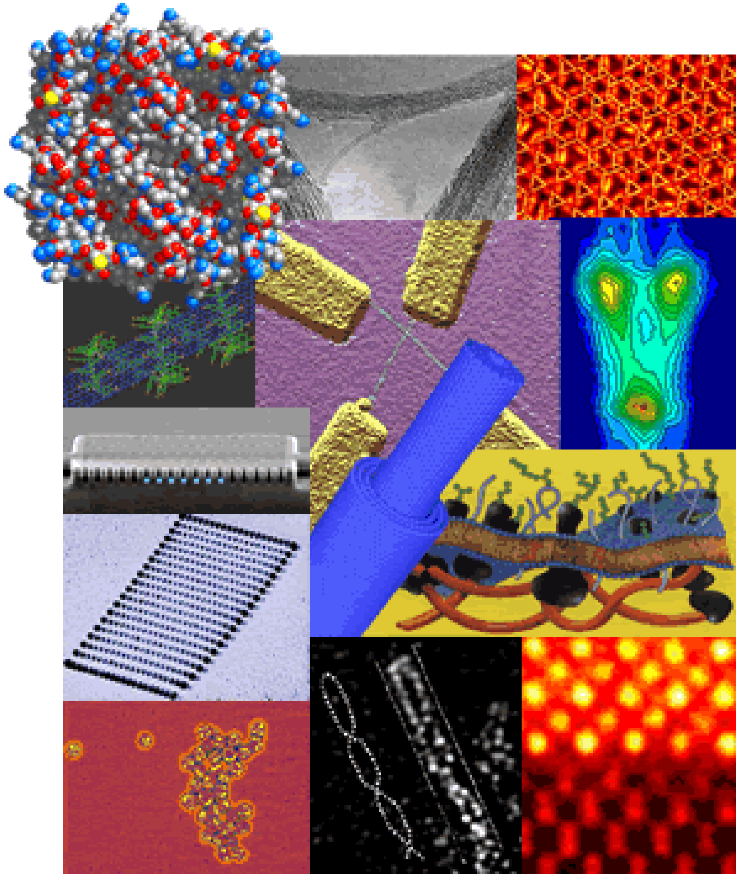
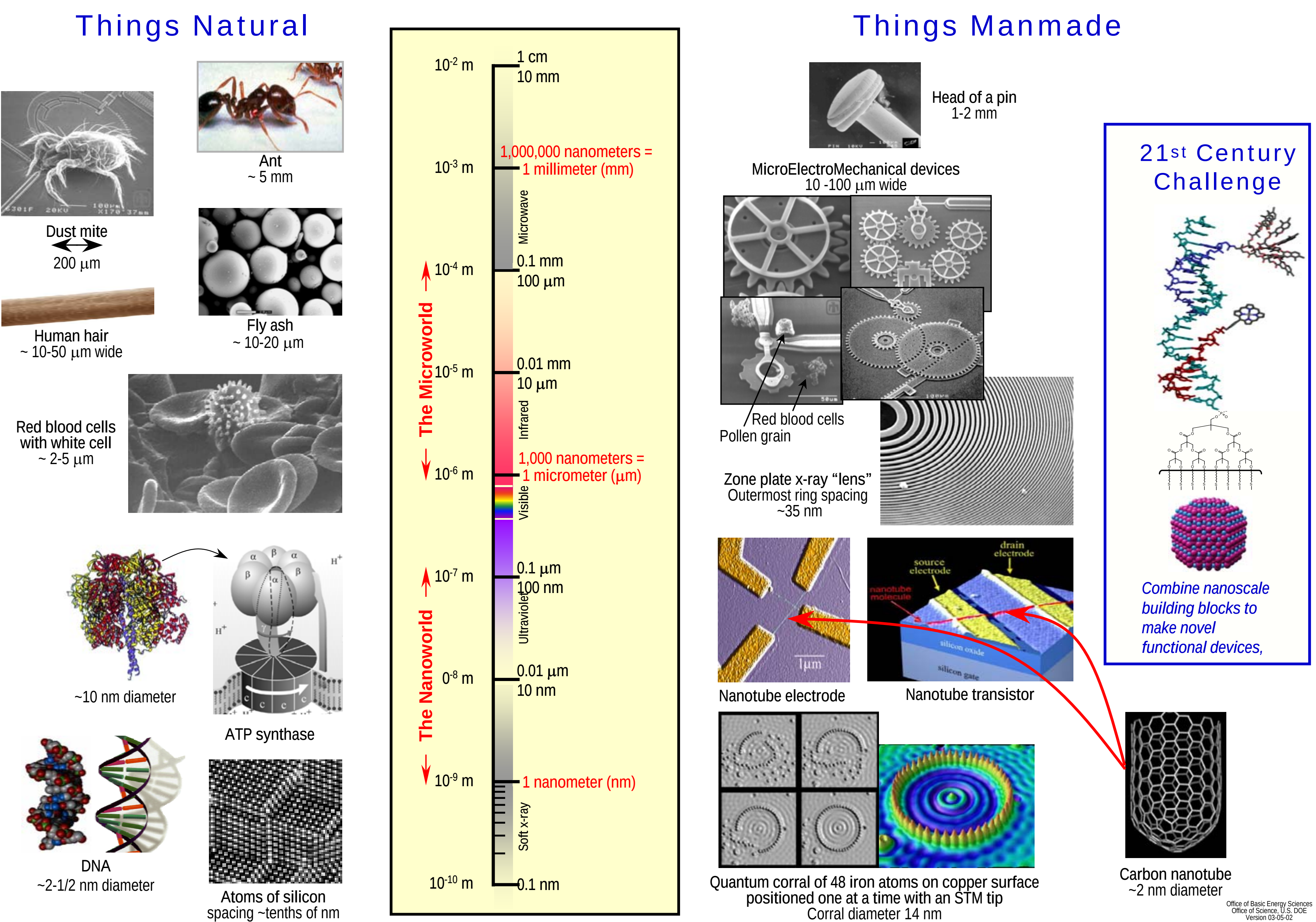


Nanotechnology and the Environment: Applications and Implications

September 15, 2003
Washington, DC

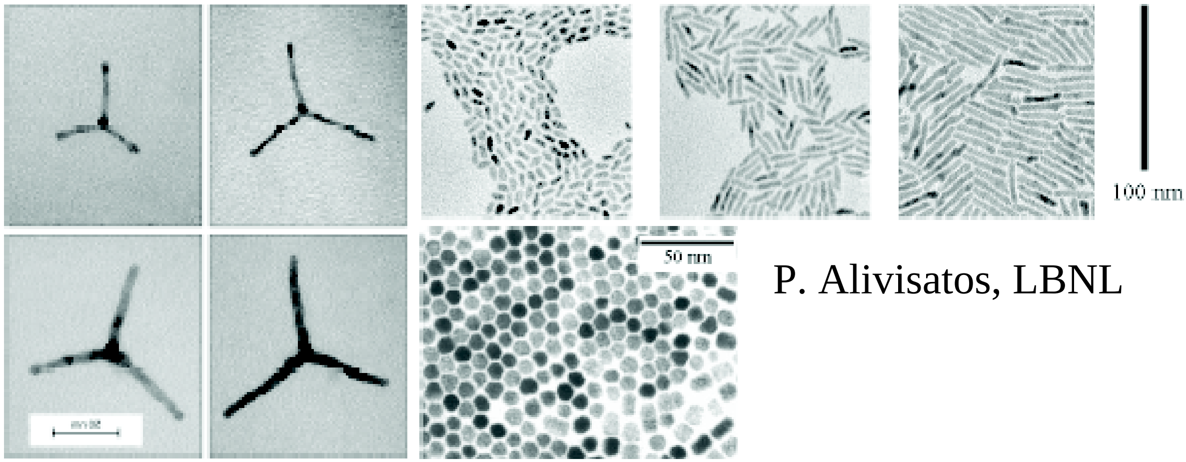
Robert Q. Hwang
Brookhaven National Laboratory

