DOE Overview
Nanoscale Science Research Centers (NSRCs) Program- and Nanoscience/Nanotechnology Activities

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U.S. DEPARTMENT OF ENERGY
Basic Energy Sciences
Program Manager

Center for Integrated Nanotechnologies
Users Workshop
June 5-6, 2003 Albuquerque, NM

Topics

- *DOE Mission & Nanoscience/ Nanotechnology Activities*
- *Overview of Nanoscale Science Research Centers (NSRCs) Program*
- *Research Applications*

DOE Mission/Nanoscience

- **Energy security**
  - **Fossil energy**
    - *Materials that perform well under the extreme conditions of temperature and pressure in energy production, e.g. materials that will increase efficiency of coal-fired power plants*
    - *Nanostructured catalysts for cheaper, cleaner, more environmentally friendly petroleum refining and product manufacturing*
  - **Energy efficiency**
    - *Strong, tough, ductile, lightweight, and low-failure-rate materials for improved fuel efficiency in ground and air transportation*
    - *Low-loss, high-performance magnets for more efficient motors*
    - *Self-assembling nanostructures for near-net-shape materials forming to reduce waste*
    - *Surface tailoring for reduced friction and improved wear to reduce fuel consumption*
    - *Hardened alloys and ceramics for cutting tools for improved manufacturing efficiency*
    - *Nanofluids with increased thermal efficiency for improved heat exchangers*
    - *Layered structures for highly efficient, low-power light sources*
    - *Smart materials such as paints that change color with temperature and windows that respond to thermal inputs*
    - *Nanostructured catalysts for fuel cells and batteries*
  - **Renewable energy**
    - *Light harvesting and energy storage systems for solar energy conversion*
    - *Nanostructured materials for hydrogen storage*
  - **Nuclear energy**
    - *Radiation tolerant materials for nuclear power plants*
    - *Nanostructures that selectively bind and concentrate radionucleotides, thereby lowering waste disposal costs*

DOE Mission/Nanoscience

- **National security**
  - **Because of NNSA's strong interest in nanoscale S&T, DP and BES established the "Nanoscience Network" to jointly fund research at NNSA and SC laboratories. Three topics were selected for support based on joint peer review for scientific quality and relevance: nanoscale tribology and micromechanics; tailored nanostructures; and nanostructural photonics.**
  - **One of three BES Nanoscale Science Research Centers is the Center for Integrated Nanotechnologies, which is jointly administered by LANL and SNL.**
- **Cleanup**
  - **Nanostructured molecular sieves and filters for improved separations for cleanup and decontamination**
  - **Nanostructured materials for selective sequestration of specific contaminants**

DOE Mission/Nanoscience

- **Homeland defense**
  - **BES Workshop on Basic Research Needs to Counter Terrorism (2/28-3/1/02) focused on chemical, biological, nuclear, and radiological threats identified research needs.**
  - **A recurring theme was better detection. Research needed to improve sensors for detection is at the nanoscale, including "single" molecule detection of explosives and chemical agents, specific virus or other biological agent detection, laboratories on a chip, and more portable and sensitive radiological detectors.**
  - **Other nanoscale areas of research included catalysts for decontamination, membranes for separations and protective gear, and nanostructured materials as absorbers and reactive filters.**

National Nanotechnology Initiative

Department of Energy's Role in NNI

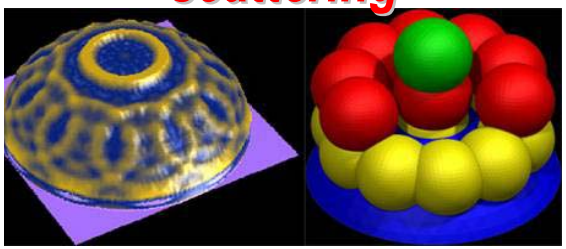
	2003	2004	Difference from 2003 to 2004	Percent Difference from 2003 to 2004
National Science Foundation	221	247	26	11.8%
Defense	243	222	-20	-8.3%
Energy	133	197	64	48.1%
National Institutes of Health	65	70	5	7.7%
Commerce	69	62	-7	-10.1%
NASA	33	31	-2	-6.1%
Agriculture	1	10	9	900.0%
EPA	6	5	-1	-16.7%
Homeland Security	2	2	0	0.0%
Justice	1	1	0	0.0%
TOTAL	**774**	**847**	**74**	**9.5%**

Seeing atoms:

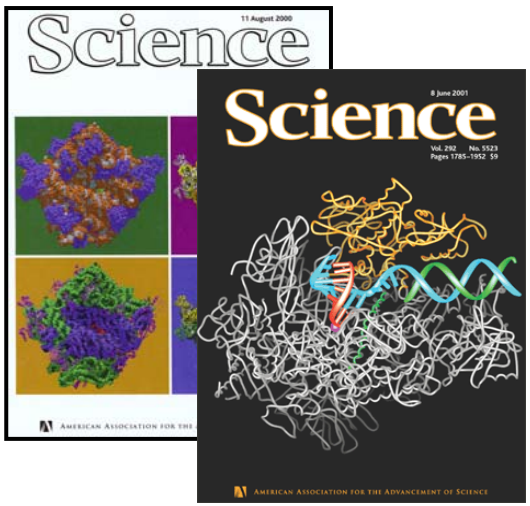
Providing national user facilities for probing materials at the atomic scale

X-ray, neutron, and electron scattering techniques have opened the world of the ultra-small. The next challenge is to open the world of the ultra-fast at this same spatial resolution.

