and cryogenic cooling
- Two ICP Etch Systems (Unaxis Shuttleline), including “Bosch” process deep silicon etching
- Two Reactive Ion Etch (RIE) Systems (Unaxis 790)
- XeF<sub>2</sub> Etch System (Xactix Xetch E1 series)
- Ion Milling System (4Wave IBE-20B), with a secondary ion mass spectrometer for end point detection
- Downstream Plasma Asher (ULVAC Solutions ENVIRO-1Xa) for resist stripping
- Deep Silicon Etcher (SPTS Omega c2L Rapier)

**Wet Chemistry** – Our multi-bench wet chemistry tool set includes RCA clean baths, KOH etching, HF vapor etching, hot solvent spray lift-off, and critical point drying.

**Back-End-of-Line Tools** – Perform post-processing with a Bruker-TMT CP-4 chemical mechanical polisher, a Disco 341 200 mm wafer dicing saw, a Kulicke & Soffa 4526 semi-automatic wire bonder, and a Tresky T-3000 flip-chip bonder.



# The NanoLab: Next Generation Measurement and Fabrication Research

While the NanoFab provides access to state-of-the-art commercial tools, the NanoLab offers opportunities for researchers to collaborate on creating and using the next generation of nanoscale measurement instruments and fabrication methods.

The NanoLab is agile and highly collaborative by design, with significant contributions from a rotating cadre of postdoctoral researchers and collaborative projects both with NIST scientists and with others from across the U.S. and abroad.

Researchers are invited to gain expertise by working directly with the NanoLab's multidisciplinary scientists and engineers, who are developing cutting-edge tools in the following three broad thematic areas:

**Nanofabrication and Nanomanufacturing**—The CNST is advancing the state-of-the-art in nanomanufacturing by developing measurement and fabrication tools for both lithographic (“top-down”) and directed (“bottom-up”) assembly approaches.

**Energy Storage, Transport, and Conversion**—The CNST is creating new methods for elucidating light-matter interactions, charge and energy transfer processes, catalytic activity, and interfacial structure in energy-related devices.

**Future Electronics**—The CNST is developing new methods to create and characterize devices, architectures and interconnects for graphene, nanophotonic, nanoplasmonic, spintronic, and other future computation and communication systems.

Although the NanoLab's project leaders are organized into three groups, their multidisciplinary research extends to a broad range of problems. Each project leader applies his or her expertise across multiple areas. The capabilities they offer are summarized below.

## Nanofabrication Research Group

The Nanofabrication Research Group (NRG) creates new measurement methods to enable the development and effective use of nanomanufacturing and nanofabrication processes.

### **J. Alexander Liddle, Group Leader**

**liddle@nist.gov** – Custom-built super-resolution fluorescence microscopy instrumentation combined with advanced statistical analysis techniques to provide information on the nanoscale structure and chemistry of materials; methods to direct the self-assembly of heterogeneous nanostructures, such as quantum dots and gold nanoparticles, with one nanometer precision.

### **Vladimir Aksyuk, vladimir.aksyuk@nist.gov** –

Unique, nanofabricated opto-mechanical devices enabling high-precision, high-bandwidth force measurements at the nanoscale, and the ability to structure and tune electromagnetic fields using mechanical actuation.

### **Henri Lezec, henri.lezec@nist.gov** –

Sophisticated instrumentation, including focused ion beam systems, femtosecond lasers, and a multi-probe scanning near-field optical microscope, that use surface plasmons to study and exploit the physical properties of light and light-matter interactions at deep sub-wavelength dimensions.

**B. Robert Ilic, robert.ilic@nist.gov** – Methods to simulate and fabricate devices for linear and non-linear dynamics measurements of suspended microscale and nanoscale electro(opto)mechanical structures designed for applications in chemical and biological sensing.

**Renu Sharma, renu.sharma@nist.gov** – Instrumentation that can determine the dynamic, atomic-scale physical and chemical changes occurring during gas-solid interactions at elevated temperatures, including a unique environmental transmission electron microscope.

**Kartik Srinivasan, kartik.srinivasan@nist.gov** – Methods to simulate, fabricate, and probe (via near-field and far-field techniques) novel nanoscale photonic systems including single-photon sources, signal transducers, and frequency-conversion devices for applications in communications, sensing, and future electronics.

**Samuel M. Stavis, samuel.stavis@nist.gov** – Nanofabricated fluidic devices and advanced fluorescence microscopy systems created and customized to control and measure nanoparticles and biomolecules.