The Scale of Things -- Nanometers and More

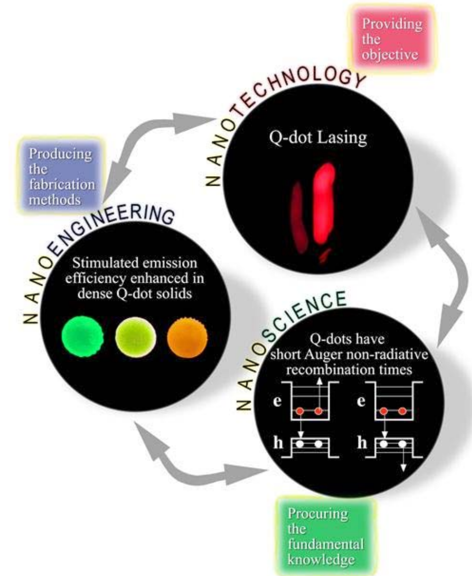


Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 03-05-02

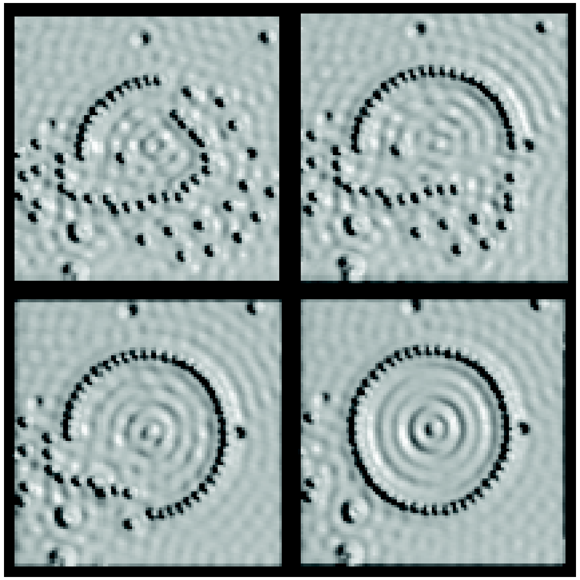
Nanoscale characterization and synthesis



