Argonne NATIONAL LABORATORY

… for a brighter future

U.S. Department of Energy

UChicago ▶ Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

Scientific Research Programs at the Center for Nanoscale Materials

Kathleen Carrado Gregar
Manager, User & Outreach Programs
Center for Nanoscale Materials
Argonne National Laboratory, IL

Post-Doc Lunch Seminar Series
November 16, 2007

Center for Nanoscale Materials

Center for Nanoscale Materials: A DOE user facility for nanoscience research

Full operations on
Sept. 28, 2007

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

State-of-the-art scientific user facility at Argonne National Laboratory that provides capabilities explicitly tailored to the creation and characterization of new functional materials on the nanoscale…, supporting the DOE BES mission in fundamental research and energy.

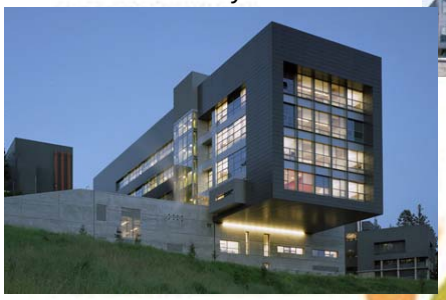
http://nano.anl.gov

cnm_useroffice@anl.gov

The Five DOE Nanoscale Science Research Centers (NSRCs)

Center for Nanoscale Materials
Argonne National Laboratory

Molecular Foundry
Lawrence Berkeley
National Laboratory

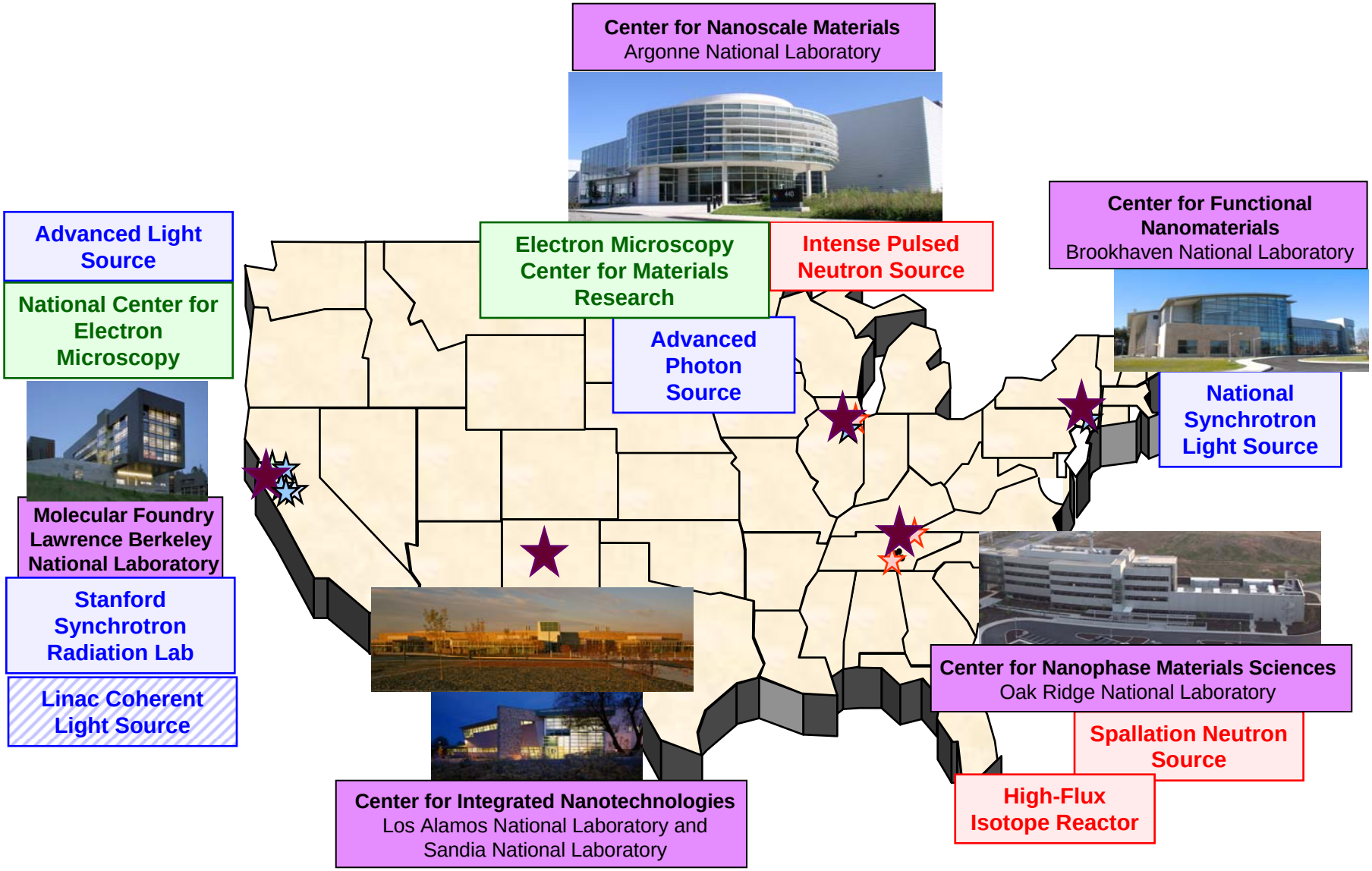


Center for Functional Nanomaterials
Brookhaven National Laboratory

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

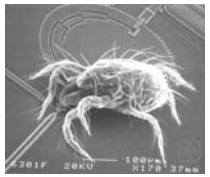
Center for Nanophase Materials Sciences
Oak Ridge National Laboratory

DOE NSRC and Facilities Integration



The Scale of Things

Things Natural

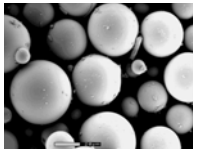


Dust mite

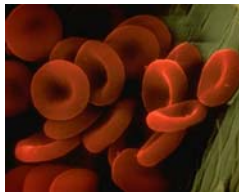
200 μm

Human hair
~ 60-120 μm wide

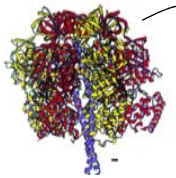
Ant
~ 5 mm



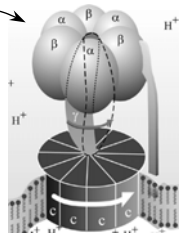
Fly ash
~ 10-20 μm



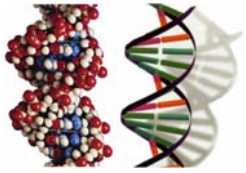
Red blood cells
(~7-8 μm)



