NIST the U. S. Nanometrology Resource for Nanotechnology and Nanomanufacturing

Dr. Michael T. Postek

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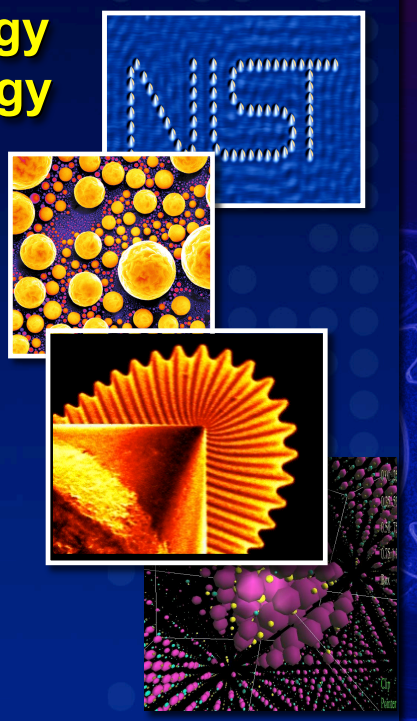
Program Manager, MEL Nanomanufacturing Program

Presented by: Kevin W. Lyons



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

National Institute of Standards and Technology

NIST Assets

- 2,800 employees
- 1,800 guest researchers
- 1,500 field agents
- Unique research facilities
- $858 million operating budget in FY05

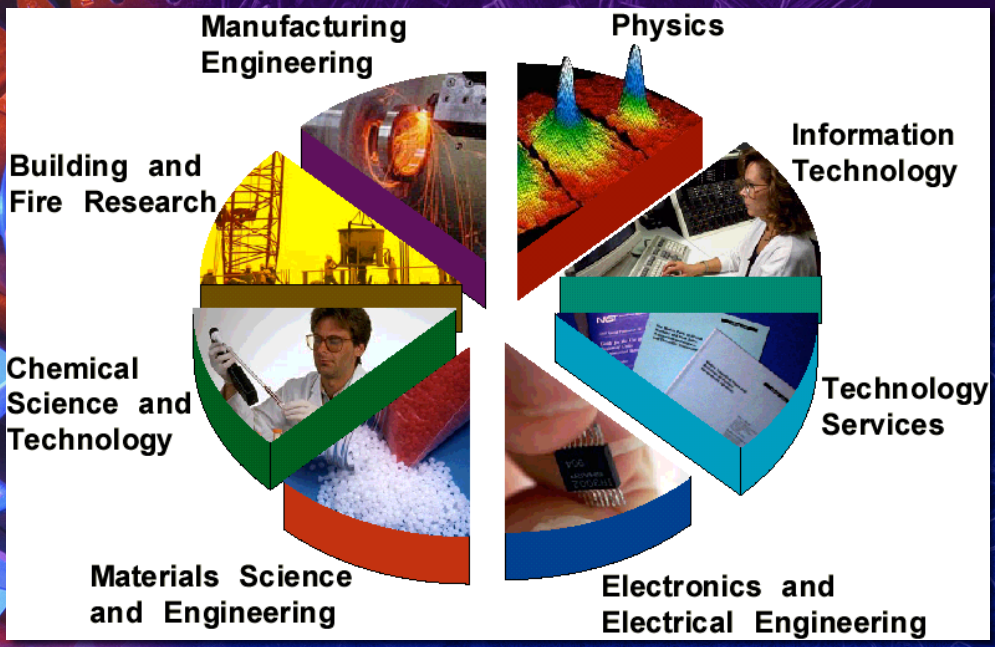
NIST Intramural Program

- NIST Laboratories
  - Mission driven research in seven scientific disciplines

NIST Extramural Programs

- Advanced Technology Program
  - Co-funding of private sector R&D in high-risk, broadly enabling technologies.
- Manufacturing Extension Partnership
  - Nationwide network to help small manufacturers
- Baldrige National Quality Award