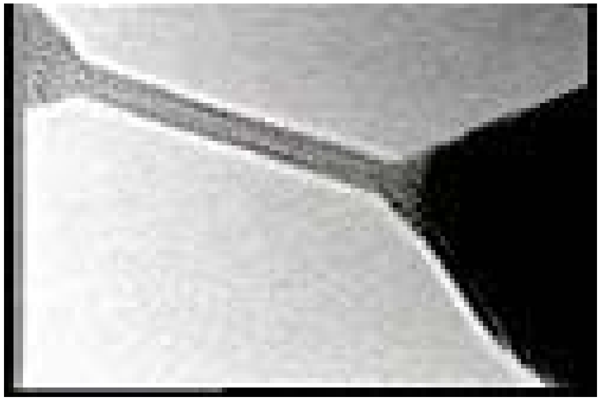
P. Alivisatos, LBNL



V. Klimov, LANL

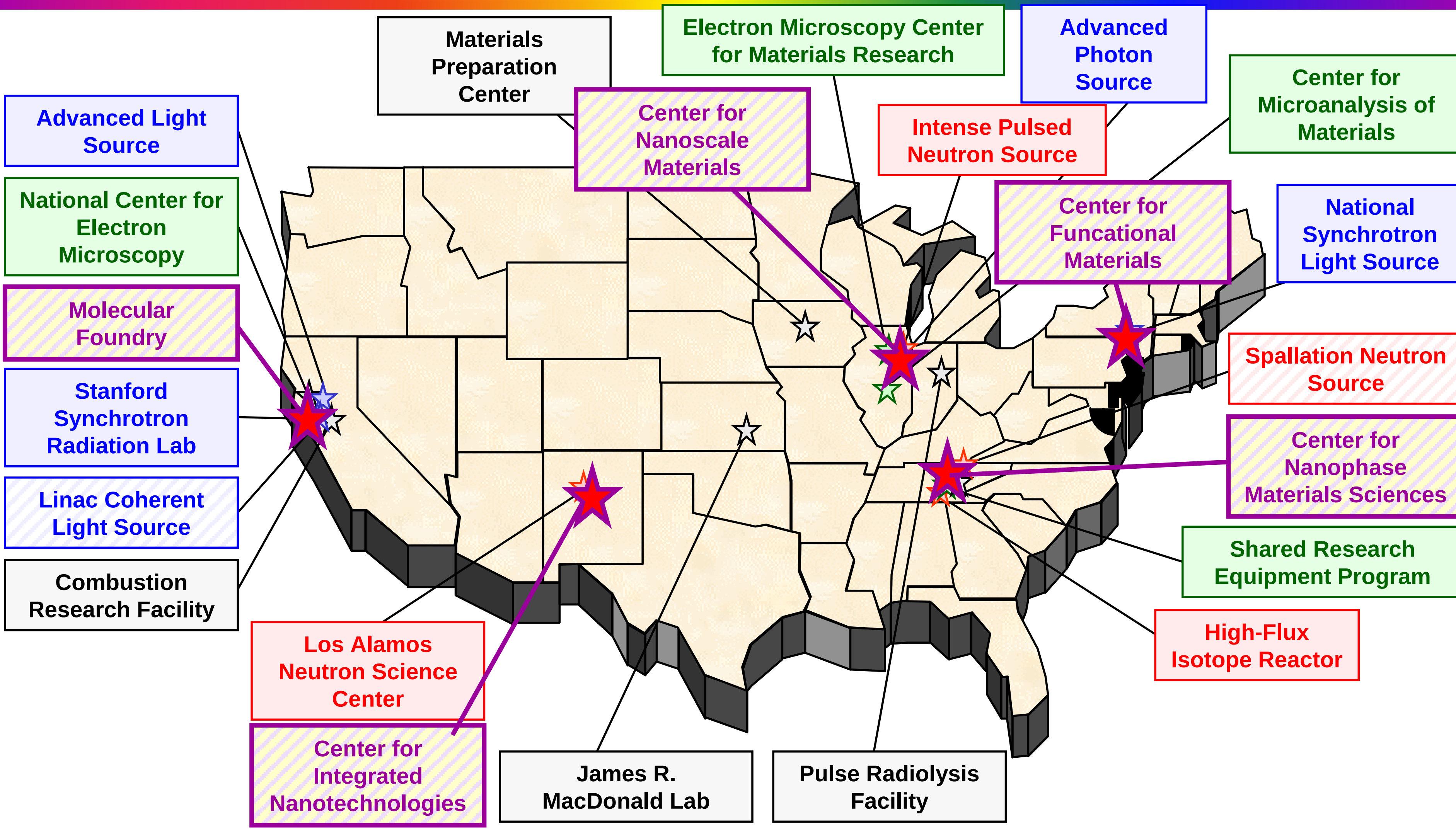


D. Eigler, IBM



K. Takayanagi, Tokyo Inst. Tech.

NSRCs ( ) and the BES User Facilities



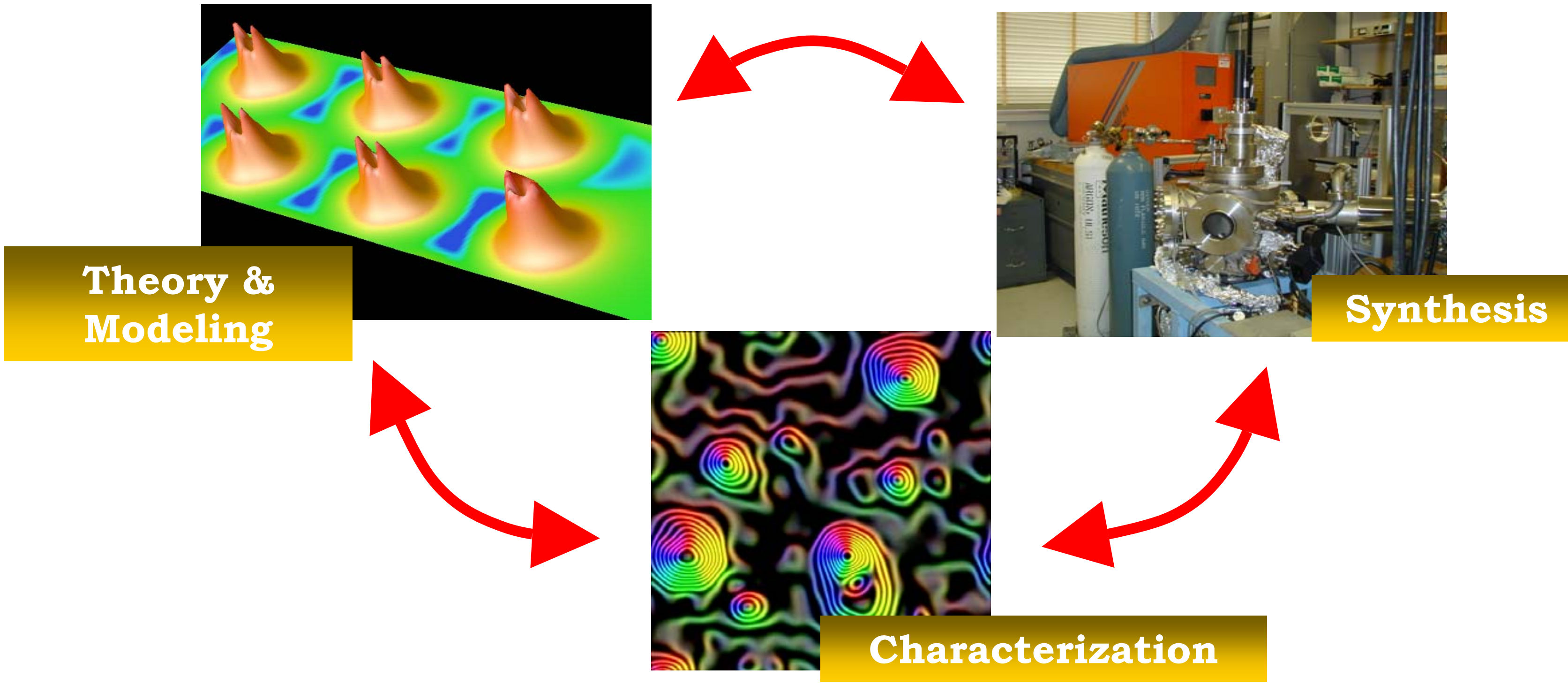
Overview

- **Nanoscale Science Research Centers (NSRCs) supported by Basic Energy Sciences will be user research facilities for the synthesis, processing, and fabrication of nanoscale materials.**

- **They will be co-located with existing user facilities to provide sophisticated characterization and analysis capabilities.**

- **In addition, NSRCs will provide specialized equipment and support staff not readily available to the research community. NSRCs will be operated as user facilities and be available to all researchers. Access will be determined by peer review of proposals.**

NSRC's: Interdisciplinary Arena for Nanoscience Research

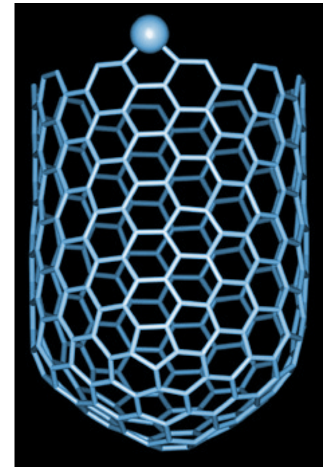


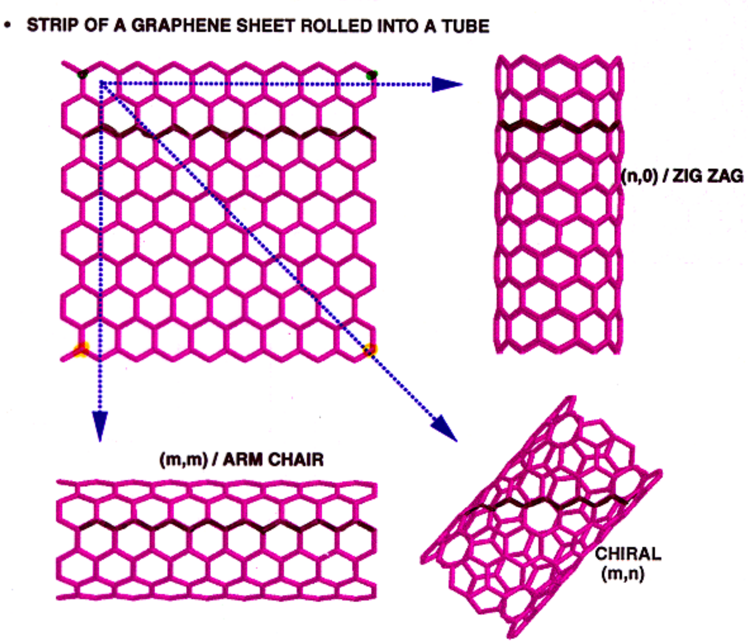
Science - based User Facilities
Scientists & Instrumentation

Carbon Nanotubes

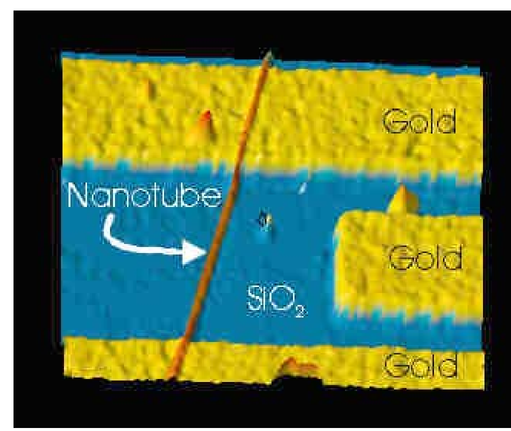
CNT exhibits extraordinary mechanical properties: Young's modulus over 1 Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.

CNT can be metallic or semiconducting depending on chirality.





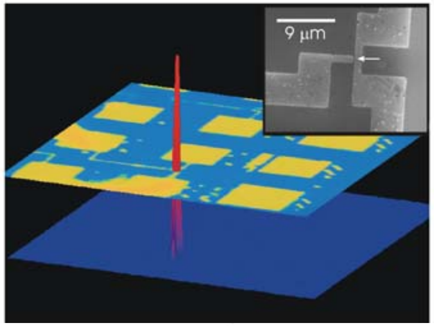
Nanotube FET



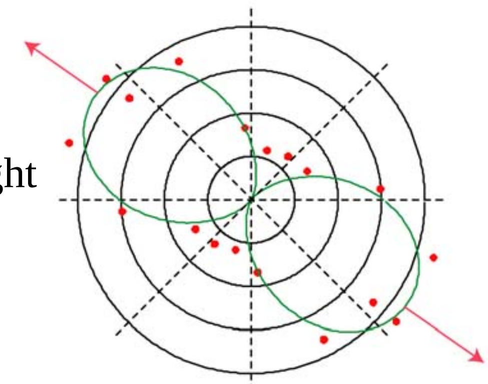
P. Avouris, IBM

Nanotube Photonic

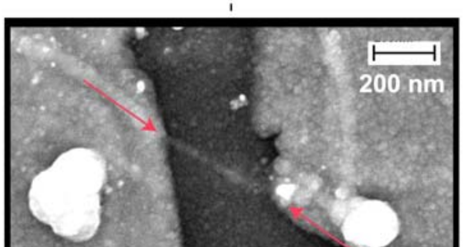
IR Emission

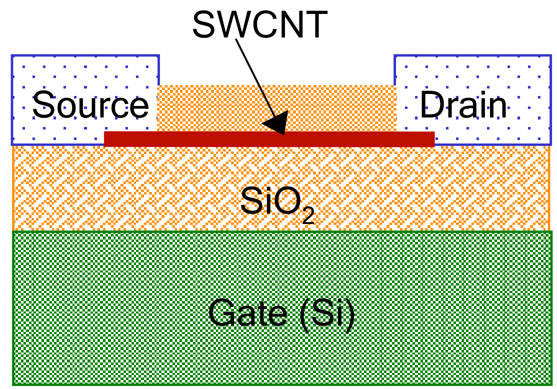


Polarization of light



SEM





Nanotube Devices for Electronic

- Importance of Schottky barrier at contacts in determining performance
- Functionalization of nanotube end caps to modify width of tunneling barrier