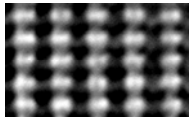
~10 nm diameter



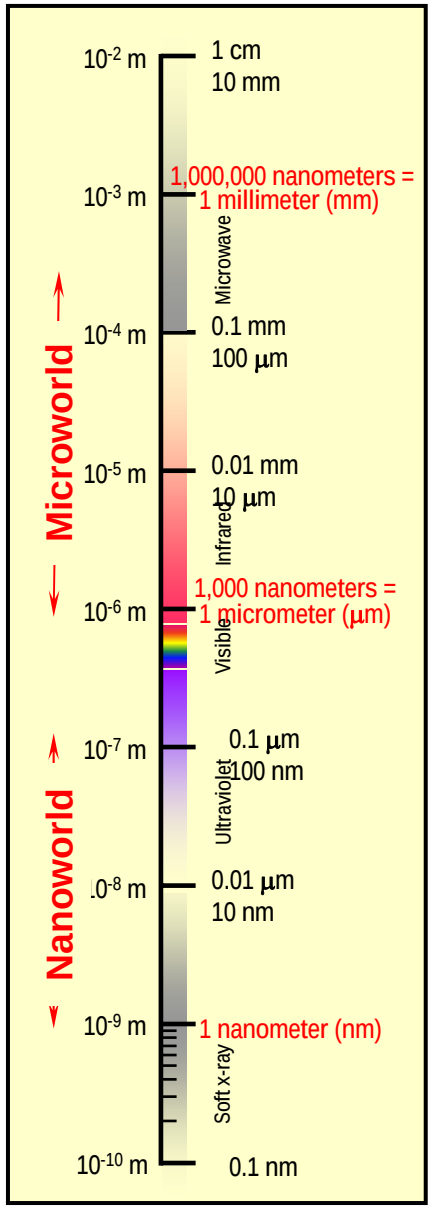
ATP synthase



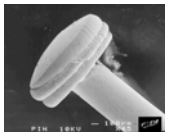
DNA
~2-1/2 nm diameter



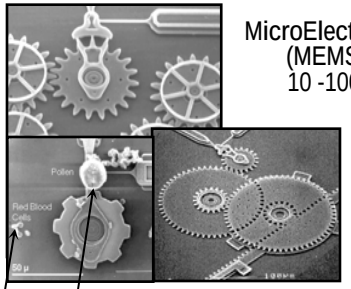
Atoms of silicon
spacing
0.078 nm



Things Manmade



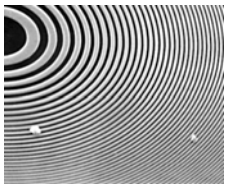
Head of a pin
1-2 mm

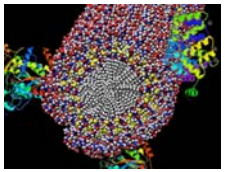


MicroElectroMechanical
(MEMS) devices
10 -100 μm wide

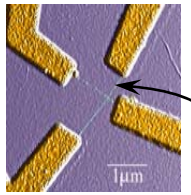
Pollen grain
Red blood cells

Zone plate x-ray "lens"
Outer ring spacing ~35 nm

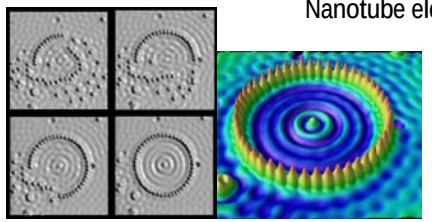




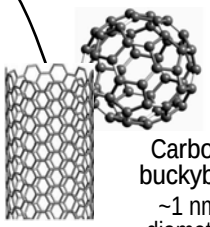
Self-assembled,
Nature-inspired structure
Many 10s of nm



Nanotube electrode



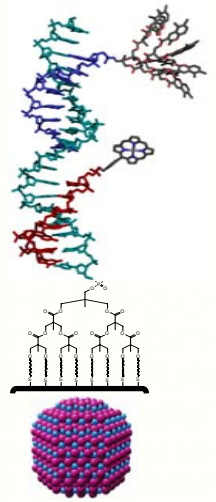
Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm



Carbon nanotube
~1.3 nm diameter

Carbon buckyball
~1 nm diameter

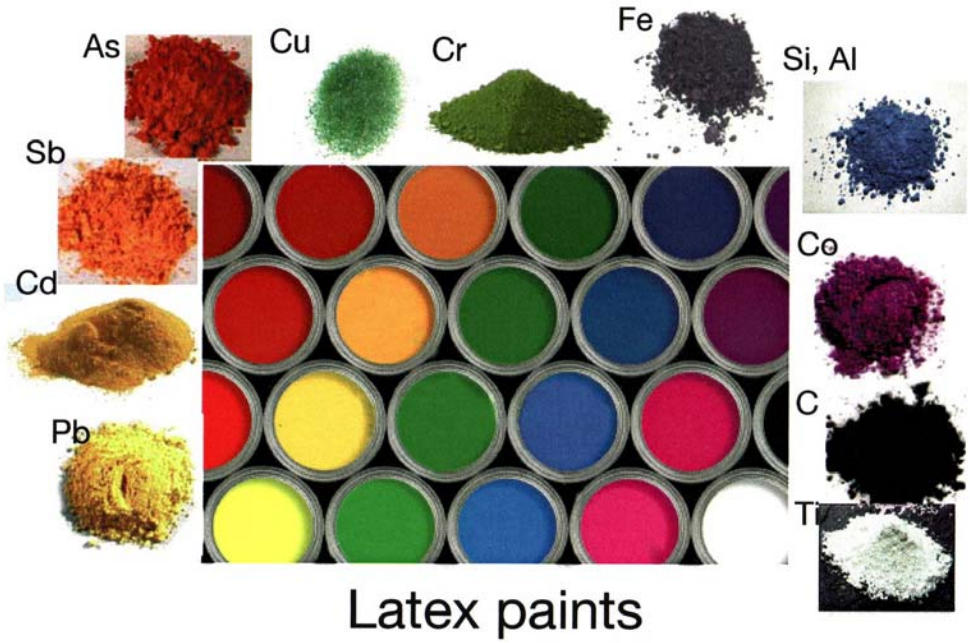
The Challenge



Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.

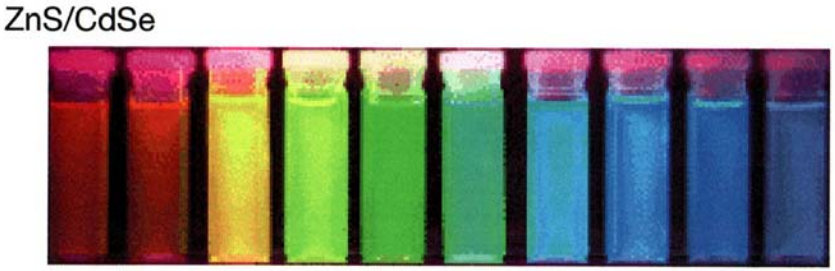
Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 05-26-06, pmd

Materials Properties are Unique at the Nanoscale



Latex paints

At the macroscale, color is based on different pigments



Semiconductor nanoparticles

At the nanoscale, color is based on size & electronic effects

The CNM is a Federal DOE & State of Illinois Partnership

CNM Cornerstone Ceremony
May 6, 2005

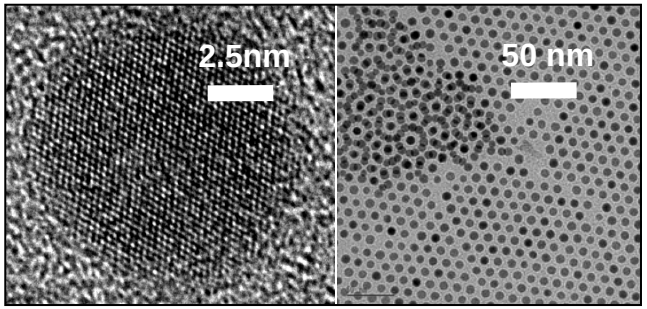
Ill. Governor
(R. Blagojevich)
Ill Rep.
(J. Biggert)
Sec'y DOE
(S. Bodman)
OS Director
(R. Orbach)
UofC President
(D. Randall)
BES Head
(P. Dehmer)

$36 Million from Dept. of Energy for Technical Equipment

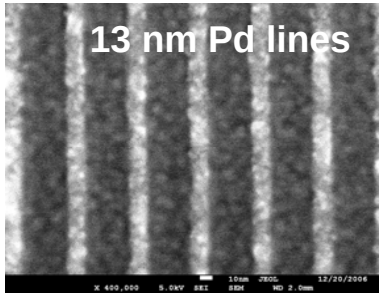
$36 Million from State of Illinois for Building Construction

CNM: Enabling Science Through Technical Capabilities

- Materials synthesis - ‘bottom-up’
  - Self-assembly, bio/organic/inorganic synthesis, thin film deposition (MBE), PECVD, peptide/DNA biosynthesis, core-shell nanoparticles…
- Nanofabrication - ‘top-down’
  - Lithography, imprint, milling, etching…
- Nanocharacterization
  - Proximal probes (AFM, SPM, NSOM, etc.)
  - Structural, magnetic, electronic, optical, chemical and dynamical properties
  - Hard x-ray nanoprobe beamline @ APS
- Computational Nanoscience
  - Beowulf-class supercomputer w/ 10 TFlop compute capacity
  - Number 150 on list of world’s 500 fastest computers (11/13/07)



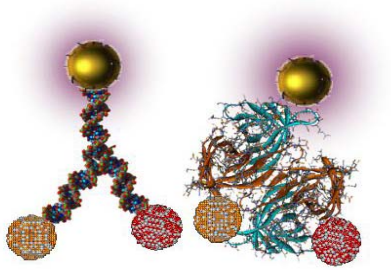
‘bottom-up’ synthesis and assembly of colloidal nanoparticles