X-ray scattering

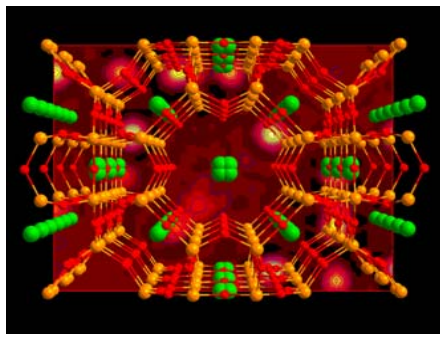


AlNiCo quasicrystal structure

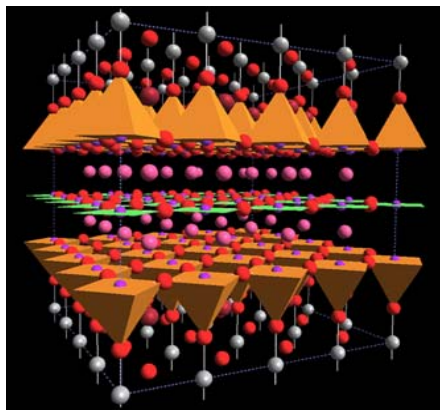


Molecular machines of life

Neutron scattering

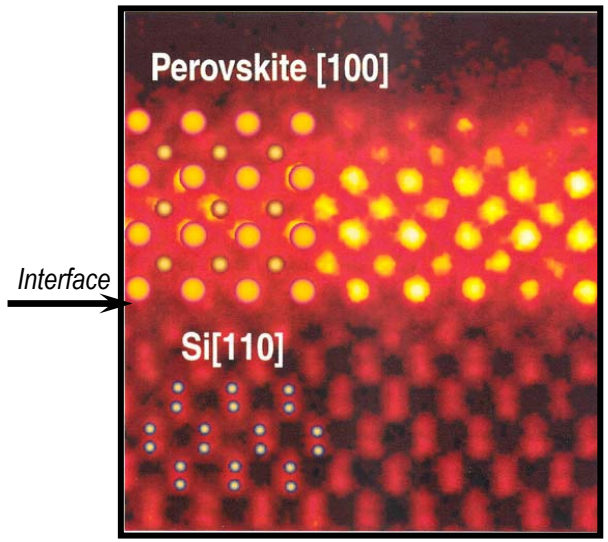


Zeolite catalyst



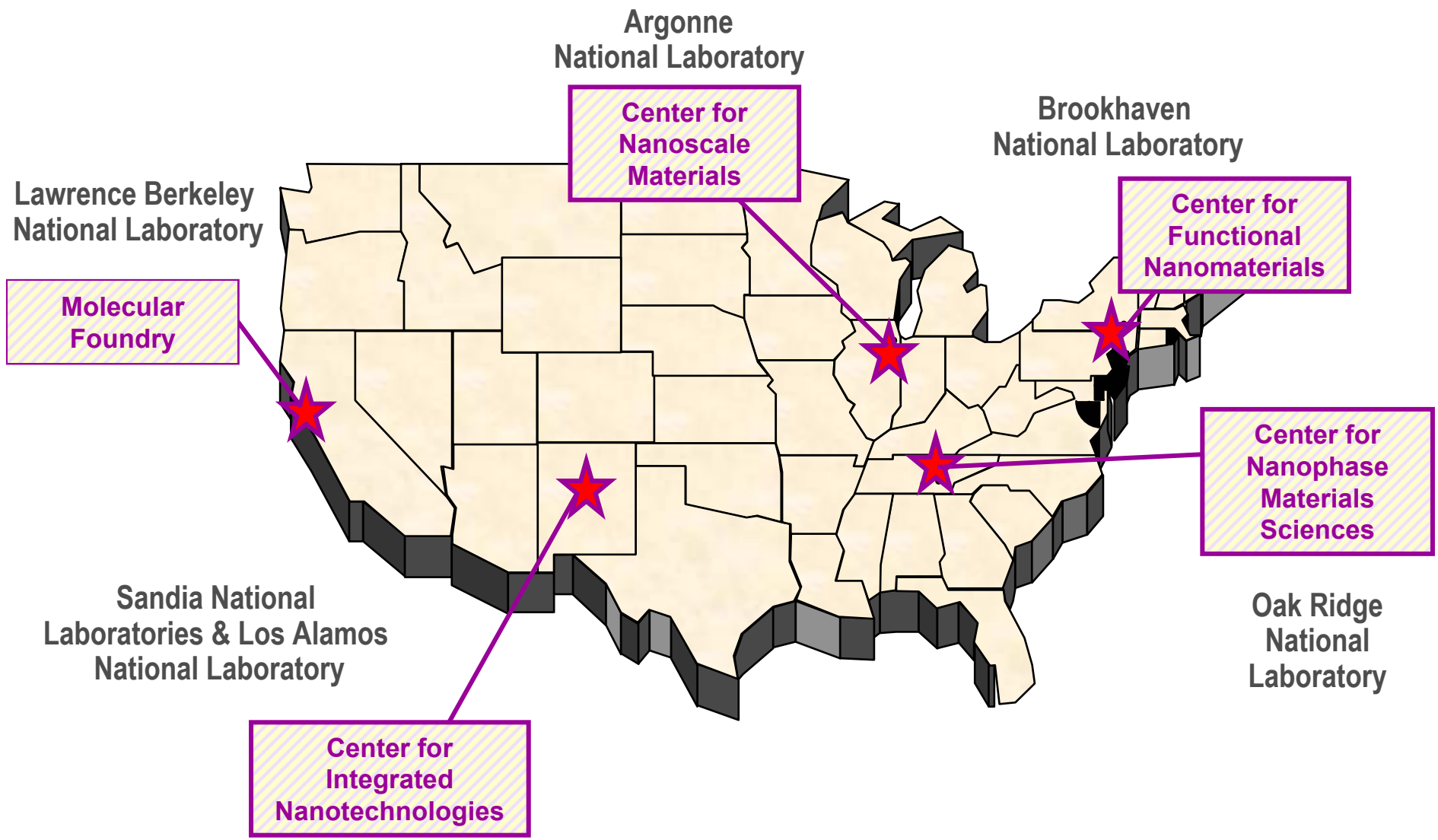
High Tc superconductor

Electron Scattering



Transmission electron microscope image showing an abrupt interface and low defect density for the ferroelectric $SrTiO_3$ on Si.