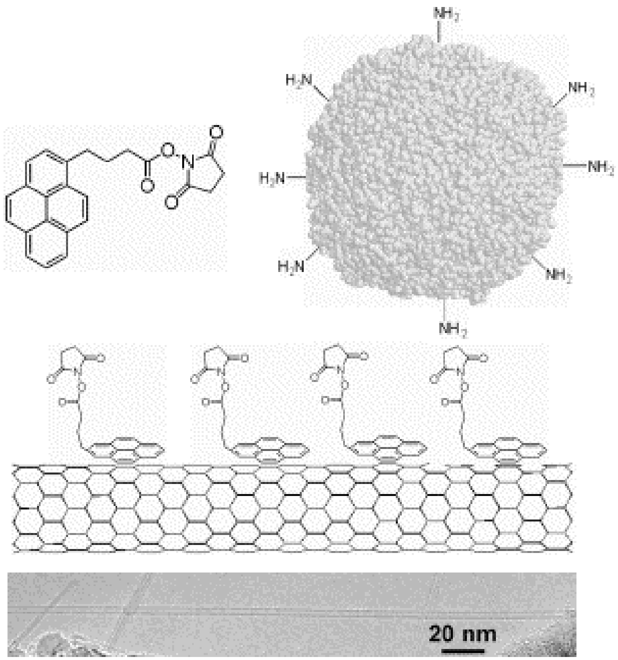
Nanotube Devices for Photonics

- Single molecule electrically pumped optical emission
- Bandgap tuning by controlling synthesis of tube diameter

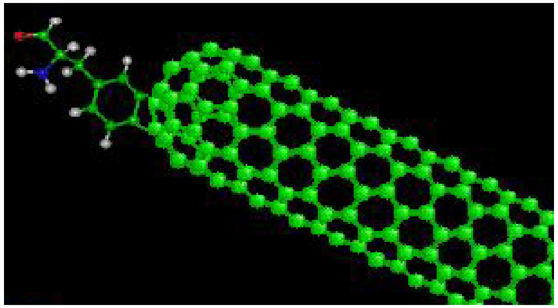
J. Misewich
Brookhaven National Lab/IBM

Funtionalized Nanotubes

Chemical Modifications of Nanotubes for Imaging and Sensing



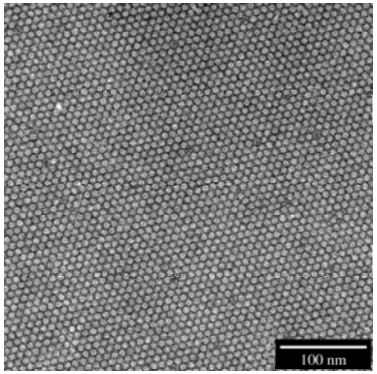
Functionalized Nanotubes for biological molecule immobilization and sensing
H. Dai, Stanford



Stanislaus Wong, Brookhaven National Lab
M. Meyyappan, NASA Ames Research Center

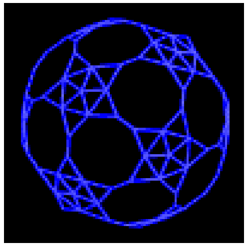
Magnetic Materials

Examples of magnetic nanoassemblies

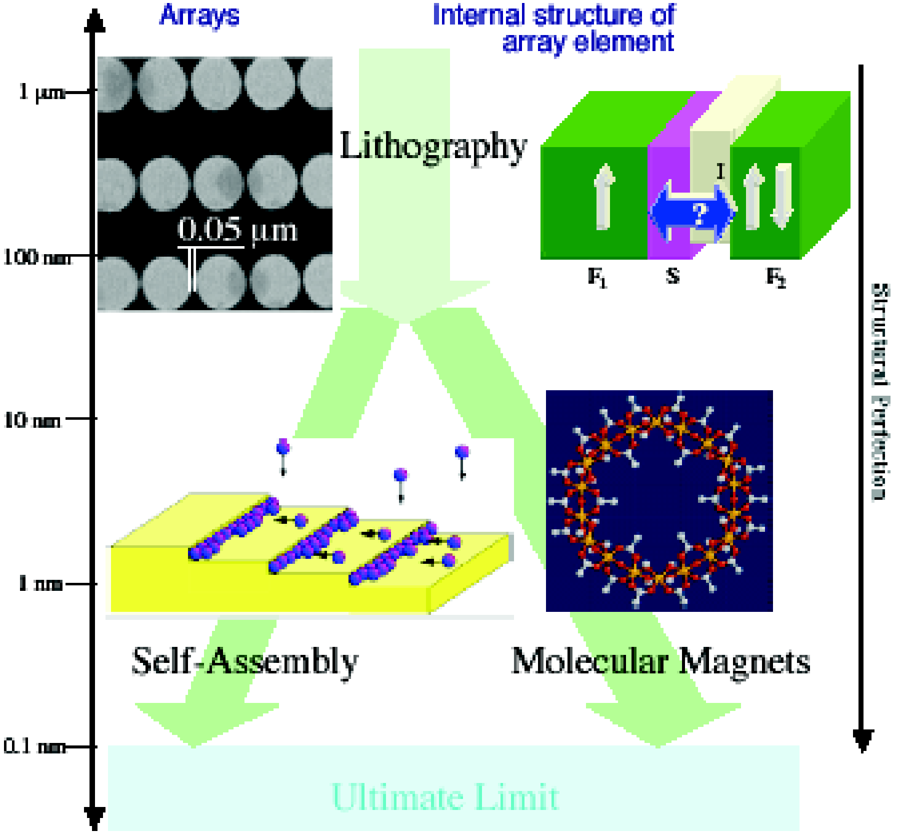


Fe nanoparticle array with hexagonal close packing. (S. M. Majetich, CMU)

Ni/NiO nanodisperse thin film
L. H. Lewis Brookhaven Nat. Lab

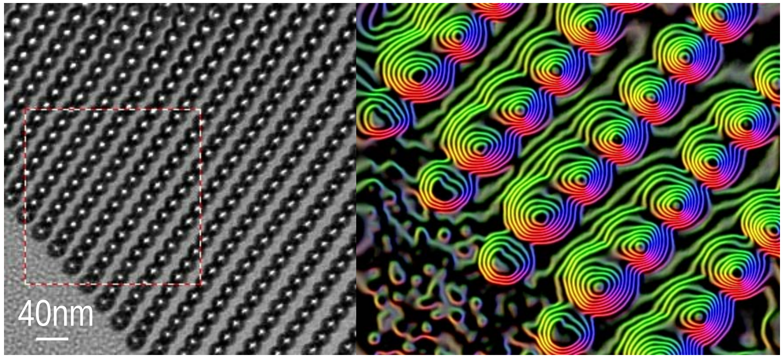


Ferromagnetic polyoxomolybdate (POM) molecules; T. Liu, BNL

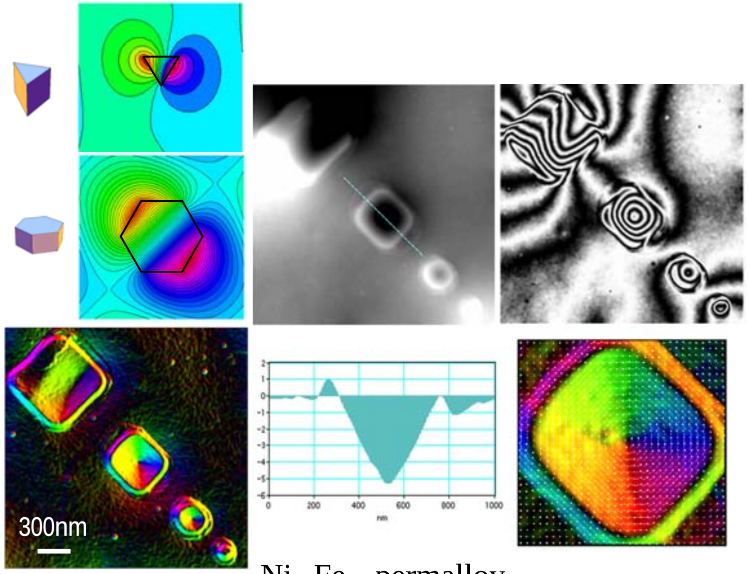


Magnetic Electronics - based on spin state
Sam Bader, Argonne National Lab

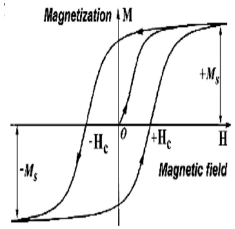
Imaging of imaging of magnetic field of nanoparticles