‘top-down’ patterning of Pd wires; new cold development process

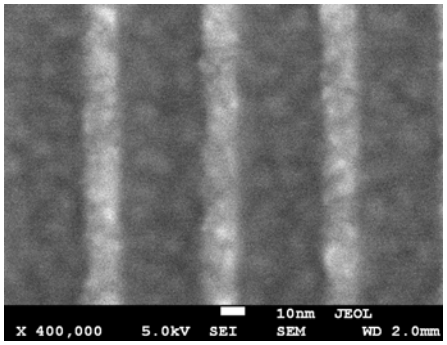
Six Integrated Scientific Themes

NanoBio Interfaces



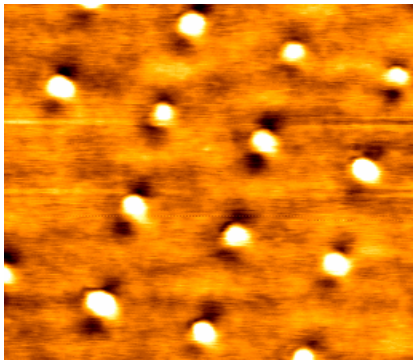
Create bio-inspired materials and processes for energy transduction

Nanofabrication



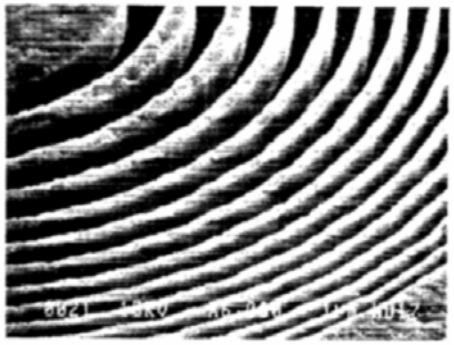
Discover new paths for nanostructured materials, including below 10 nm

Nanophotonics



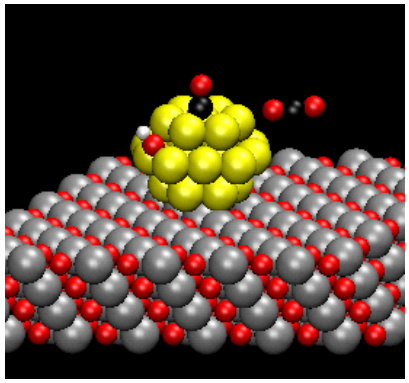
Understand and control optical energy pathways

X-ray Microscopy



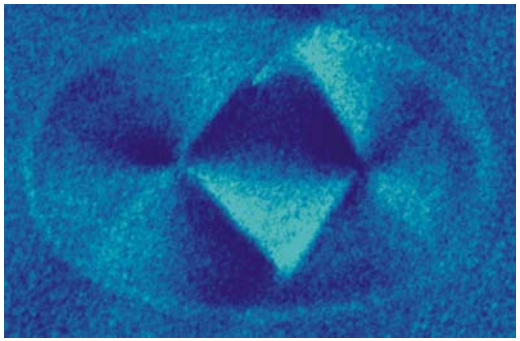
Create images of the nanoworld with hard x-rays

Theory & Modeling



Towards the 'virtual fab lab'

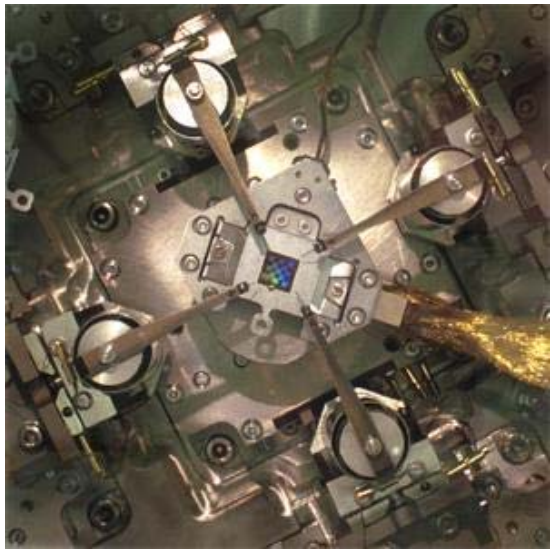
Electronic & Magnetic Materials



Understand and control charge and spin-based materials for energy and information transport

Key Fabrication and Characterization Tools

Combined STM/SEM

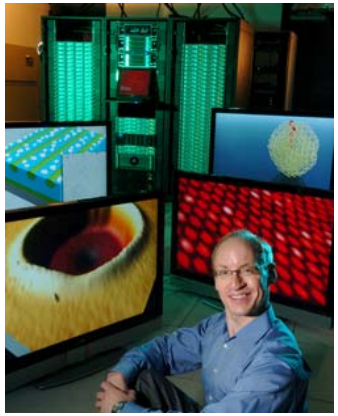


Complex oxide MBE

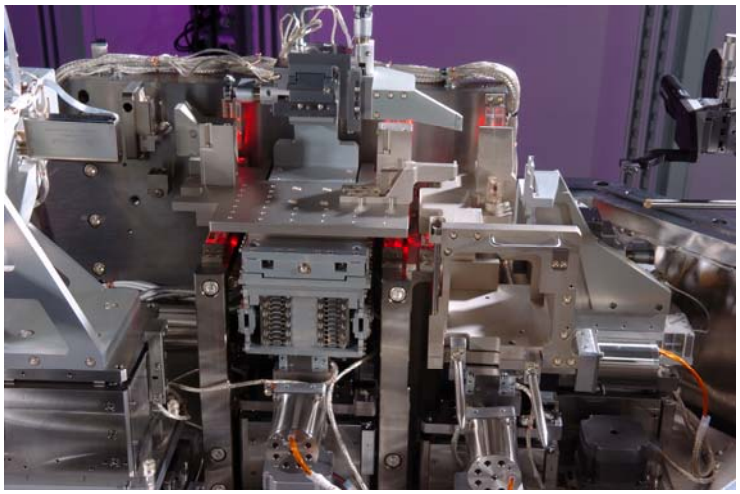
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