The NIST Laboratories



NIST has two campuses…


Gaithersburg, MD


Boulder, CO

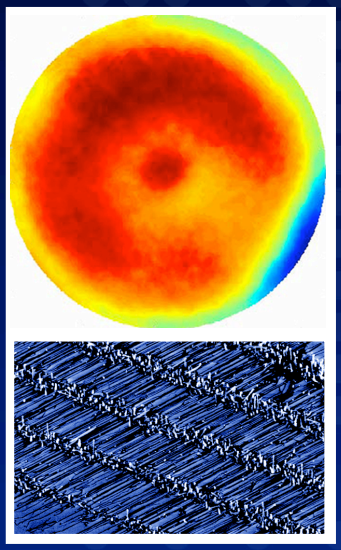
..and two joint Institutes


CARB (Center for Adv. Research in Biotech)
University of Maryland


JILA
University of Colorado

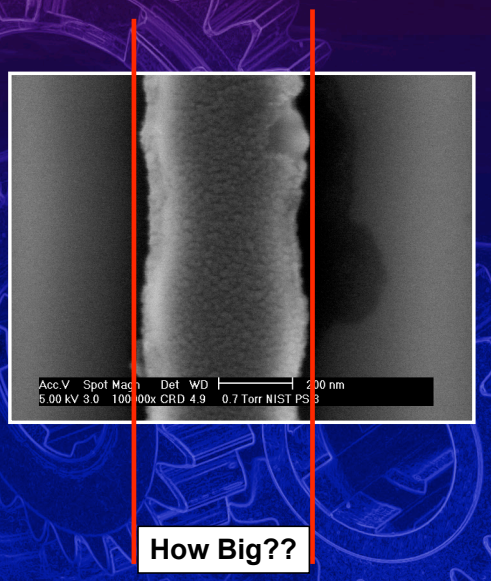
Measurements/Metrology

- NIST is the U. S. National Measurement Institute (NMI)
  - NIST promotes 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.
- Nanotechnology is one of the most dynamic growth areas in the U. S. and World economy
  - Large and growing U. S. Federal government investment



NIST's Technical Role

- Development of the measurement technology
  - What is measured ?
  - How it is measured ?
  - Determination of the limitations of the measurement process
- Development of new standards
- Development of uncertainty statement
  - Provides a means of comparison of metrology techniques
- Value of metrology
  - Economics of nanometrology

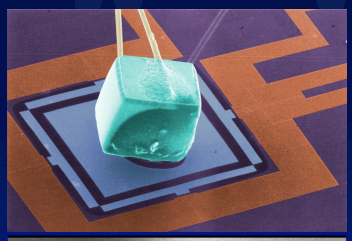


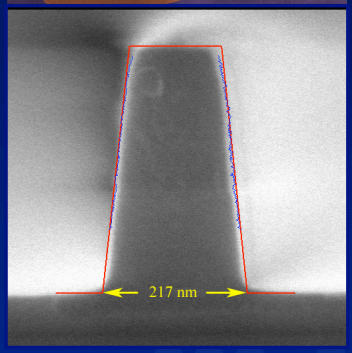
Metrology is Value Added

- It is often erroneously stated that "metrology is not value added to the product" but, today it is *becoming* a key enabler in a number of areas
- Metrology is a check and a balance in the nanomanufacturing process
  - Enables process control
- Metrology does provide an economic benefit
- But, it is often difficult to assess this economic benefit as it is often hidden and often forgotten

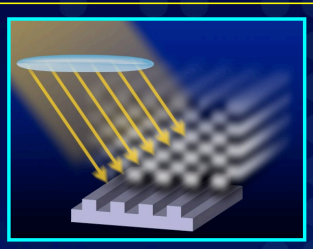
NIST and Nanotechnology

- Nanometrology is needed by nanotechnology and nanomanufacturing more than for any other prior technology
  - Nanotechnology will require:
    - Atomic level accuracy and repeatability
    - Ability to precisely measure the desired performance attributes
    - Commercially viable manufacturing costs
- For the NNI, NIST is the:
  - Lead Agency for: Instrumentation Research, Metrology, and Standards for nanotechnology
  - Co-Lead Agency with NSF for: Nanomanufacturing