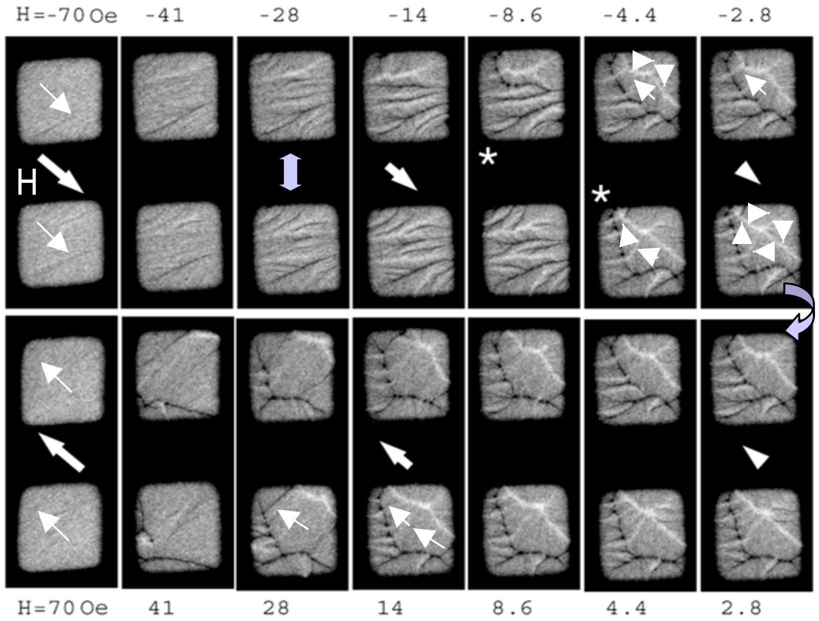
TEM lithography and patterning of Ni-dot array



$Ni_{20}Fe_{80}$ permalloy



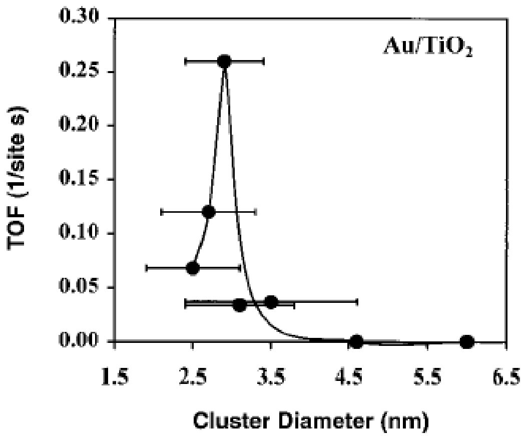
In-situ magnetization of patterned Co-islands



Y. Zhu, Brookhaven National Lab

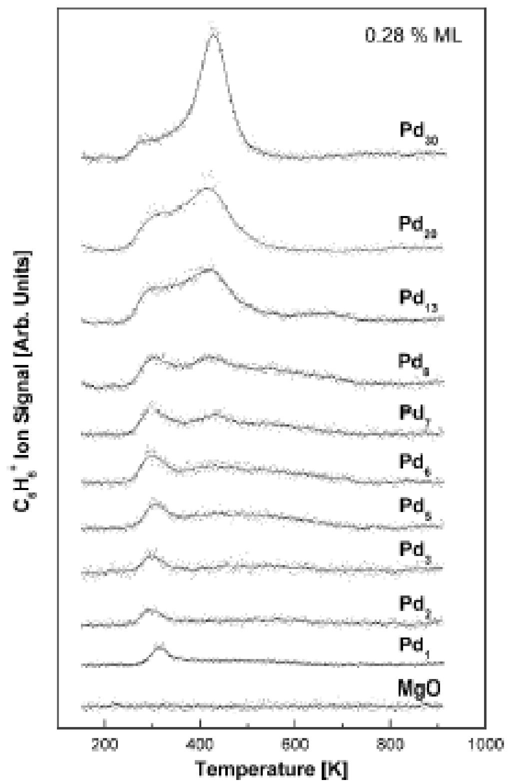
Catalysis of Nanoscale Materials

CO oxidation vs. Au cluster size ($Au/TiO_2(110)$)



Valden, Lai, Goodman, Science 281, 1648 (1998)

Acetylene-to-benzene conversion on Pd clusters Pd/MgO(100)



Sanchez, Heiz, Schneider, Ferrari, Pacchioni, Rosch, JACS, 122 3453 (2000)

TiO_2 particle size photocatalytic effects

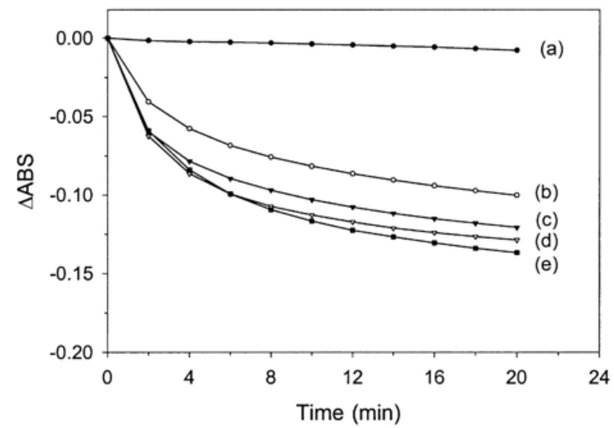
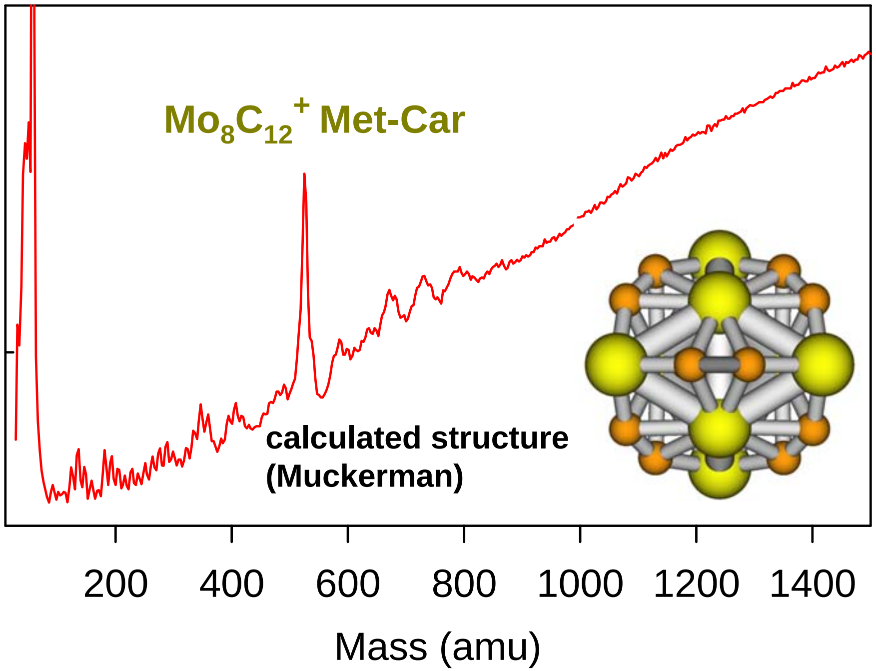
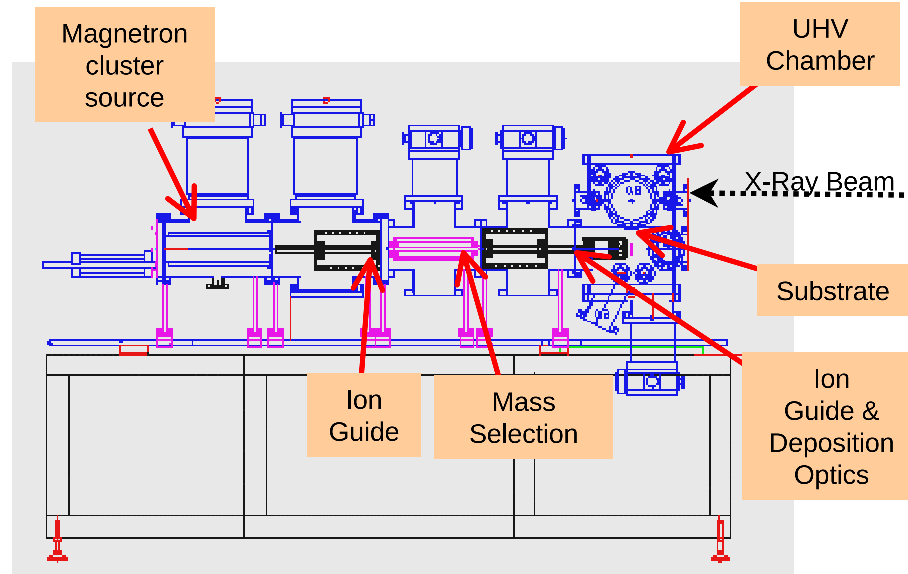