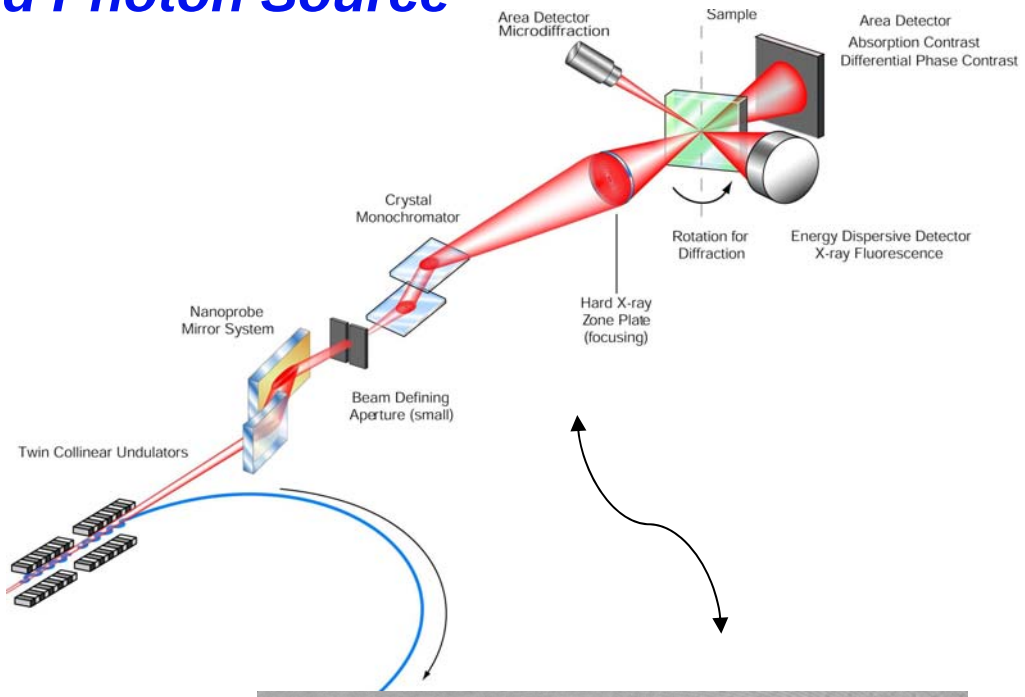
NSOM

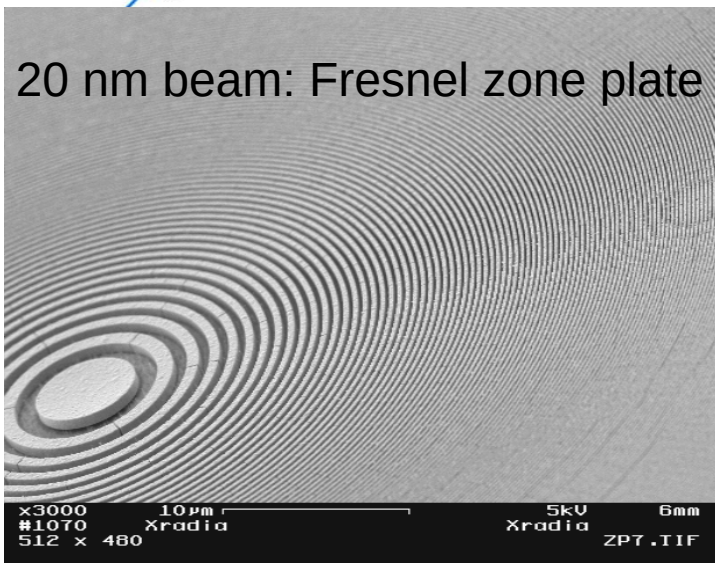
10 Tflop Supercomputer



CNM Nanoprobe at the Advanced Photon Source

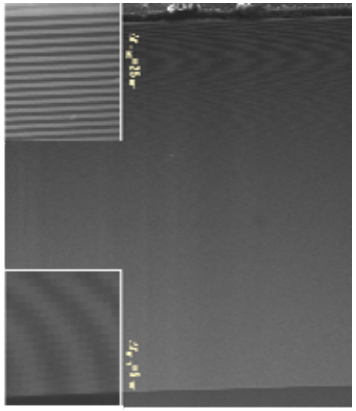




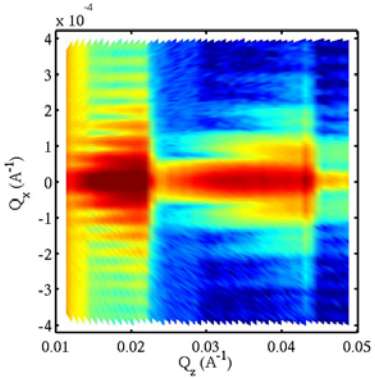


Research @ Sector 26

X-ray Optics

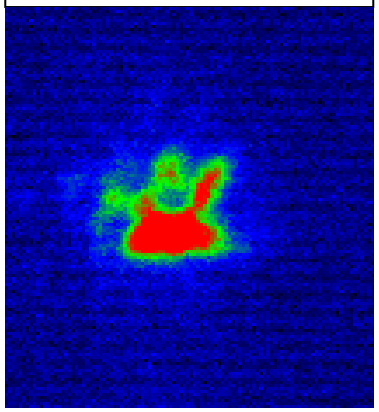


Courtesy A. Macrander et al



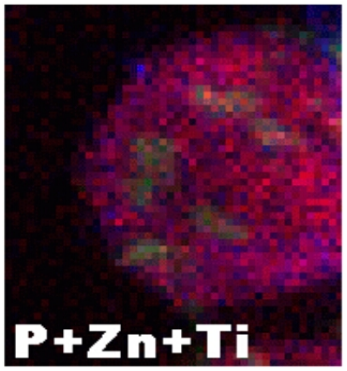
Courtesy H.C. Kang et al.

Nanodiffraction



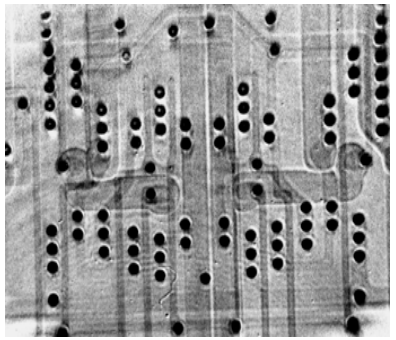
Courtesy Z. Cai

Fluorescence Microscopy



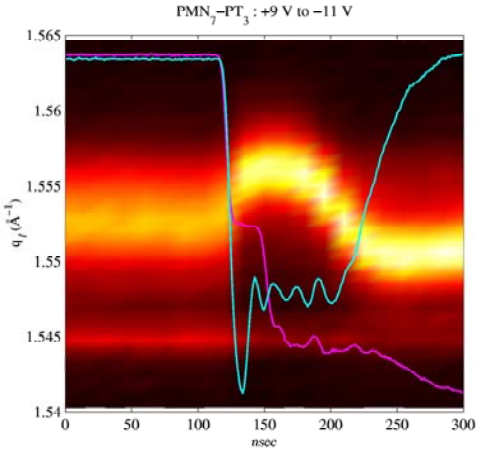
Courtesy T. Paunesku et al

Transmission Imaging



Courtesy J. Susini et al.

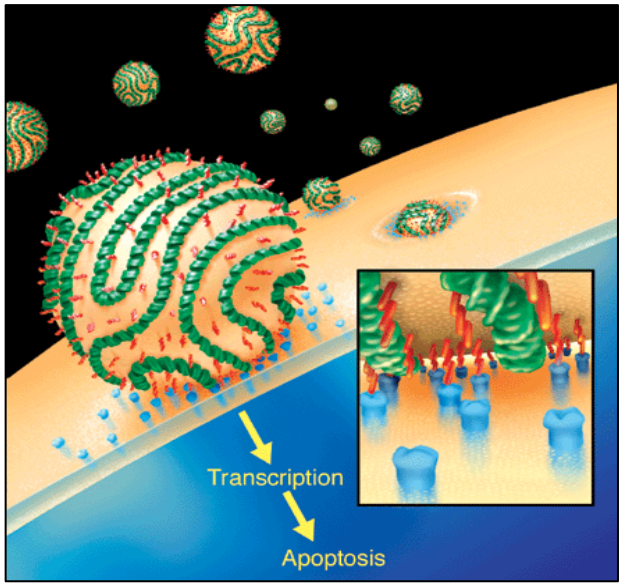
Dynamics



Courtesy G. B. Stephenson et al.

Example: Nano-Bio-Medical Imaging

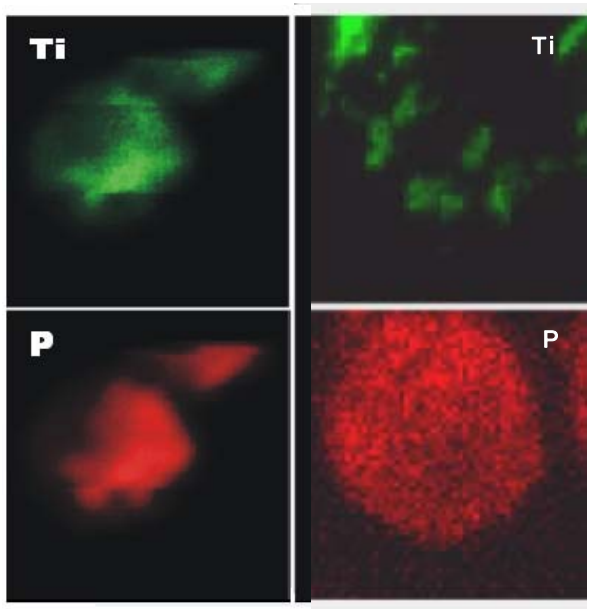
In-vivo cell biology



- Affinity of transfected DNA for ribosomes causes localization to the **mitochondria**.
- Potential for *in-vivo* gene surgery - DNA cleaves under optical/IR illumination.