The Five DOE Nanoscale Science Research Centers (NSRCs)



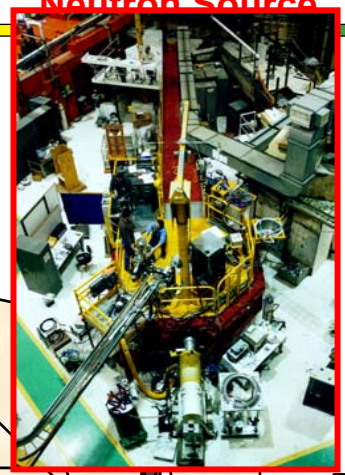
Co-location of NSRCs with leveraged BES Facilities

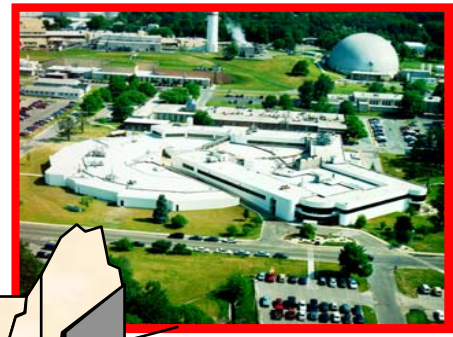
Office of Basic Energy Sciences
Serving the Present, Shaping the Future

Advanced Light Source

Advanced Photon Source

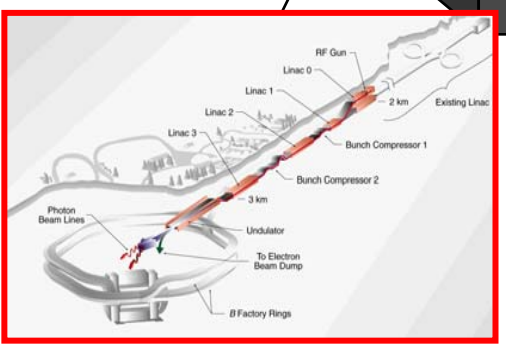
Intense Pulsed Neutron Source





National Synchrotron Light Source

Stanford Synchrotron Radiation Laboratory



Linac Coherent Light Source

Manuel Lujan Jr. Neutron Scattering Center

High-Flux Isotope Reactor

Spallation Neutron Source

Nanoscale Science Research Centers (NSRCs)

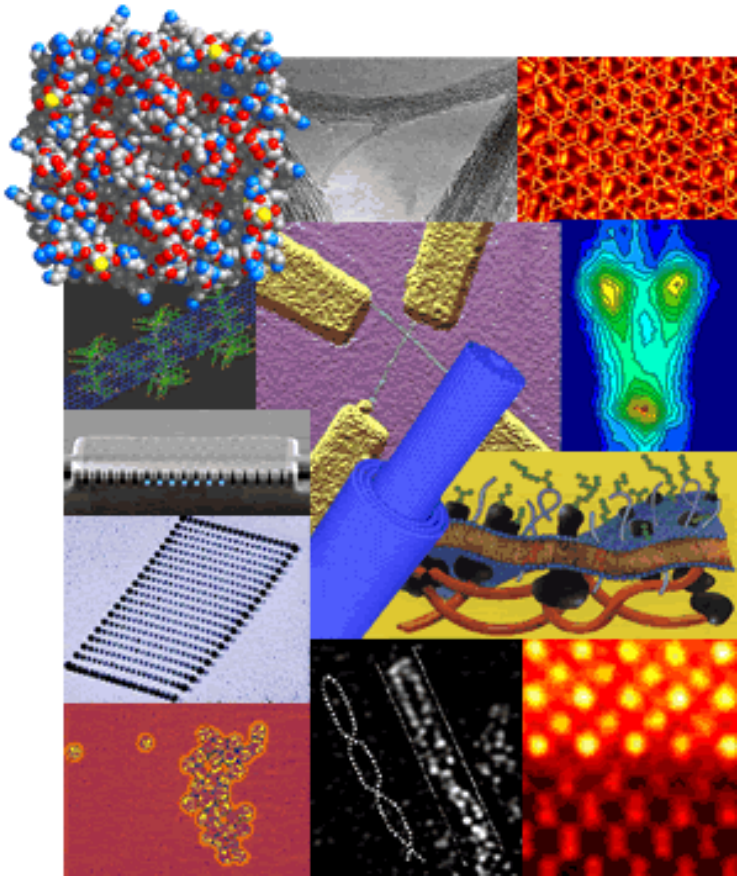
- **NSRCs are:**
  - ***Research facilities for synthesis, processing, and fabrication of nanoscale materials***
  - ***Co-located with existing user facilities (synchrotron radiation light sources, neutron scattering facilities, other specialized facilities) to provide characterization and analysis capabilities***
  - ***Operated as user facilities; available to all researchers; access determined by peer review of proposals***
  - ***Provide specialized equipment and support staff not readily available to the research community***
  - ***Conceived with broad input from university and industry user communities to define equipment scope***

- **Each NSRC has unique attributes, which complement those of other centers, and several research focus areas chosen for scientific impact and mission relevance. The five Centers utilize the DOE scientific user facilities and provide broad regional coverage.**

- **NSRCs have been extensively reviewed by external peers and by the Basic Energy Sciences Advisory Committee**

DOE Nanoscale Science Research Centers Workshop:

Enabling the Nanoscience Revolution



Renaissance Hotel
Washington, D.C.
February 27-28, 2003

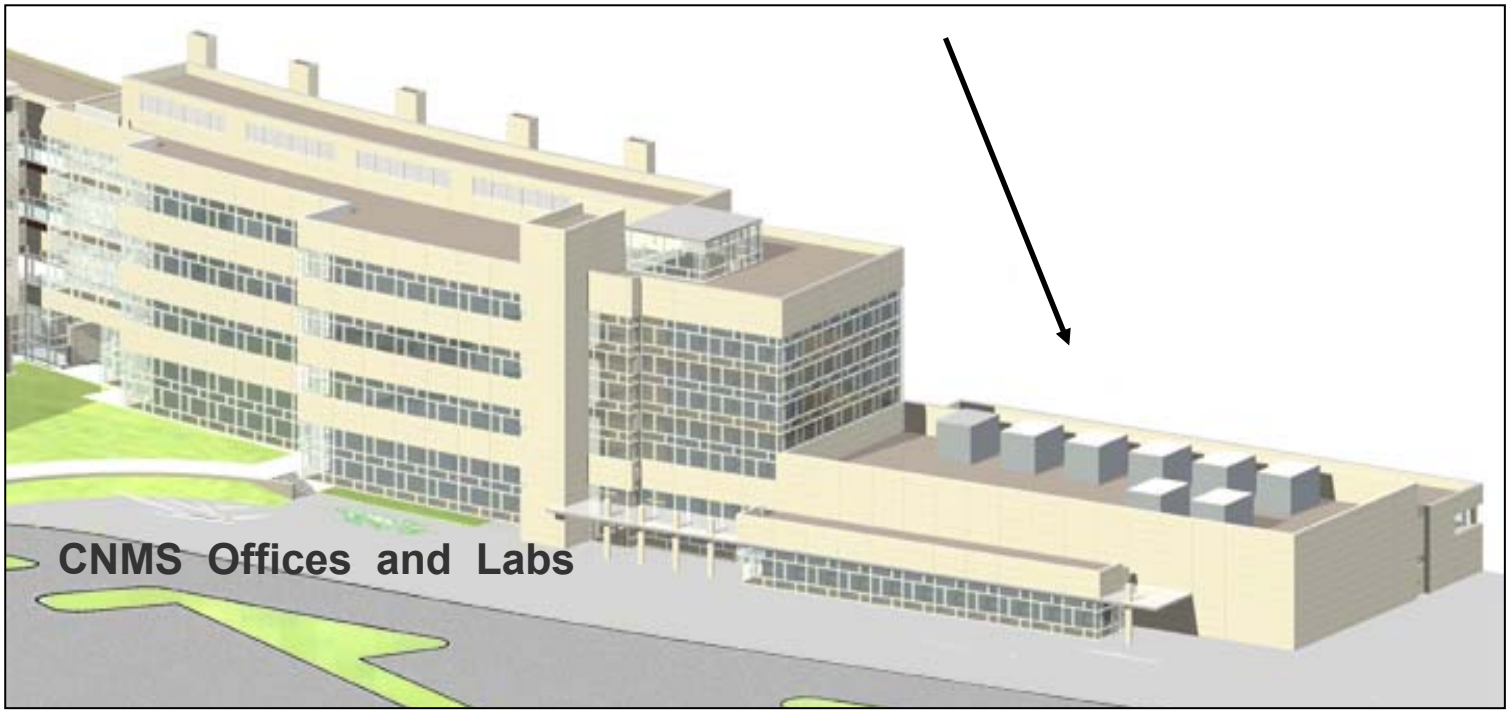
Presentations by:

Congresswoman Judy Biggert
Ray Orbach, Director, DOE Office of Science
John Marburger, Director, White House Office of Science and Technology Policy
George Whitesides, Harvard University
Richard Smalley, Rice University
Gabor Somorjai, University of California at Berkeley and Berkeley Lab
Paul Alivisatos, University of California at Berkeley and Berkeley Lab
All of the DOE Nanoscale Science Research Directors
… and many more …

All workshop presentations are downloadable at:
http://www.ornl.gov/doe_nsrc_workshop/


Front-End Building
Klystron Building
Central Helium Liquefaction Building
Linac Tunnel
Ring
Radio-Frequency Facility
Target
Future Target Building
Support Buildings
Central Laboratory and Office Complex
Center for Nanophase Materials Sciences
Joint Institute for Neutron Sciences

Center For Nanophase Materials Sciences (CNMS) Oak Ridge National Laboratory



Science Thrusts

- Neutron Science
- Synthesis and integration of soft and hard materials
- Theory / Modeling / Simulation

Unique Facilities

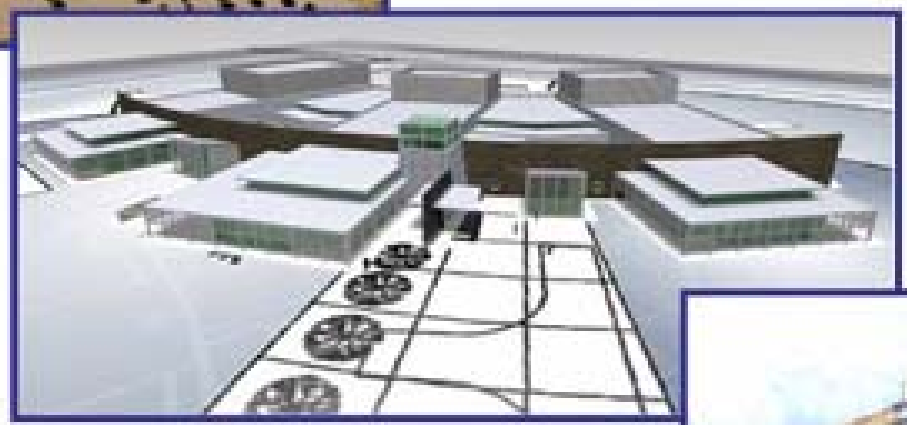
- Spallation Neutron Source
- High Flux Isotope Reactor
- Center for Computational Sciences
- High Temperature Materials Laboratory

Center For Integrated Nanotechnologies

Sandia National Laboratories/Los Alamos National Laboratory

Science Thrusts

- Nanoelectronics/nanophotonics
- Nano/Bio/Micro Interfaces
- Complex Functional Nanomaterials
- Nanomechanics
- Theory and Simulation



Center for Integrated Nanotechnologies
at Sandia National Laboratories and
Los Alamos National Laboratory

Unique Facilities

- Compound Semiconductor Research Lab
- Microelectronics Development Lab
- Combustion Research Facility
- Los Alamos Neutron Science Center
- National High Magnetic Field Laboratory
- High-Performance Computing

Center For Functional Nanomaterials

Brookhaven National Laboratory

Unique Facilities

- National Synchrotron Light Source
- Transmission Electron Microscopy
- Laser Electron Accelerator Facility

Scientific Thrust Areas

- Strongly Correlated Oxides
- Magnetic Nanoassemblies
- Nanocatalyst Materials
- Charge Injection and Transport
- Nanostructured Organic Films
- Applications of Nanoscience