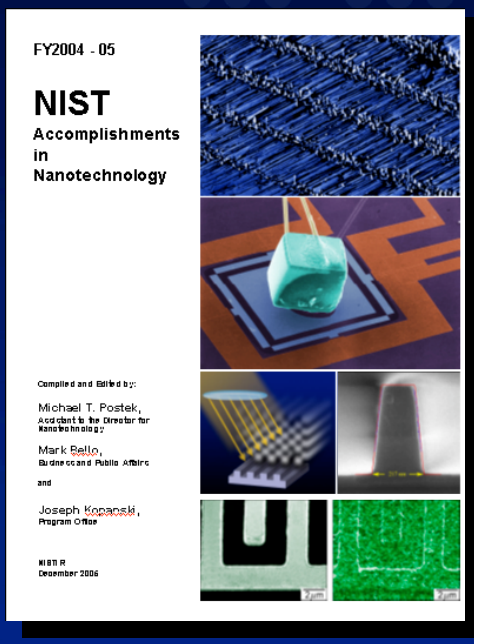
NIST and Nanotechnology



- Nanotechnology research is pervasive across all of the technical laboratories at NIST
- Nanotechnology is the logical extension of NIST's interest to continually push the limits of measurement science - metrology
- Accurate metrology is NIST's core competence
  - Achieving accuracy requires:
    - Fundamental scientific research
    - Theory and modeling
    - Experimentation (agreement to theory and experiment)
- Accurate nanometrology is critical to both nanotechnology and nanomanufacturing

NIST and Nanotechnology

- There are approximately 120 nanotechnology related projects across NIST that reported notable accomplishments for FY 2004-2005.
  - Available now in corridor
- Currently, about 15% of the NIST budget is devoted to nanotechnology-related research



FY2004 - 05

NIST
Accomplishments in Nanotechnology

Compiled and Edited by:

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and

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NISTIR
December 2006

NIST Nanotechnology Research Taxonomy

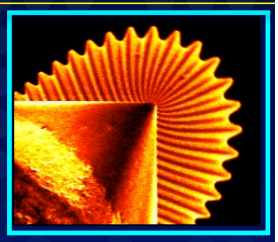
- **Measurement Science:**
  - Fundamental understanding of nanoscale properties and phenomena
  - Extremely accurate, repeatable measurements
  - Reliable benchmarks
  - Advances in measurement and analytical capabilities.
- **Standards and Measurement Infrastructure:**
  - Practical, high-resolution measurements of length, time, electric current, force, mass, and chemical composition
  - High-accuracy measurement technologies and databases on the fundamental properties of "nano-structured" materials.

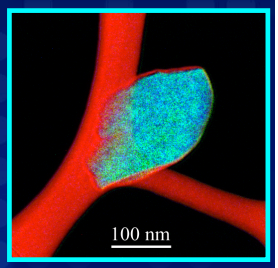
NIST Nanotechnology Research Taxonomy

- **Nanomanufacturing:**
  - Reliable, scaled-up, cost effective manufacturing of nanoscale materials, devices and systems
  - Robust manufacturing practices coupled with the necessary standards and measurement infrastructure
  - Development of the instrumentation, tools and processes needed to bridge the gap between discovery and commercialization.
  - Development of the measurement infrastructure for nanomanufacturing to reduce the barriers for technological innovation and successful commercialization of nano-based products.

MEL Nanomanufacturing Program

- Measurements are critical to developing complete understanding of any new phenomena
  - Only those things that can be measured can be fully understood.
- Nanometrology is needed for nanomanufacturing to control fabrication, production, ensure product quality, and enable different parts to work together.
  - Sizes and tolerances - extremely important





"If you can't measure it you can't make it"

Nanomanufacturing Program Strategic Vision

- Develop the measurement infrastructure for nanomanufacturing to reduce the barriers for technological innovation and successful commercialization of nano-based products
  - Accurate metrology that is needed by nanomanufacturing
    - Fundamental scientific research
    - Theory
    - Experiment
- Fundamental Focus Areas:
  - Imaging, Metrology and Modeling
  - Nano-Fabrication
  - Control and Assembly
  - Integration, Interoperability, and Information Management