T. Paunesku et al, *Nature Materials 2, 343-346*

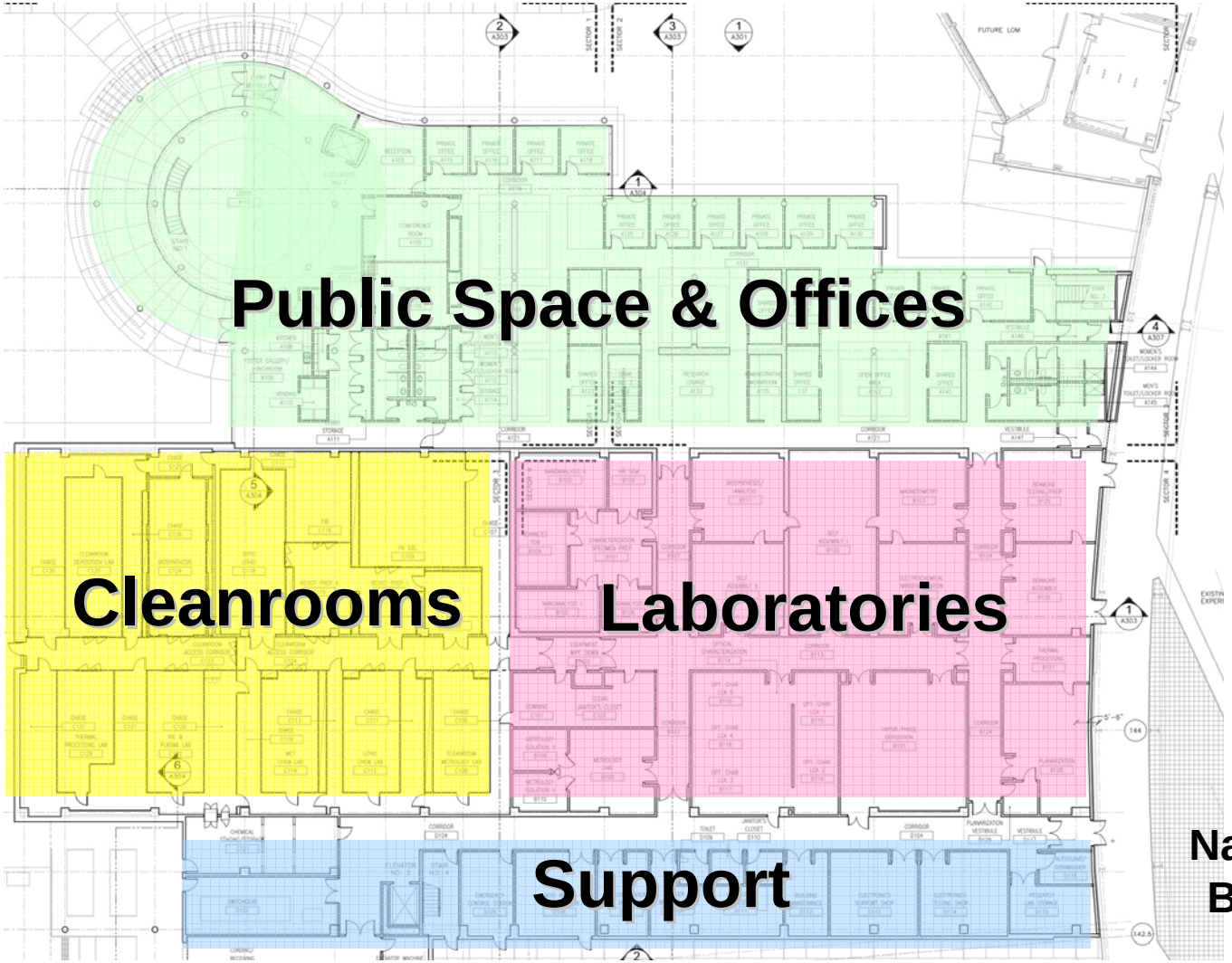
Some important length scales:
- Mitochondria - sub-micron
- Membrane thickness - sub-10 nm



Genomic DNA Mitochondrial DNA

K_a X-ray fluorescence image of phosphorus (red) and titanium (green) in cells transfected with TiO2 nanocomposites linked to genomic and mitochondrial DNA.

CNM Building Layout



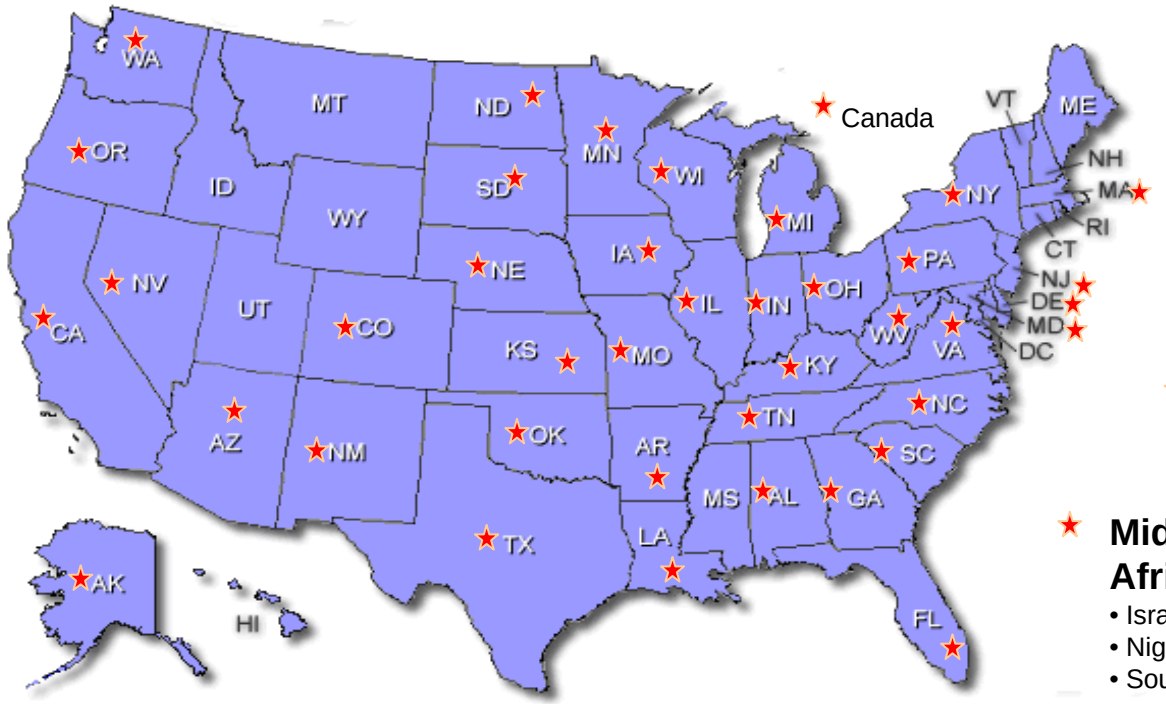
X-ray Nanoprobe Beamline

CNM User Program

Current CNM Users

- Summer ‘07 call-for-proposals resulted in 85 new user programs
- Users from academia, industry and government labs; US and international
- >160 publications, May ‘06 - September ‘07 (staff + users)