Workshops

- Major BNL Workshop-March 2002
- Other workshops
  - ✓ Workshop on Applications of Synchrotron Radiation in Nanoscience and Technology, May 23, 2001
  - ✓ "Charge Transfer on the Nanoscale," Chemical Sciences sponsored workshop, January 2002
  - ✓ EPENS, "International Workshop on Electron-Phonon Effect in Nanosystems, September 23-25, 2002
  - ✓ CESP Nanomagnetic Materials Workshop, October 21-22, 2002
  - ✓ Nanotechnology Business Roadmap, October 15, 2002
  - ✓ Nanoscience Writers Roundtable, October 30, 2002
  - ✓ LI Business Alliance Workshop, December 2002

Center for Nanoscale Materials (CNM)

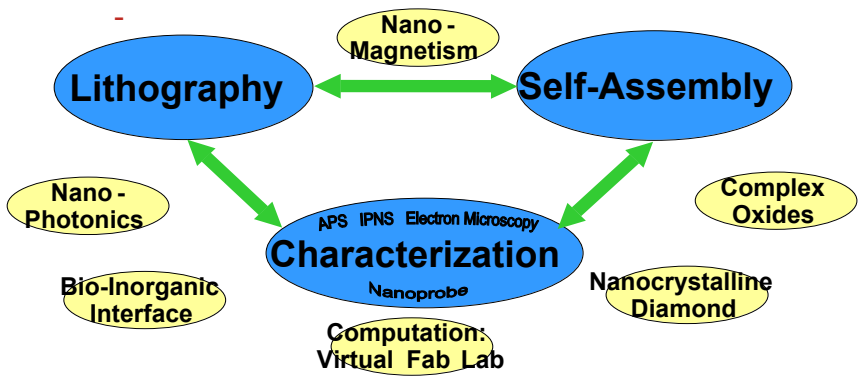
Argonne National Laboratory

- **CNM building is funded by the State of Illinois**
- **CNM instrument suite is funded by DOE**

Unique Facilities

- **Advanced Photon Source**
- **Intense Pulsed Neutron Source**
- **Electron Microscopy Center for Materials Research**

Scientific Thrust Areas



The Molecular Foundry

Lawrence Berkeley National Laboratory

Unique Facilities at Berkeley Lab

Advanced Light Source

National Center for Electron Microscopy

National Energy Research Scientific Computing Center

Nanowriter

Thrust Areas

Inorganic Nanostructures

Nanofabrication

Organic, Polymer/Biopolymer Synthesis

Biological Nanostructures

Imaging and Manipulation

Theory

Proposed Construction Start Dates

Oak Ridge 2003

Berkeley 2003

Brookhaven 2005

Argonne
2003

Los Alamos – Sandia
2003

CNMS (ORNL)

Jump Start Ramp-Up Capabilities

Nanofabrication Research Laboratory

- Ramp-up capabilities
  - Photolithography / e-beam lithography
  - Analytical SEM / EDX
  - Scanning probe microscopy
  - Materials deposition / etching / polish-ing / inspection / characterization
  - Probe station / wire bonder / electrical test facilities

Nanoscale Imaging and Manipulation

- **Ramp-up capabilities**
  - High-resolution SEM / TEM / STEM imaging via SHaRE/HTML user programs
  - Nanomachining using existing FIB
  - Holography for 3D imaging and visualization (existing TEM)
  - AFM and other scanning probe microscopies
- **Representative research**
  - Develop user-friendly but truly novel imaging and manipulation tools:
  - Simultaneous SPM / SEM for mater-ials manipulation while imaging
  - Holographic 3D metrology of nanoscale structures & fields
  - Joint ion / e-beam / imaging tools for cutting / shaping / joining / coating

CFN (BNL)

Materials Synthesis

Wet Chem, MBE, PLD, e-beam dep.

Nanopatterning

JEOL 9300 FS: e-beam patterning,
Resist process & develop.
Deep Reactive Ion Etch, Ion Beam Patterning

Ultrafast Optical Sources

SFG, DFG, XUV/SXR THz Microscopy,
Laser-Electron Accelerator Facility (LEAF)

Electron Microscopy

High Res. TEM, Scanning Auger, SEM,
Electron Holography, STEM, EELS

Proximal Probes

UHV-SPM, NSOM, IR microscope,
Env. SPM, LEEM, SPLEEM

Theory & Computation

LAPW, Plane Wave Pseudo Potl., Quantum Chem.,
QMC, MD, and SMP computing

CINT (SNL/LANL)

CINT Gateway to Los Alamos Nanomaterials/Biosciences

Biosciences
- Cell Culture, Genetic Engineering
- Phage Display, Molecular Biology
- Imaging & characterization