Strategic Themes and Technologies

MEL Nanomanufacturing Program

Integration, Interoperability, and Information Management

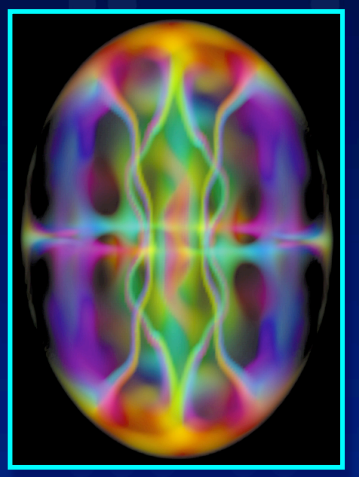
Imaging Metrology and Modeling
- SEM Metrology and Modeling
- Optical Metrology and Modeling
- SPM Metrology and Modeling
- Nano-force Metrology
- Atom-based Standards

Nanofabrication
- Electron Beam Lithography
- Scanned Probe Lithography
- Imprint Lithography
- Focused Ion Beam
- Micro and Nanomachining

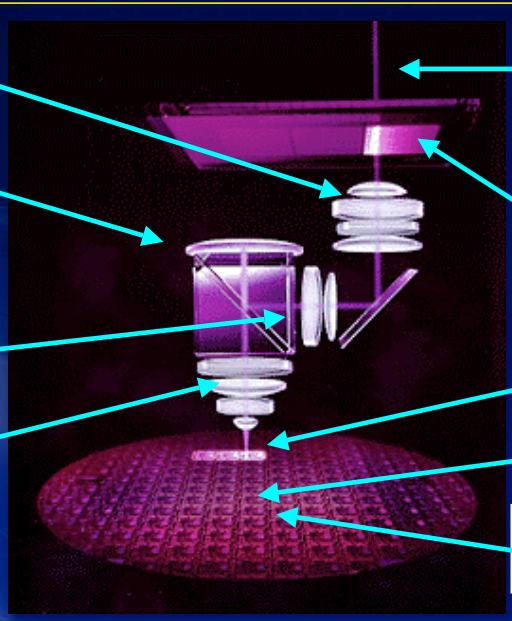
Control and Assembly
- Optical Tweezers
- High Precision Stages

Metrology for Nanomanufacturing

- Good metrology practice is more than just reading numbers from a data sheet.
- In order to measure a quantity accurately, it is necessary to study and understand the measurement process itself
- This <u>requires</u> multiple disciplines working closely together to achieve the final goal



NIST Measurements & Standards for Manufacturing -- an Integrated Approach



NIST supports the entire lithography process to manufacture microelectronic devices – Coordinated through OMP

n a n o t e c h n o l o g y

Measurements & Standards for Nanotechnology

What we have discovered…

- **Nanometrology is not easy**
- **Some needed metrology does not exist - yet**
- **We are now working in the nano-world where we have little experience**

n a n o t e c h n o l o g y

New measurement technologies:
New Infrared Tool for Measuring Silicon Wafer Thickness

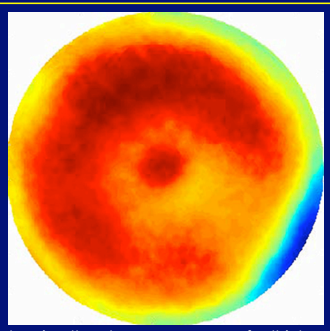


Image showing the changes across wafer thickness. Green represents the average wafer thickness, while red, orange and yellow areas are thicker, and turquoise and blue areas are thinner.

Objective:

- Develop an improved Interferometer using Infrared laser illumination that can illuminate both the top and bottom on a 300 mm wafer and produce a detailed spatial map of differences in thickness in one pass

Industry Need Addressed:

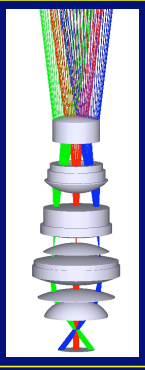
- Higher yield of finished devices has enabled wafers to be enlarged from 200 mm to 300 mm
- Wafers must meet higher quality control specifications.
  - Extremely flat and of uniform thickness.

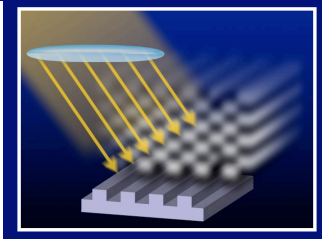
Accomplishments:

- Developed an instrument that accurately measures differences in thickness across a 300 mm wafer with a repeatability of 5 nm.
- Q. Wang, U. Griesmann and R. Polvani. Interferometric thickness calibration of 300 mm silicon wafers. ASPE Summer Topical Meeting on Precision Interferometric Metrology (July 20-22, 2005).