505 registered users:
40 States and Puerto Rico
20 Countries



Asia/Pacific
- Australia
- China
- India
- Japan
- Korea
- Taiwan

Europe
- Belgium
- France
- Germany
- Italy
- Spain
- United Kingom

Others
- Sweden
- Ukraine

Middle East & Africa
- Israel
- Nigeria
- South Africa

Medellín, Colombia
Cali, Columbia

Mayaguez, Puerto Rico
San Juan, Puerto Rico

as of 11/13/07

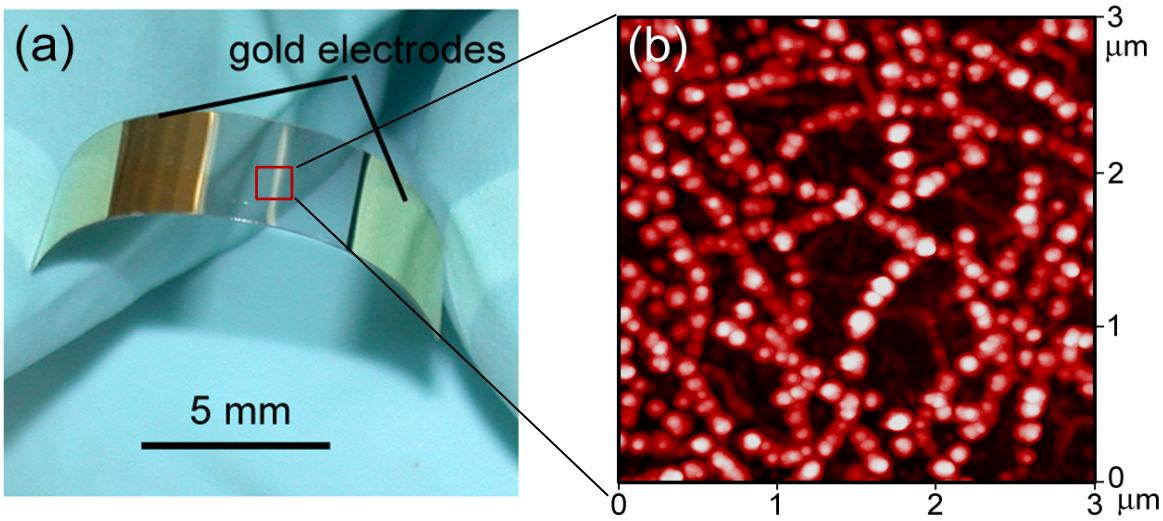
User Access to the CNM

- On-line proposal submission
  - Initial Internal Technical Feasibility Screen
- Peer review
  - user proposals are subject to peer review
  - no fees unless proprietary
- Proposal Evaluation Board (PEB)
  - Evaluations are based on scientific merit (1-5 IUPAP scale)
  - consists of scientists external to the CNM with requisite expertise
  - 75 members from academia, industry and government; also includes international members

Examples of CNM Science

Palladium Nanoparticle Electrodeposition on Nanotubes Results in New Flexible Hydrogen Sensors

Y. Sun and H. Wang
Applied Physics Letters, 90, 213107 (2007)



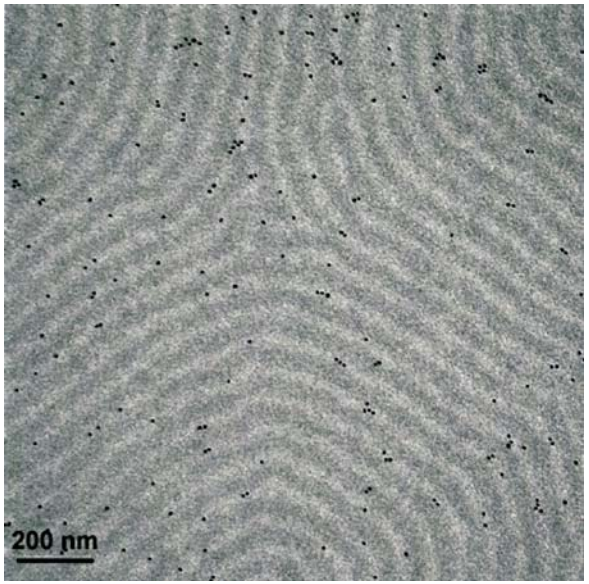
Current hydrogen sensors are rigid and use expensive, pure palladium. These new sensors are flexible and use single-walled carbon nanotubes (SWNTs) as supports to improve efficiency and reduce cost. Fabrication involves a two-step process of chemical vapor deposition and dry transfer printing, allowing a film of nanotubes to form on plastic, after which palladium nanoparticles are deposited on the SWNTs to make the sensors.

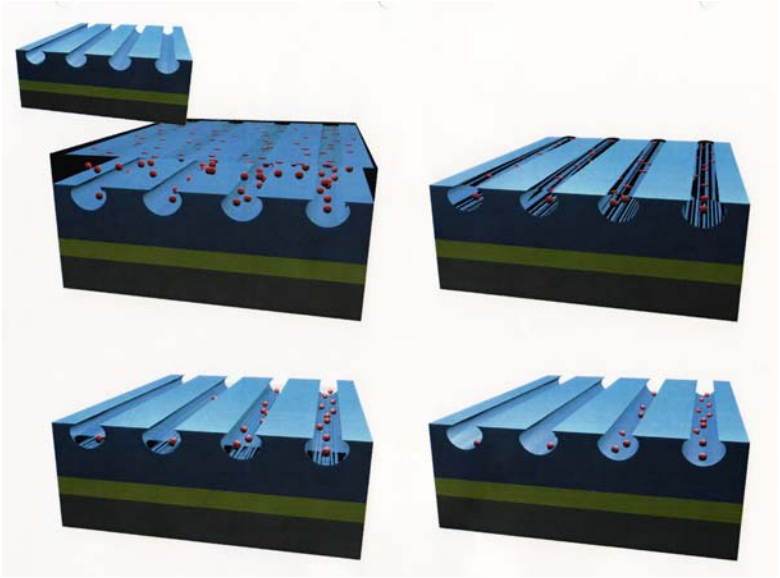
Flexible hydrogen sensors can detect the presence of 1% hydrogen at room temperature in 3 seconds.

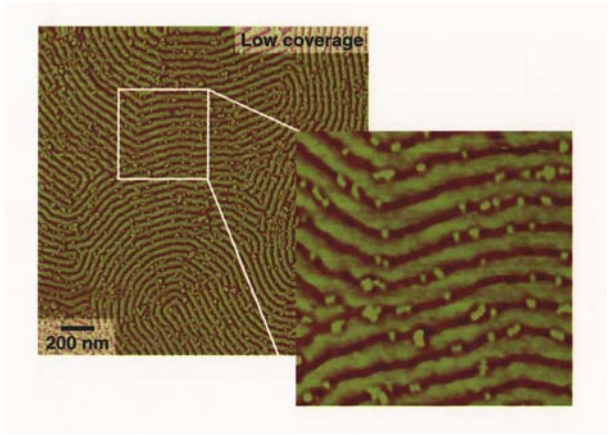
Top-down AND bottom-up self-assembly of nanomaterials

"A Materials Chemistry Perspective on Nanomagnetism"
Seth Darling, Sam Bader
J. Mater. Chem. 2005, 15, 4189

3-5 nm FePt magnetic nanoparticles in diblock copolymer template that are lithographically aligned







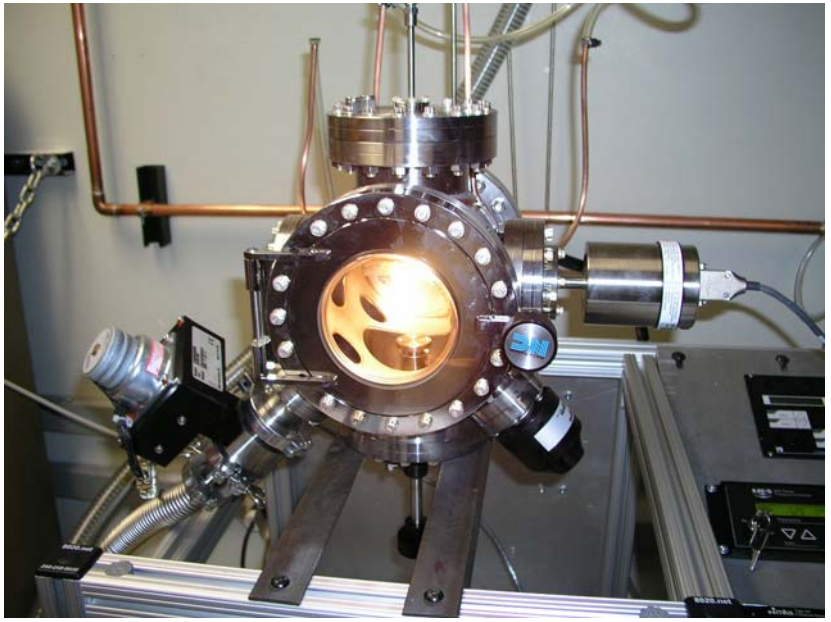
Heavier hydrogen on the atomic scale reduces friction

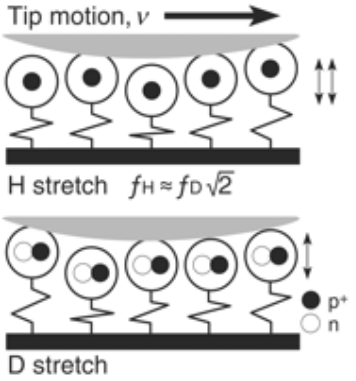
"Nanoscale Friction Varied by Isotopic Shifting of Surface Vibrational Frequencies"
Cannara et al., *Science* 2007, 318, 780.