Nanomaterials
- MRFM, fast NSOM&STM, TEM
- LANSCE, HMFL

Theory & Computing

Visitor Space

CINT Gateway to Sandia Nanomaterials/Microfabrication

Microfabrication
- CMOS, MEMS, NEMS
- MOCVD

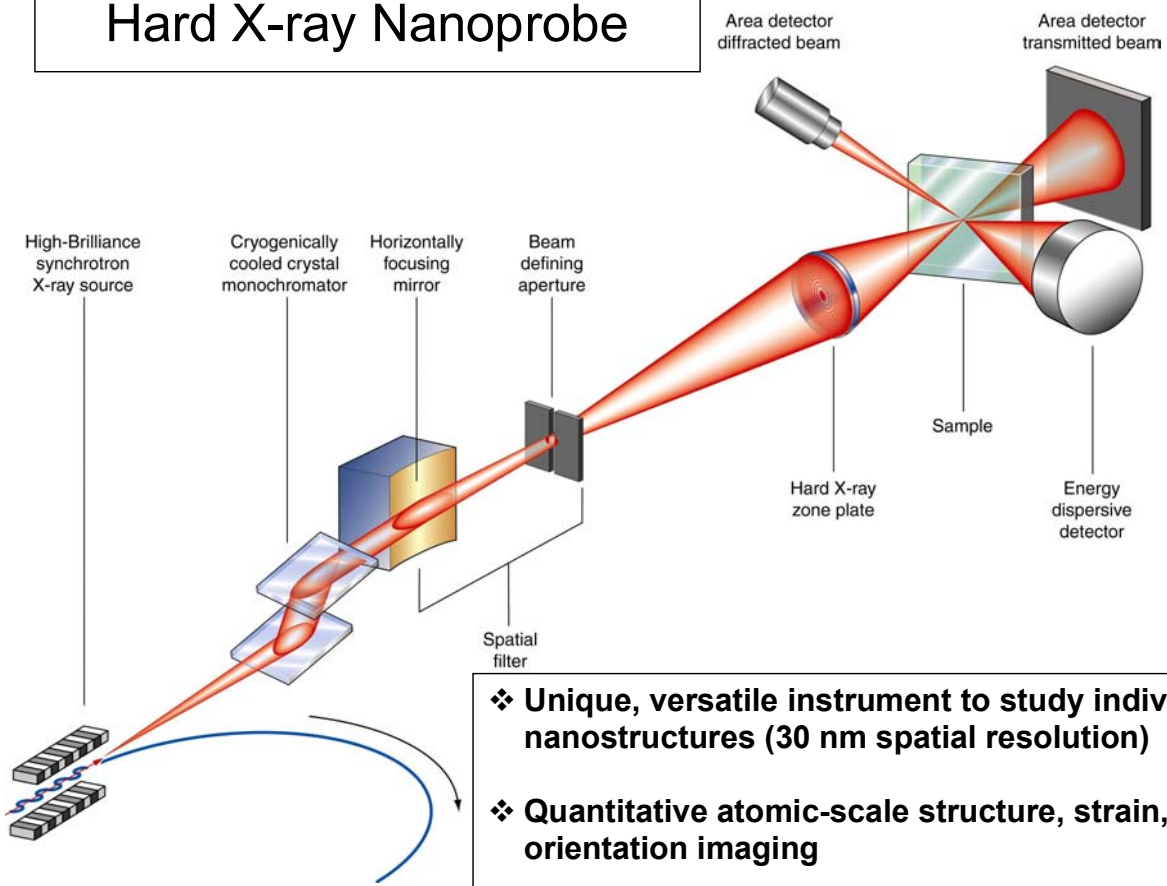
Nanomaterials
- AT-STM, IFM, NSOM
- LEEM, TEM
- Nanocluster synthesis

Theory & Computing

Visitor Space

Hard X-ray Nanoprobe beamline
CNM (ANL)

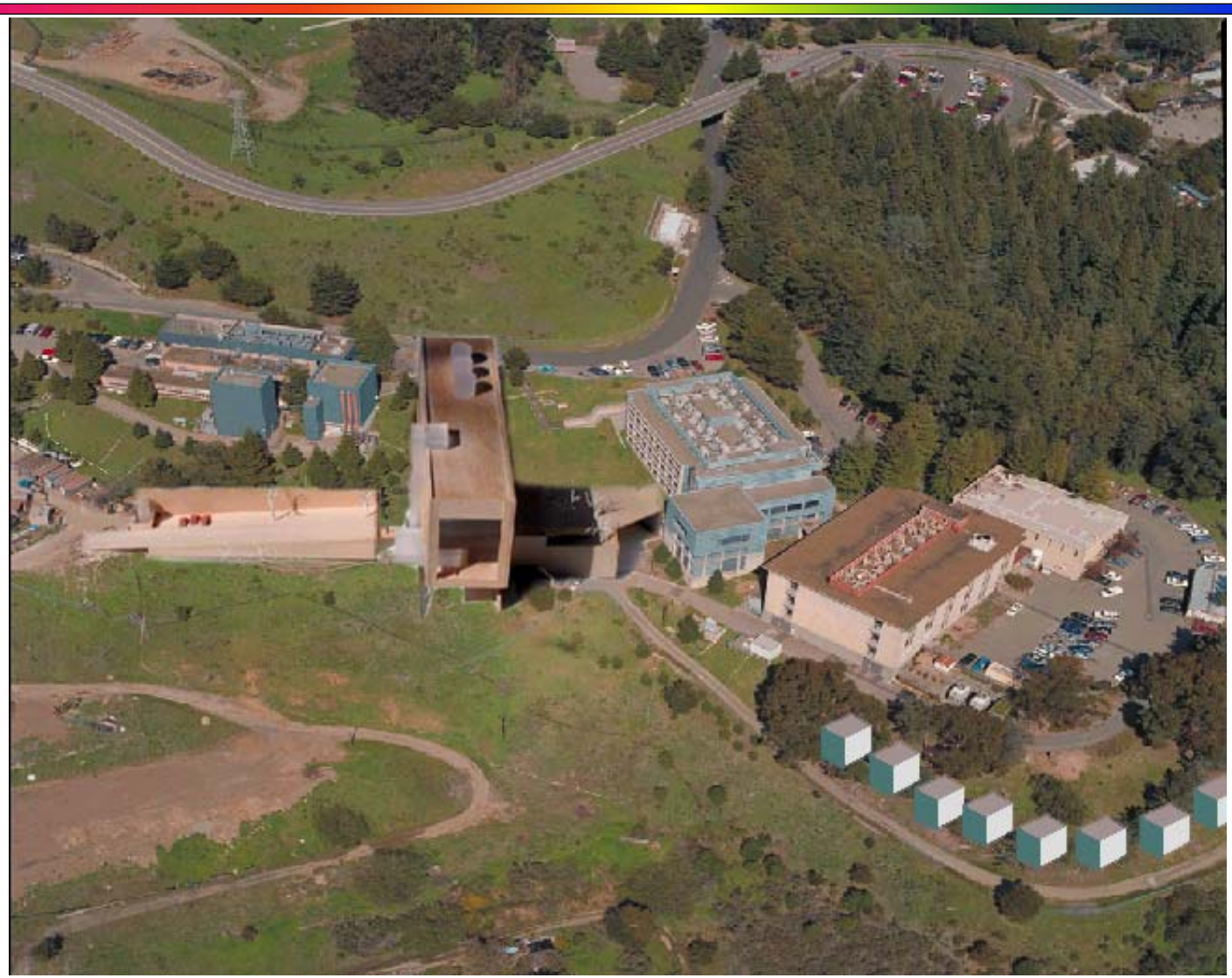
Hard X-ray Nanoprobe



- **Unique, versatile instrument to study individual nanostructures (30 nm spatial resolution)**
- **Quantitative atomic-scale structure, strain, and orientation imaging**
- **Sensitive trace element and chemical state analysis**
- **Ability to penetrate overlayers, environments, and fields**