Figure 6. Effect of particle size of TiO_2 nanoparticles on the decomposition of methylene blue ((a): without TiO_2, (b): d_p = 30 nm, (c): d_p = 26 nm, (d): d_p = 23 nm, (e): d_p = 15 nm).

Jang, Kim, Kim, J. Nanopart. Res.3, 141, (2001)

Controlled Nanocluster Fabrication

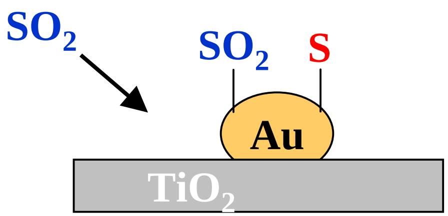




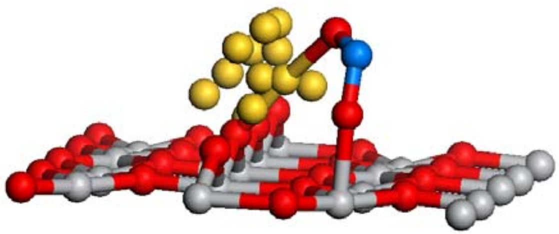
M. White, BNL

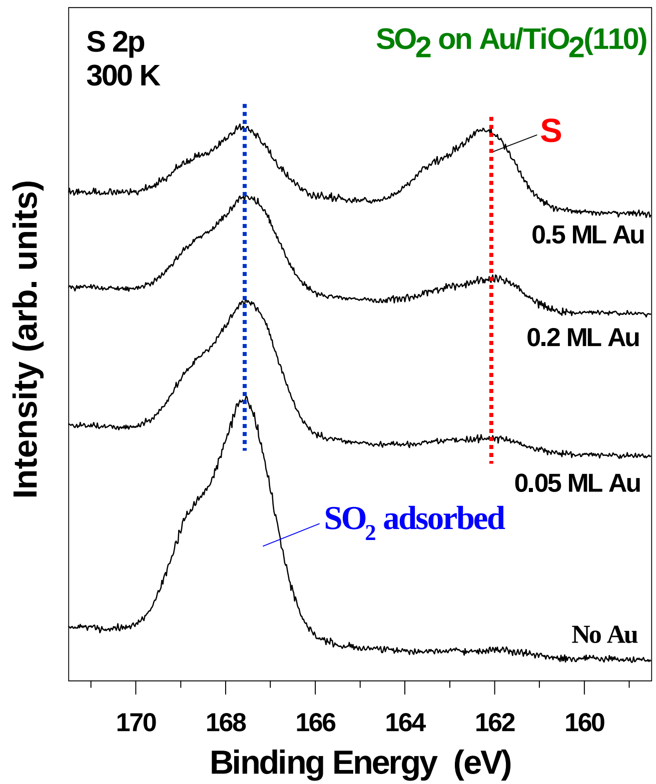
NanoCatalysis Research: 3D Nanoparticles

Supported metal nanoparticles can exhibit reactivity not characteristic of the bulk metal or support



Calculations show that SO_2 binds to both Au particle and TiO_2support





Au particle size

3-5 nm

2-3 nm

> 1 nm

Au nanoparticles supported on TiO_2 are extremely reactive towards SO_2.

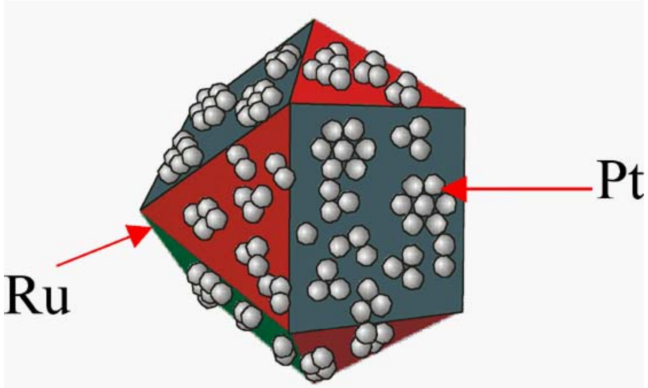
Au/TiO_2 catalyst is 7-10 times more active than commercial catalyst.

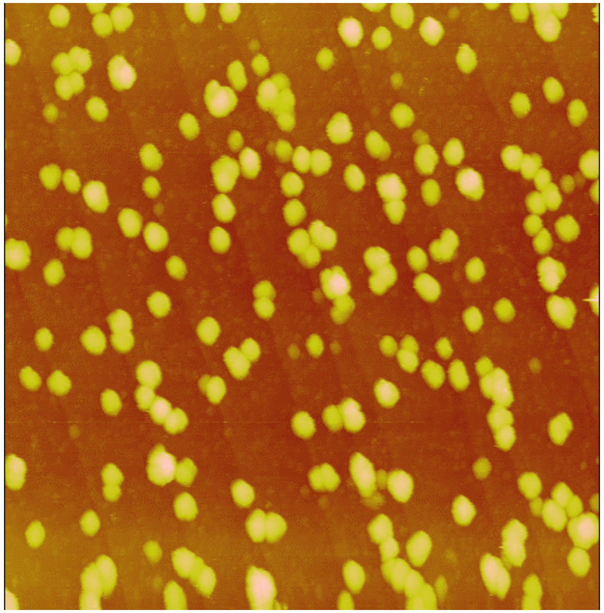
Bulk metallic Au and TiO_2 exhibit a low reactivity for the dissociation of SO_2.