Scientists lack a comprehensive model of friction on the nanoscale and only generally grasp its atomic-level causes, which range from local chemical reactions to electronic interactions to phononic, or vibrational, resonances.

This paper finds a significant difference in friction exhibited by diamond surfaces that had been coated with different isotopes of hydrogen and then rubbed against a small carbon-coated tip.

Anirudha Sumant et al. use single-crystal diamond surfaces coated with layers of either atomic hydrogen or deuterium, a hydrogen atom with an extra neutron. The deuterium-terminated diamonds have lower friction forces because of their lower vibrational frequencies, attributed to that isotope's larger mass.



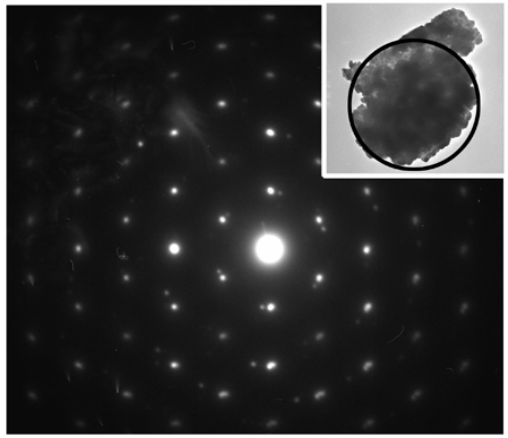


Growth of Ag nanoplates on semiconductor wafer via galvanic reaction

Y. Sun and G. Wiederrecht
Small, 2007, 3(11), in press.

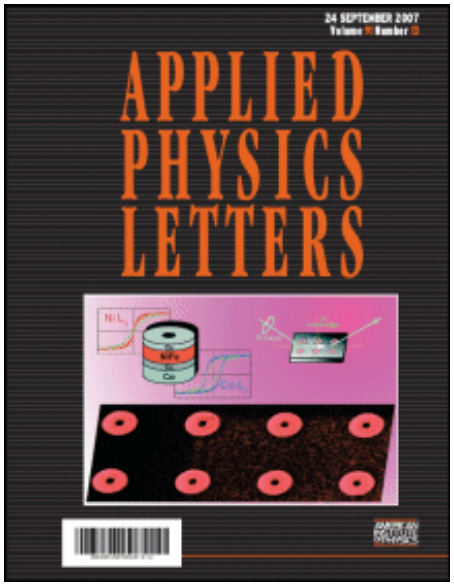
50-70 nm thick Ag(0) on GaAs

For potential in: efficiency increase of photochemical processes such as photoelectrolysis of water with solar energy for producing hydrogen, plasmonic-enhanced photophysical and photochemical processes and surface-enhanced spectroscopies.



$$12AgNO_3 + 2GaAs + 6H_2O \rightarrow 12Ag + Ga_2O_3 + As_2O_3 + 12HNO_3$$

Logic Tells Us that Appearances May Be Deceptive

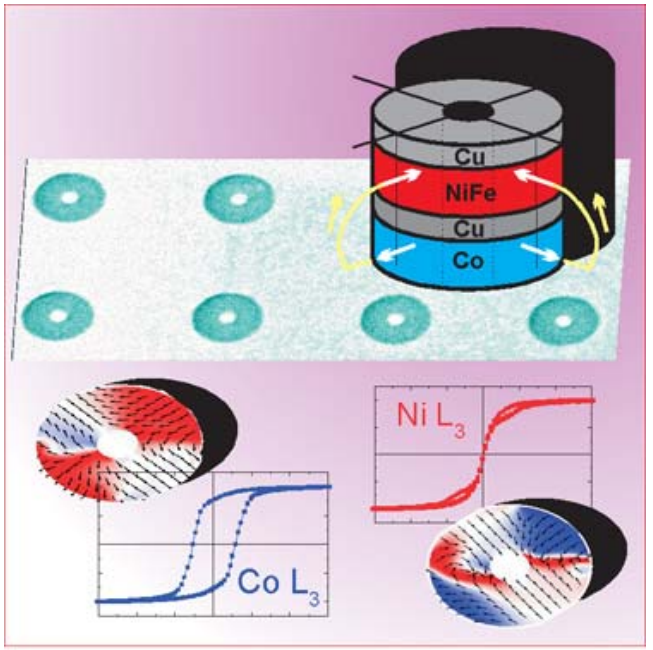


"The breakdown of the fingerprinting of vortices by hysteresis loops in circular multilayer ring arrays," V. Rose, X.M. Cheng, D.J. Keavney, J.W. Freeland, K.S. Buchanan, B. Ilic, and V. Metlushko; *Appl. Phys. Lett*. 91, 132501 (2007).

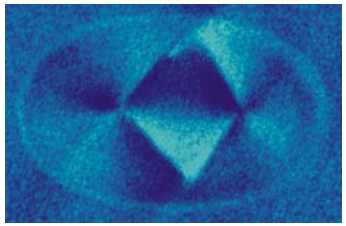
Microscale single-layer ferromagnetic rings typically exhibit a magnetic vortex state at remanence, characterized by a flux-closed magnetic state with zero stray fields. Magnetic reversal in such systems yields a vanishing remanent magnetization.

In contrast, the authors show that in individual layers in thin rings, which alternate magnetic and nonmagnetic materials (NiFe/Cu/Co), layer-resolved hysteresis loops, measured by using X-ray resonant magnetic scattering, exhibit the characteristics of a vortex formation, although photoelectron emission microscopy and micromagnetic simulations clearly prove that multidomain states are formed.

This result is of considerable importance for the development of pseudo-spin-valve-type structures.



Electronic & Magnetic Materials & Devices



Major Tools

- Electron beam evaporator and sputtering deposition (Oct 2007)
- Luminescence spectrometer
- Magnetometry (PPMS & MPMS)
- Oxide MBE (Fall 2007)
- Raman spectrometer (Fall 2007)
- Rheometer
- Scanning probe microscope
- Solar simulator (June 2007)
- SPM/SEM combined (Omicron UHV)
- TGA/DSC
- UV-Vis-NIR
- X-ray diffractometer

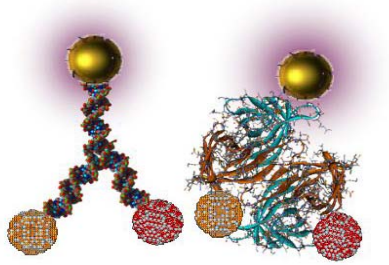
Group Leader

Matthias Bode
mbode@anl.gov

Group Members

- Anand Bhattacharya, anand@anl.gov
  - oxide MBE
- Matthias Bode, mbode@anl.gov
  - spin-polarized STM
- Kristen Buchanan, buchanan@anl.gov
  - magnetometry
- Seth Darling, darling@anl.gov
  - AFM/SPM, lithographic self-assembly
- Axel Hoffman, hoffman@anl.gov
  - magnetism
- Xiao-Min Lin, xmlin@anl.gov
  - synthesis of nanocrystal building blocks

Nanobio Interfaces



Major Tools

- Electrochemical Workstation BAS 100B/W
- Electron paramagnetic resonance
- Functionalization, electro- & photochemical
- HPLC
- Laser Scanning Confocal Microscope
- PCR (available Dec. 2007)
- Post-self-assembly processing
- Schlenk Lines
- Solvent Purification
- Spectroelectrochemistry
- Synthesis & surface modification of nanoparticles

Group Leader

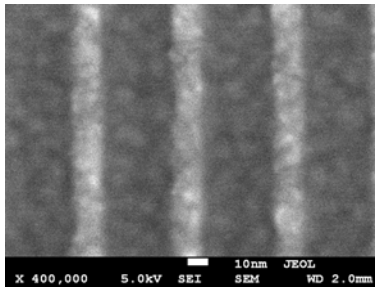
Tijana Rajh
rajh@anl.gov

Group Members

Integrating “soft” biological molecules with “hard” inorganic nano-architectures is applied to catalysis, sensors, information storage, artificial vision, biological intervention, etc.