Contact: Ulf Griesmann (301) 975-4929
ulf.griesmann@nist.gov

New measurement technologies:
Scatterfield Microscopy to Measure sub-20 nm Features Optically





Zemax model-based designs for the scatterfield illumination configuration

Objective:

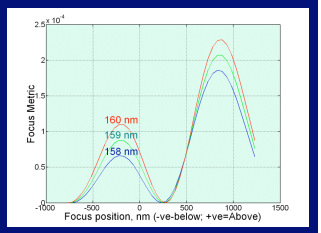
- Develop a phase-sensitive, scattered-field optical imaging tool with: small target size, high throughput, good sensitivity, low cost of ownership for metrology and process control

Industry Need Addressed:

- Extend the theoretical limits of optical microscopy using new, advanced capabilities.
  - illumination engineering
  - structured target design
  - wavelength
  - high resolution CCD acquisition
  - rapid analysis of complete intensity profiles
  - accurate modeling

Accomplishments:

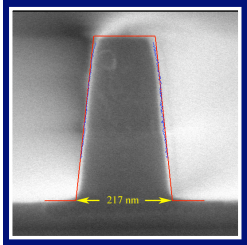
- New project begun in 2005
- Several manufacturers already are incorporating the concepts

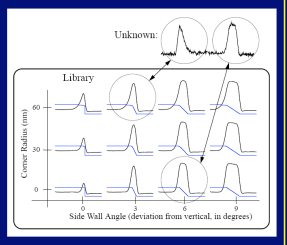


• Demonstrated nm sensitivity using modified optical methods

Contact:
Richard Silver (301) 975-5609 silver@nist.gov

New measurement technologies:
Model-based Library for Accurate SEM Metrology





Scanning electron micrograph of both actual and modeled cross-section images overlain to show the degree of agreement provided by this method.

Objective:

- Develop highly accurate SEM measurement, image processing and modeling methods for shape and size measurements and relevant calibration standards with better than 1 nanometer resolution.

Industry Need Addressed:

- Accuracy in production line scanning electron microscope metrology requires the development of a mathematical model to deconvolute the actual sample edge information from the SEM image collected and measured.

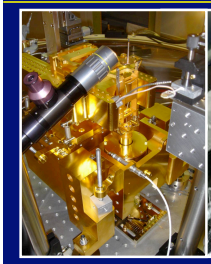
Accomplishments:

- Named a winner in the technology category of the 2005 Nano 50™ Awards and 2005 DOC Silver Medal
- Concept incorporated in Soluris and Hitachi Instruments

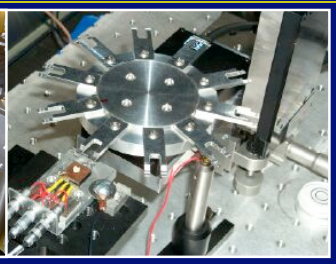
Contact:

- John Villarrubia (301) 975-3958; john.villarrubia@nist.gov

New measurement technologies:
Realization of the Unit of Force at the Micro- and Nanoscales



Traceable nano to micronewtons from NIST Electrostatic Force Balance



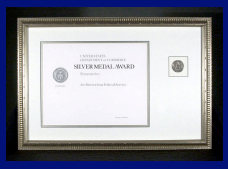
Traceable micro to millinewtons from NIST wire deadweight loader and modified Hysitron force cell

Objective:

- Extend force measurements down to the nano-newton regime by developing a highly innovative null-force electromechanical balance
  - Measure forces traceable to the SI using precision measurements of voltage, length, and capacitance.