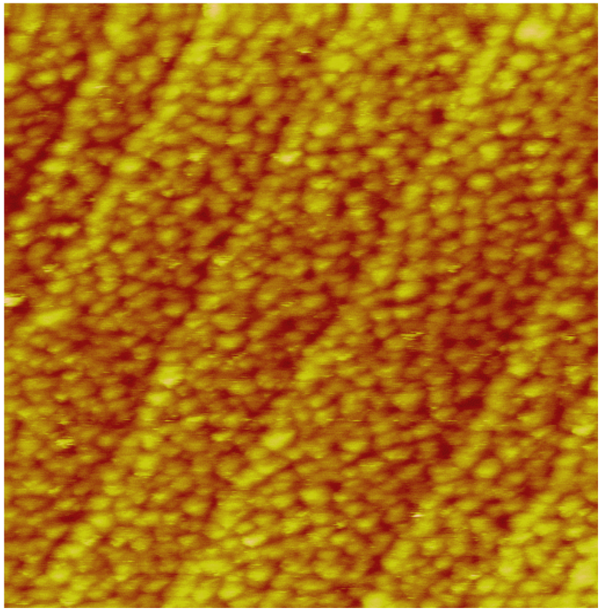
J. Rodriguez, BNL

Pt nanocluster electrocatalysts

- H_2 oxidation and O_2 reduction electrocatalysts Low Pt loading
- Reduced CO poisoning - oxidation of 1000ppm CO/H_2 at 2500 rpm extended from <3 hours to >6 hours good activity after 222 hours
- Loading in anode: 18μg Pt/cm_2 + 180μg Ru/cm_2 (DOE target for 2004: 300 $μg/cm_2$)