- Tijana Rajh, rajh@anl.gov
  - EPR, quantum dots, semiconductor-bio composites
- Elena Rozhkova, rozhkova@anl.gov
  - bio(in)organic, biological chemistry, synthetic biology
- Elena Shevchenko
  - 2- and 3-D nanoparticle assembly

Nanofabrication



Major Tools

- JEOL 9300 FS, 100 KV Electron Beam Lithography
- Raith 150, 30 KV Electron Beam Lithography
- FEI Nova 600 NanoLab DualBeam FIB/SEM
- Nanonex NX-3000 Step and Repeat Nanoimprint
- Direct write optical lithography (Oct 2007)
- Interferometric lithography (Oct 2007)
- Resist processing
- Plasma processing (chlorine, fluorine chambers barrel asher system)
- Wet Chemistry & Metrology
- Deposition (ebeam evaporator and sputtering, MOCVD)
- Nanocrystalline diamond deposition) (Oct 2007)

Group Leader

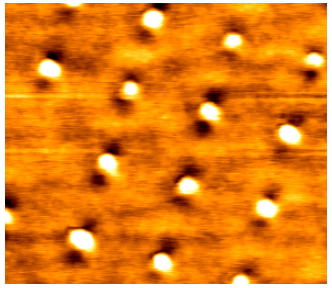
Derrick Mancini
mancini@anl.gov

QuickTime™ and a
FF (LZW) decompressor
eeded to see this picture.

Group Members

- Orlando Auciello, auciello@anl.gov
  - oxide and nanocarbon films, MEMS, NEMS
- Ralu Divan, divan@anl.gov
  - lithography, nanogels, MEMS/NEMS technology
- Valentina Kutepova, kutepova@anl.gov
  - cleanroom manager
- Derrick Mancini, mancini@anl.gov
- Leo Ocola, ocola@anl.gov
  - nanofabrication, electron beam lithography
- Anirudha Sumant, sumant@anl.gov
  - UNCD/PZT for diamond-based NEMS

Nanophotonics



Major Tools

Aperture NSOM
- CW laser excitation
- ultrafast laser excitation

Apertureless NSOM
- CW laser excitation
- ultrafast laser excitation

Colloidal synthesis
Confocal Raman microscopy (Aug 2007)
NSOM fiber puller
Time-correlated single photon counting

Group Leader

Gary Wiederrecht
wiederrecht@anl.gov

QuickTime™ and a
(LZW) decompresso
ded to see this picture

Group Members

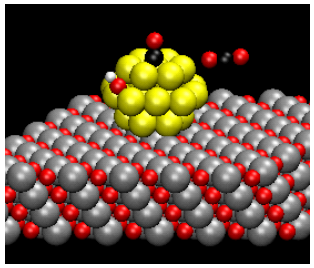
David Gosztola, gosztola@anl.gov
- laser spectroscopy and electrochemistry

Matthew Pelton, pelton@anl.gov
- physical phenomena of light interacting with nanomaterials

Yugang Sun, ygsun@anl.gov
- synthesis/fab of functional nanomaterials
- optical, electronic, mechanical properties

Gary Wiederrecht, wiederrecht@anl.gov
- new microscopies with spatial resolution below the diffraction limit

Theory & Modeling



Major Tools

Access to computational codes
- Density-functional-based tight-binding electronic structure package
- MPI-based parallel versions of nanophotonics and tight-binding codes
- Time-domain nanophotonics simulation
- Web-based magneto-optic simulation

Access to Argonne computer facilities
Support for experimental projects
Support for theoretical projects

Group Leader

Larry Curtiss
curtiss@anl.gov

Group Members

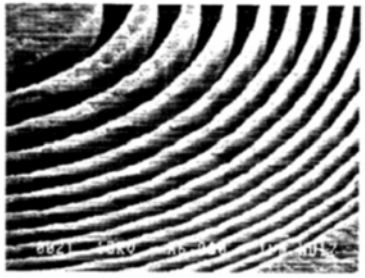
Larry Curtiss, curtiss@anl.gov
- quantum chemical studies

Jeff Greeley, jgreeley@anl.gov
- nanocatalysis

Michael Sternberg, sternberg@anl.gov
- software development

Stephen Gray (affiliation), gray@tcg.anl.gov
- quantum dynamics, FDTD

X-ray Microscopy



Major Tools

Hard X-ray nanoprobe beamline, sector 26 of APS (rampup Oct 2007 – Sept 2008)
Full field transmission microscopy (8-12 keV)
- 2D imaging in absorption contrast and phase contrast (Zernicke)
- Tomography

Scanning probe microscopy (8-12 keV in 2007, 3-30 keV in 2008)
- Nanodiffraction (2007)
- X-ray fluorescence microscopy (2007)
- Differential phase contrast imaging (2008)
- Magnetic imaging (2008)
- Time resolved experiments (2008)

Group Leader

Jorg Maser
maser@anl.gov

Group Members

Martin Holt, mvholt@aps.anl.gov

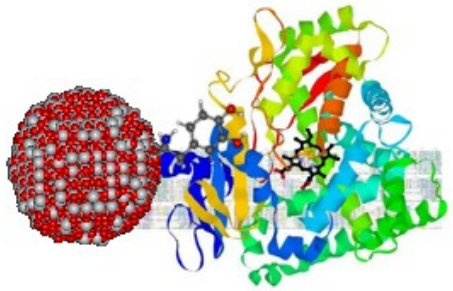
Jorg Maser, maser@anl.gov
- x-ray microscopy, x-ray optics

Brian Stephenson, stephenson@anl.gov

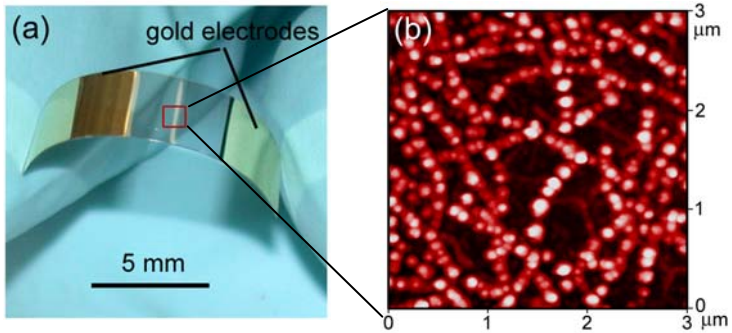
Robert Winarski, winarski@aps.anl.gov
- x-ray imaging

Argonne NATIONAL LABORATORY

An Integrated Vision for the Future



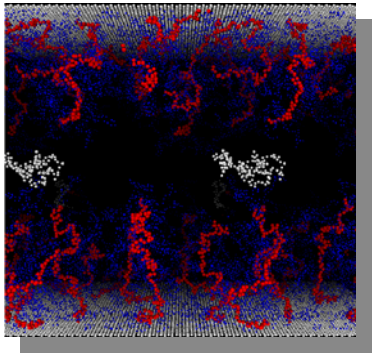
Materials creation:
Synthesis & assembly for control of processes and function



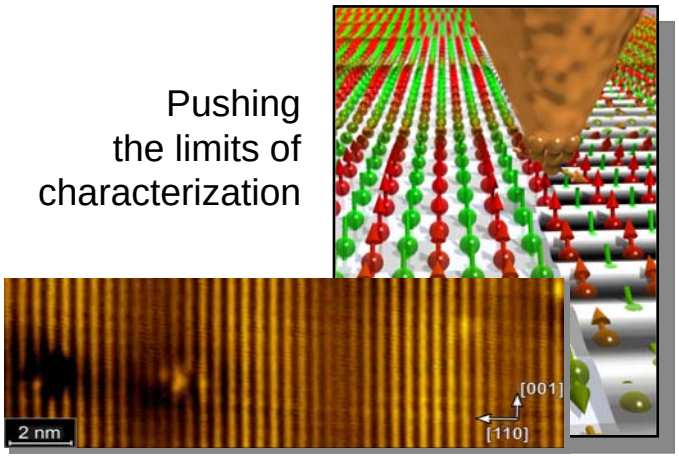
Nanofabrication
of novel architectures

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Virtual Fab Lab:
Guiding the search, understanding functionality



Pushing
the limits of characterization



CNM Staff Spring 2007