Industry Need Addressed:

- Provide SI traceability for small force measurement and instrumentation
- Develop and test internationally accepted primary and secondary standards of force in the regime below 10^{-5} N



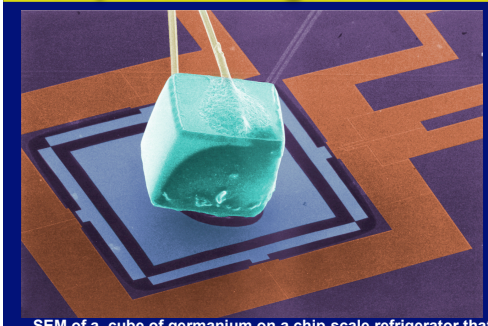
Accomplishment:

- Successfully extended force measurements down to the nanonewton regime
  - Developed a highly innovative null-force electromechanical balance that measures forces traceable to the SI using precision measurements of voltage, length, and capacitance.
- Awarded 2005 DOC Silver Medal

Contact:

- Jon Pratt (301) 975-5470 jon.pratt@nist.gov

New measurement support technologies:
Chip-scale Refrigerators for Nano Applications



SEM of a cube of germanium on a chip-scale refrigerator that cooled the cube to only a few hundred thousandths of a degree above absolute zero.

Objective:

- Develop smaller and less expensive devices than conventional equipment used for cooling down to 100 mK, to optimize the performance of cryogenic sensors.
- Detection of very small differences in X-rays
  - microcalorimeter

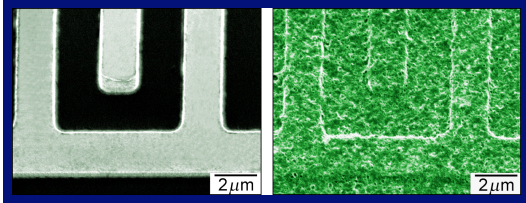
Industry Need Addressed:

- Development of solid-state refrigerators that have applications such as cooling cryogenic sensors in highly sensitive instruments for semiconductor defect analysis and astronomical research.

Accomplishments:

- Cooled the contents of a silicon nitrate membrane that was 450 micrometers on a side and 0.4 micrometers thick.
- A cube of germanium 250 micrometers on a side was glued on top of the membrane and cooled down to about 200 mK .
  - The cube is about 11,000 times larger than the combined volume of the refrigerators.
- A.M. Clark, N.A. Miller, A. Williams, S.T. Ruggiero, G.C. Hilton, L.R. Vale, J.A. Beall, K.D. Irwin, J.N. Ullom. Cooling of Bulk Material by Electron-Tunneling refrigerators. Applied Physics Letters. April 25, 2005.
- Contact: Mary Clark (301) 975-3159 mary.clark@nist.gov

New measurement support technologies:
Gas Sensors Patterned with Conducting Polymer



NIST microheater device before (left) and after (right) application of the sponge-like polyaniline coating.

Objective:

- Conducting polymers are of increasing interest in microelectronics because they are inexpensive, flexible and easy to synthesize.
- Polyaniline is difficult to process because it doesn't dissolve in most solvents.

Industry Need Addressed:

- Develop a general technique for reproducibly fabricating microdevices such as sensors for detecting toxic chemicals.

Accomplishments:

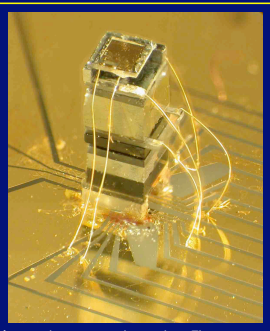
- NIST researchers have circumvented this problem by dispersing nanoscale particles of polyaniline into a mild solvent.
- The process produces a sponge-like coating that efficiently captures gaseous molecules.
- Demonstrated that coatings can detect the difference between methanol and water vapor
- G. Li, C. Martinez, S. Semancik. Controlled electrophorectic patterning of polyaniline from a colloidal suspension. *Journal of the American Chemical Society*, April 6, 2005.

Contact:

- Steve Semancik (301) 975-2606 stephen.semancik@nist.gov

New measurement device technologies:

Sensor to Measure Magnetic Field Changes as Small as 50 Picoteslas



NIST chip-scale magnetometer. The sensor is about as tall as a grain of rice

Industry Need Addressed:

- Development of a highly sensitive sensor for hand-held devices for sensing unexploded ordnance, precision navigation, geophysical mapping to locate minerals or oil, and medical instruments
  - The sensor works by detecting minute changes in the energy levels of electrons in the presence of a magnetic field.