**Michael Zwolak, michael.zwolak@nist.gov** – Computational and theoretical techniques to predict the properties of molecular nanostructures and nanofluidic devices, and to guide the development of pioneering approaches for sensing and measurement.



# NanoLab

## Energy Research Group

The Energy Research Group (ERG) develops instruments that reveal the nanoscale physical and chemical processes and properties critical to advances in energy conversion, transport, and storage.

### **Nikolai Zhitenev, Group Leader**

**nikolai.zhitenev@nist.gov** – A multifaceted tool set for correlating the nanoscale structure and composition of solar cell materials and devices with their functional performance, including near-field optical, electron beam induced current, cathodoluminescence, and photoconductive atomic force microscopies.

**Amit Agrawal, amit.agrawal@nist.gov** – Optical and optoelectronic techniques, including multi-color pump-probe, differential absorption and terahertz spectroscopy, to study light-matter interactions in nanoscale photonic systems with femtosecond time-resolution.

**Andrea Centrone, andrea.centrone@nist.gov** – Innovative measurement methods that combine infrared spectroscopy and atomic force microscopy to determine chemical composition with nanoscale resolution.

**Paul Haney, paul.haney@nist.gov** – Theory and modeling expertise for interpreting next generation measurements on materials for energy applications, including photovoltaics and lithium-ion batteries.

**Andrei Kolmakov, andrei.kolmahov@nist.gov** – Methods and instrumentation for *in situ* electron and x-ray microscopies and photoelectron spectroscopy, and for electrical measurements of interfaces and of nanodevices functioning in realistic operating environments, including in liquid or dense gaseous media.

**Veronika Szalai, veronika.szalai@nist.gov** – *In situ* and *ex situ* characterization, primarily based on electron paramagnetic resonance spectroscopy, of nanostructured solar fuel catalysts and bionanomaterials.

## Electron Physics Group

The Electron Physics Group (EPG) develops and provides innovative measurement instrumentation supporting nanotechnology development with an emphasis on applications for future electronics.

### **Jabez McClelland, Group Leader**

**jabez.mcclelland@nist.gov** – One-of-a-kind instrumentation for the study and manipulation of materials at the nanoscale using focused ion beams created by a magneto-optical trap ion source, including light-ion microscopy with 30 nm resolution and the ability to implant ions with nanoscale precision.

**Robert McMichael, robert.mcmichael@nist.gov** – Ferromagnetic resonance force microscopy and complementary tools for measuring the magnetization dynamics in individual magnetic nanostructures in order to advance the development of magnetic nanotechnology.

**Mark Stiles, mark.stiles@nist.gov** – Fundamental theoretical methods for calculating and elucidating measurements of nanostructures and devices made from materials ranging from ferromagnets to graphene.

**Joseph Stroscio, joseph.stroscio@nist.gov** – Unique, low temperature scanning probe microscopy systems integrated with comprehensive sample preparation and thin-film growth capabilities enabling the atomic and electronic structure of nanostructures and novel materials for future electronics to be determined with unprecedented spatial and energy resolution.

**John Unguris, john.unguris@nist.gov** – Scanning electron microscopy with polarization analysis, a NIST-developed, spin-sensitive microscopy method that reveals the magnetic structure within materials or devices with nanoscale-resolution and without disturbing sample magnetization, with notable applications in emerging magnetic media and magneto-electronic device development.

Founded in 1901, the National Institute of Standards and Technology is a non-regulatory federal agency within the U.S. Department of Commerce. NIST's mission is 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. The agency operates primarily in two locations: Gaithersburg, Maryland (headquarters) and Boulder, Colorado. NIST employs about 3,400 scientists, engineers, technicians, and support and administrative personnel, and hosts about 3,700 associates from academia, industry, and other government agencies, who collaborate with NIST staff and access user facilities.

## CNST

The NIST Center for Nanoscale Science and Technology (CNST) supports the development of nanotechnology by providing industry, academia, NIST, and other government agencies access to world-class nanoscale measurement and fabrication methods and tools.

- The CNST's NanoFab provides economical access to and training on a commercial state-of-the-art tool set.
- The CNST's NanoLab offers opportunities for researchers to collaborate on creating and using the next generation of nanoscale measurements and fabrication tools and methods.

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*Supporting the  
Development of  
Nanotechnology  
from Discovery  
to Production*