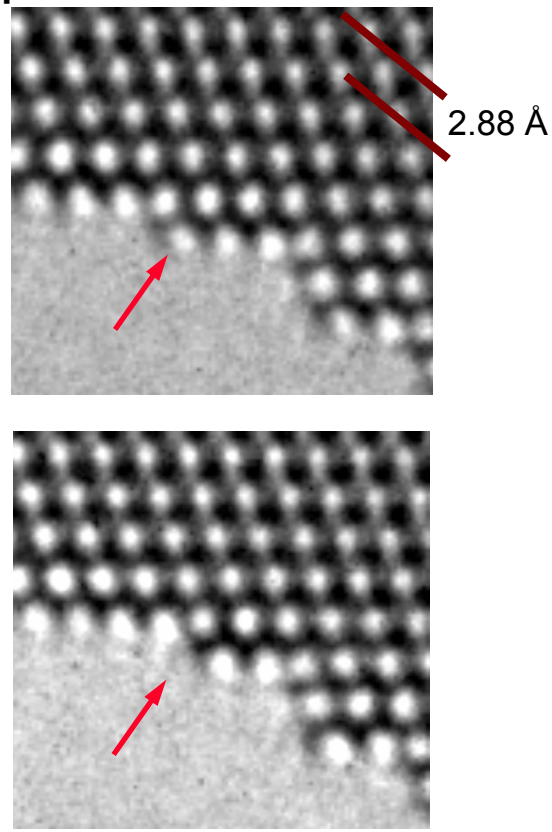
Many APS beamlines are already available for nanoscience research.

Foundry (LBNL)
"Nanocampus" Concept



The Transmission Electron Achromatic Microscope (TEAM) (LBNL)

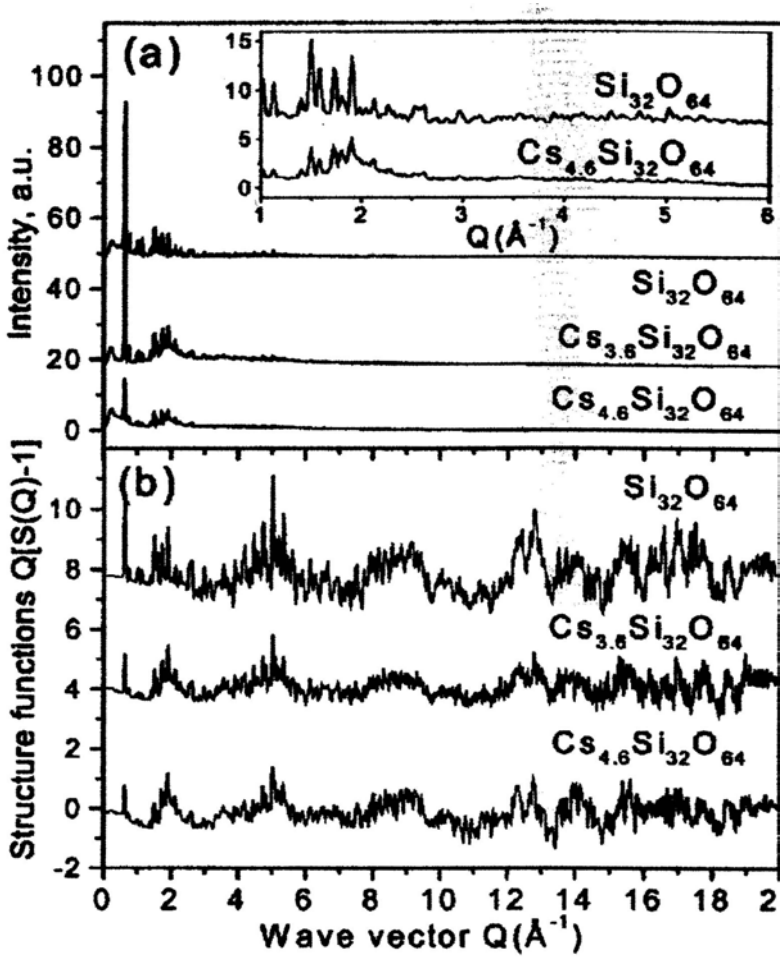
GOAL: Design and develop a new generation of intermediate-voltage (200-300 kV) electron microscopes in which the two major lens deficiencies that limit performance – spherical and chromatic aberration – are compensated.



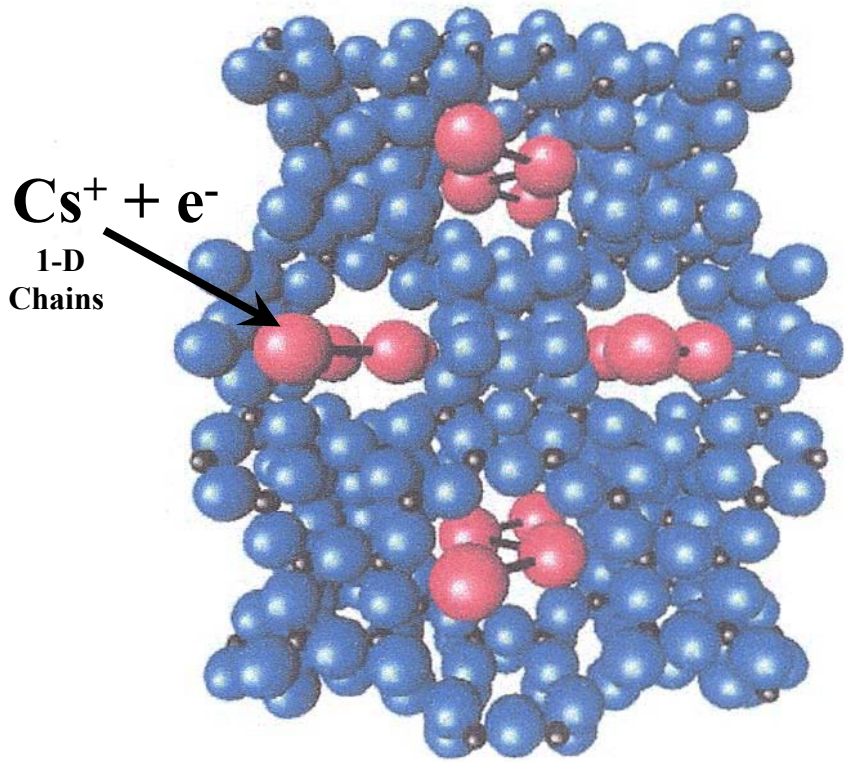
Time sequence of high-resolution images taken by NCEM scientist at the only existing spherical aberration-corrected microscope (Jülich, Germany) showing removal of a single atomic column at a gold surface.