Objective:

- A highly compact magnetic sensor that can be fabricated and assembled on semiconductor wafers
- Detect magnetic field changes as small as 50 picoteslas
  - million times weaker than the Earth's magnetic field

Accomplishments:

- The miniature magnetometer developed is sensitive enough to:
  - Detect a concealed rifle about 12 meters (40 feet) away
  - A six-inch-diameter steel pipeline up to 35 meters (120 feet) underground..
- P. Schwindt, S. Knappe, V. Shah, L. Hollberg, J. Kitching, L. Liew, J. Moreland. "Chip-scale atomic magnetometer." *Applied Physics Letters*. 27 Dec. 2004

Contact:

Peter Schwindt (303) 497-7969 peter.schwindt@nist.gov

Future Nanomanufacturing Metrology Needs

- Industry will require measurement tools for mass-production applications.
  - Tools that can span the continuum from nanometers to micrometers to millimeters.
  - Tools that do not all require ultra-high-vacuum environments or extreme levels of vibration isolation.
  - Tools that can be configured in mass arrays.
  - Tools that can be directly integrated into manufacturing processes.
  - Tools with high throughput that deliver data in real time.
- Tools must be affordable and versatile.
  - Who will pay?

Unique Measurement and Research Facilities

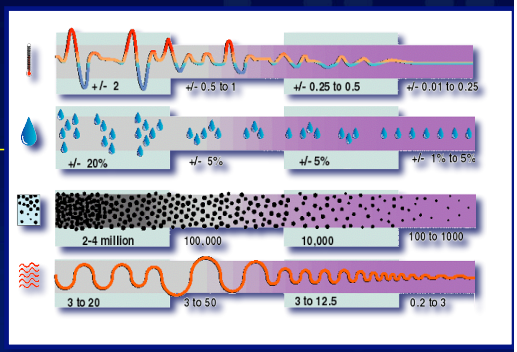
Advanced Chemical Sciences Laboratory

Provides critical capabilities in nanobiotechnology and analytical chemistry

NIST Center for Neutron Research

Most versatile neutron facility in the US with over 1750 users annually

Advanced Measurement Laboratory (AML)



The AML:

- Is the world's best measurements laboratory
- Will provide the measurements and standards needed for 21st century key technologies.
- Establishes the Center for Nanoscale Science and Technology (CNST) to provide the best measurement capabilities to industry.

Center for Nanoscale Science and Technology Announcement March 20, 2006


Commerce Secretary Gutierrez Announces New Nanotechnology Center

Nanotechnology :: March 20, 2006 Newsletter Print Email Blog It Font size: - N +

U.S. Secretary of Commerce Carlos M. Gutierrez today in Detroit announced the launch of a state-of-the-art center for collaborative nanotechnology research at Commerce's National Institute of Standards and Technology. Scientists from U.S. companies, universities and government will focus on overcoming major technical obstacles to cost-effective manufacturing of products made with components the size of atoms and molecules.

Related stories:
Rice student earns top Texas nano honors for nanoparticle assembly study January 30, 2006
Nanogen Funding Advances Nanotech Research December 05, 2004

Vision

- CNST leverages NIST's unique c[illegible] expertise and facilities in me[illegible]o facilitate innovation in na[illegible]ated frontier areas of scien[illegible]

Mission

- CNST will dev[illegible]nfrastructure at NIST neces[illegible]pursue nanometrology, nanosta[illegible]anufacturing research
- *The [illegible]ill be removing barriers to US in[illegible]anufacturing*
- Edu[illegible]ext generation of nano-metrologist

POC: [illegible]obert Celotta, (301)-975-3710 robert.celotta@nist.gov

What NIST Brings to a Partnership

- Unique mission
- World-renowned and highly trained
- scientists and engineers
- Unique capabilities and facilities
- Strategic focus
- Strong relationships with
  - Industry
  - Academia
  - Government agencies

Concluding: Partnering with NIST

- Cooperative Research and Development Agreements (CRADAs)
- Contracts
- Guest Researchers
- Memoranda of Understanding and Letters of Agreement
- Grants
- SBIR
- National Research Council Post-Doctoral Research Associates
- Summer Students
- Summer Undergraduate Research Fellowships (SURF)
- Sabbatical
- others

Thank you for your attention

Questions ?