- **When optimized for resolution, the correction of aberrations should allow recovery of direct spatial resolution in the range of 50 pm.**
- **Alternatively, improvements in the electron optics would ease tight constraints on sample space surrounding the specimen due to the lenses. The resulting larger chamber could accommodate improved spectrometers or in-situ modules for dynamic imaging of reactions, deposition, deformation, and response to electric and magnetic fields.**
- **Custom aberration-corrected instruments are planned based on a common, standardized core platform. Individual instruments will be configured to meet distinct scientific goals – atomic resolution tomography, single column microanalysis, or in-situ manipulation.**

Electrons Confined in Nanoporous Hosts

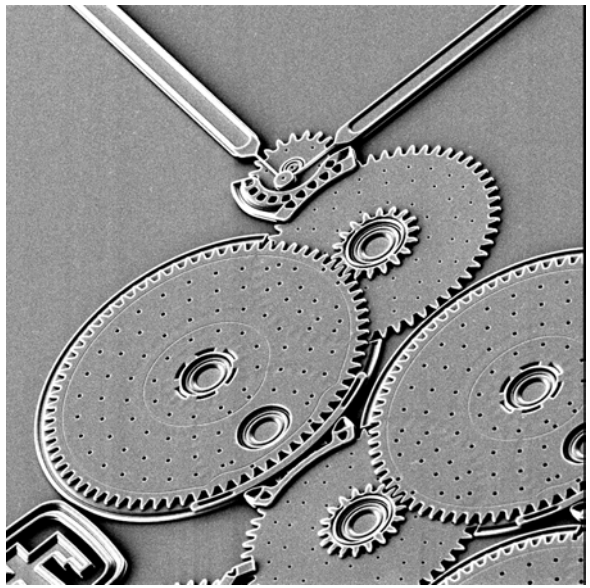


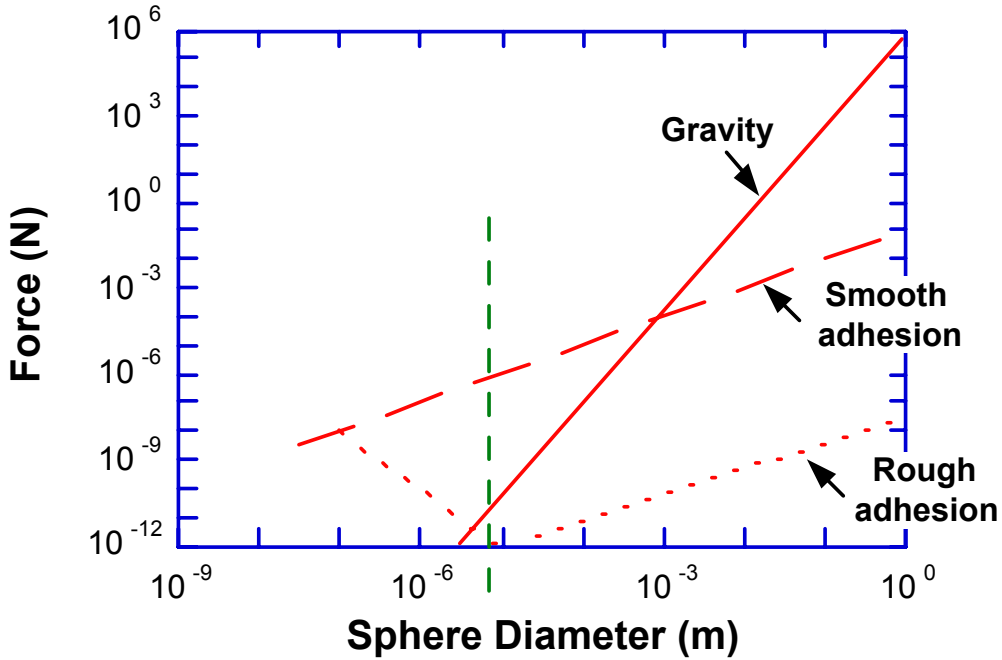
SiO_2 no charge-balancing required



V. Petkov, S.J.L. Billinge, T. Vogt, A.S. Ichimura, J.L. Dye, PRL 89, 075502 (2002)

Surfaces and interfaces control MEMS performance





Conventional mechanical design rules do not apply for such high surface to volume structures.

JOIN US!

http://www.sc.doe.gov/bes/NSET_NSRC_brochure_FEB03.pdf

Contact Information for DOE's Nanoscale Science Research Centers

Center for Functional Nanomaterials, Brookhaven National Laboratory • www.bnl.gov/CFN/

Center for Integrated Nanotechnology, Sandia National Laboratories and Los Alamos National Laboratory • cint.sandia.gov • www.cint.lanl.gov

Center for Nanophase Materials Sciences, Oak Ridge National Laboratory • www.cnms.ornl.gov

Center for Nanoscale Materials, Argonne National Laboratory • www.nano.anl.gov

Molecular Foundry, Lawrence Berkeley National Laboratory • www.foundry.lbl.gov