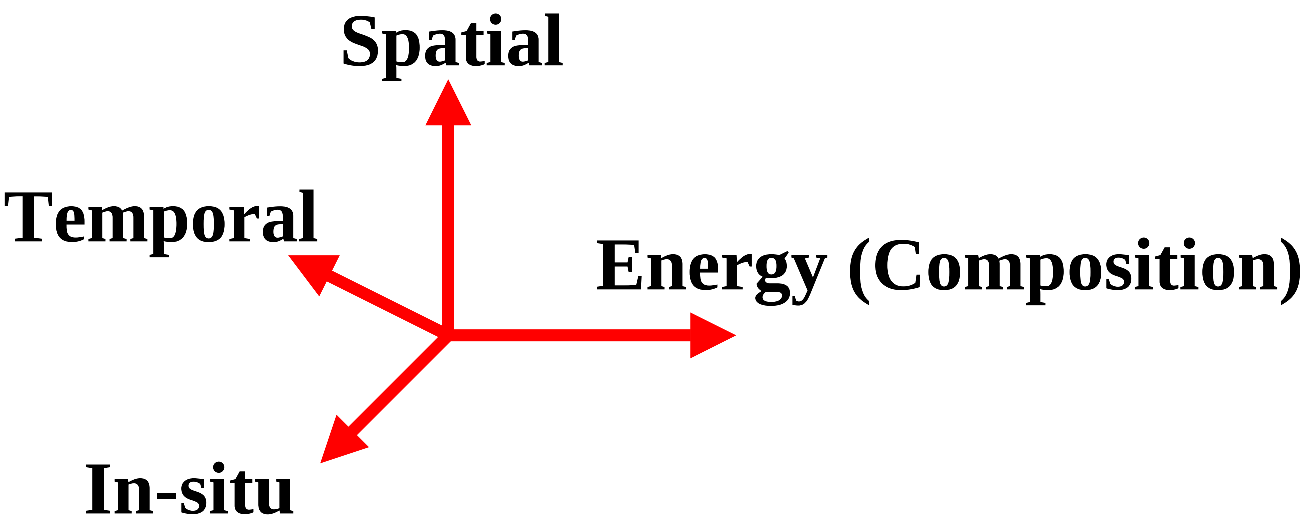


R. Adzic, BNL

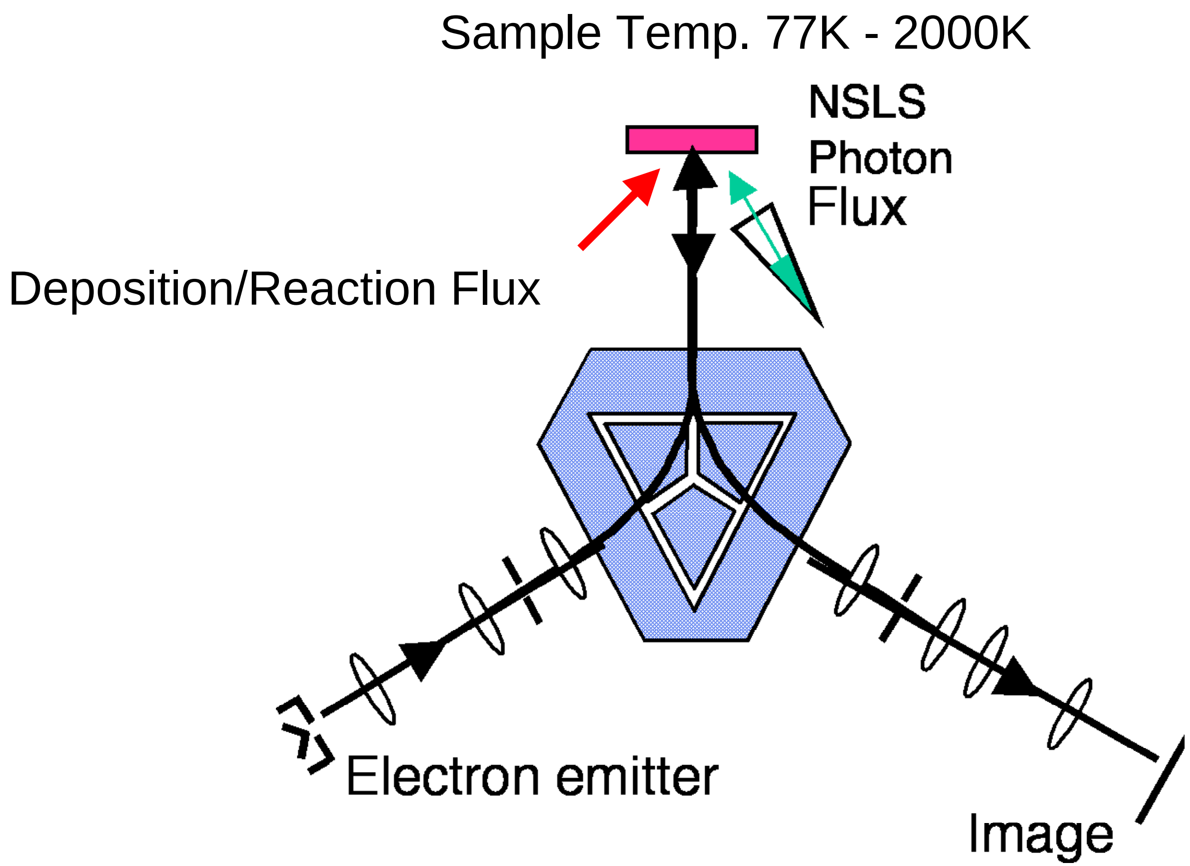
Capability Development

Coupling between structure, composition and chemistry

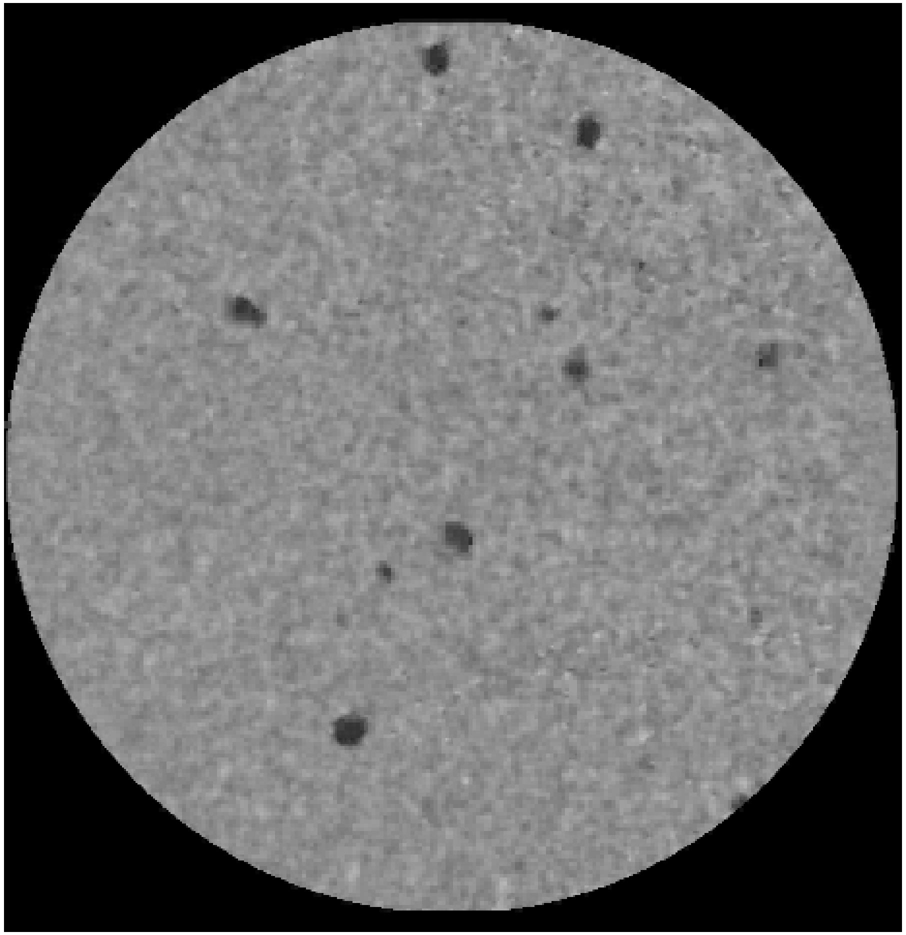
Multi-dimensional Imaging



Low Energy Electron Microscopy



Sn Deposition on Cu(111)

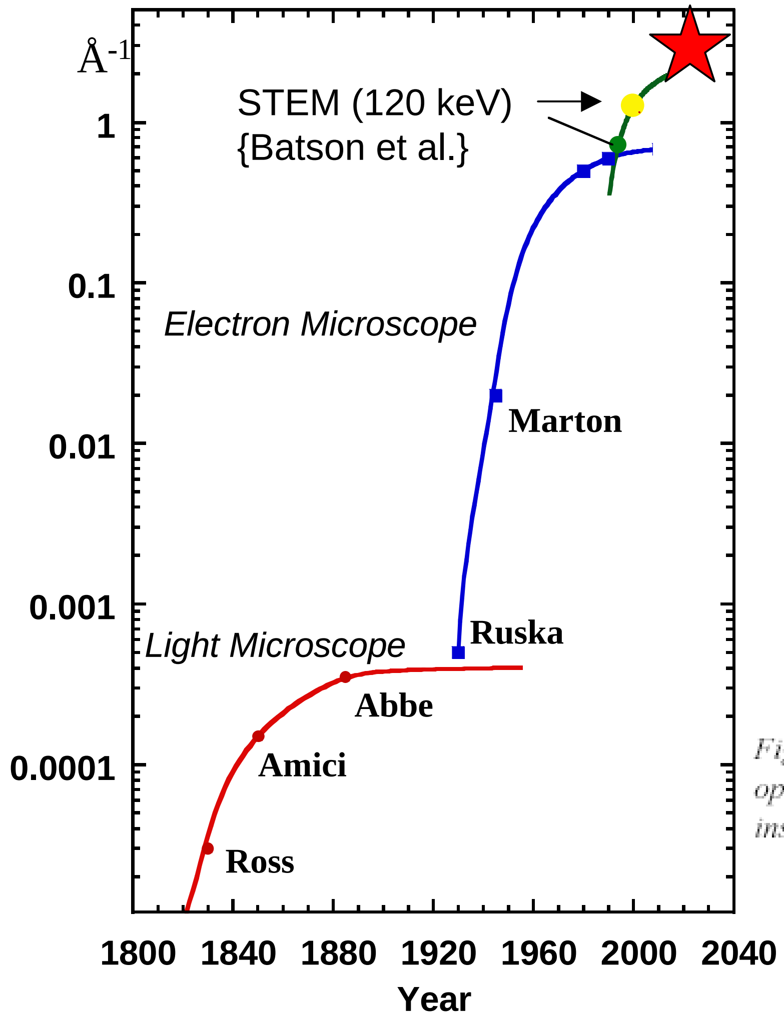


1.5μ field

Science , **290**, 1561-1564, 2000

TEAM - Transmission Electron Aberration-corrected Microscope

- A collaborative development project to design, build, and operate next-generation electron microscopes
- 5 Lab collaboration - LBNL, ANL, BNL, ORNL, FS-MRL
- Definition of a common base instrument platform, with a modular approach to tailoring instruments for specific purposes
- Focus on enabling new, fundamental science via
  - quantitative in-situ microscopy
  - synchrotron spectral resolution at atomic spatial resolution
  - sub-Ångstrom resolution in real time and 3-D



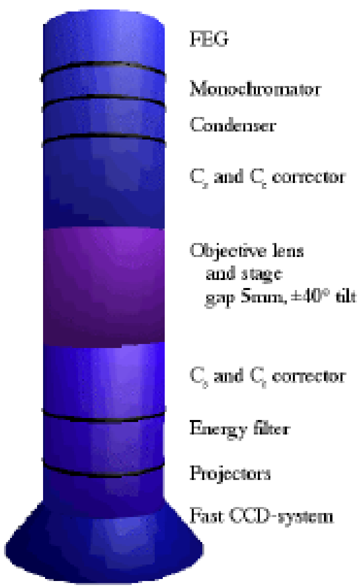
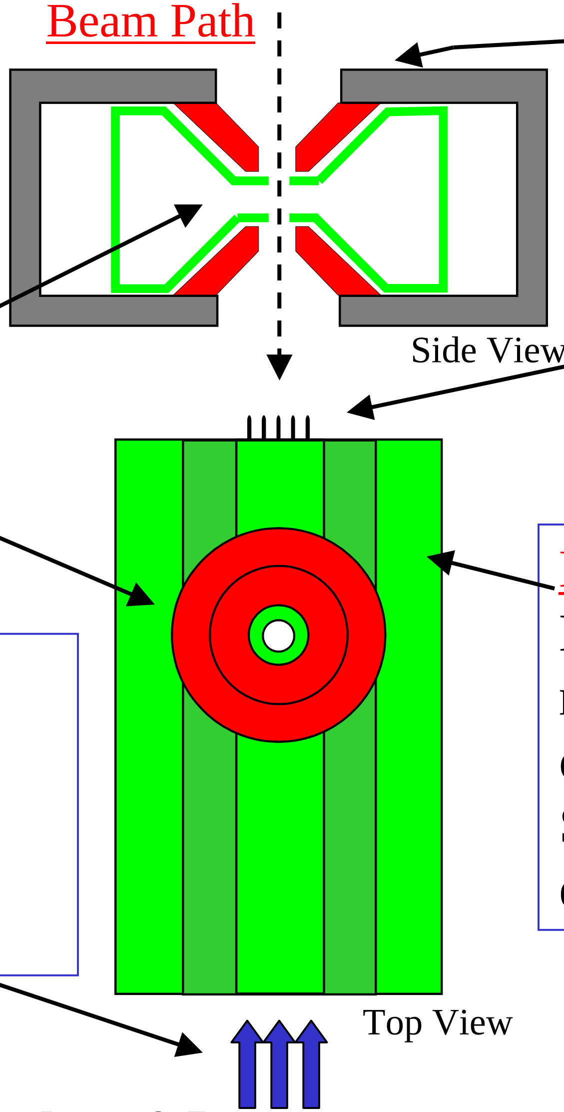


Figure 1 – Schematic of electron optical components in the TEAM instrument.

Modular experimental stations for in-situ work

Beam Path



Shrouding and support:
Designed to Allow Insertion of Experiment Station

High takeoff angle
Line of Sight to Sample for Deposition and Detectors

Objective lens:
- Large gap
- Low C_c

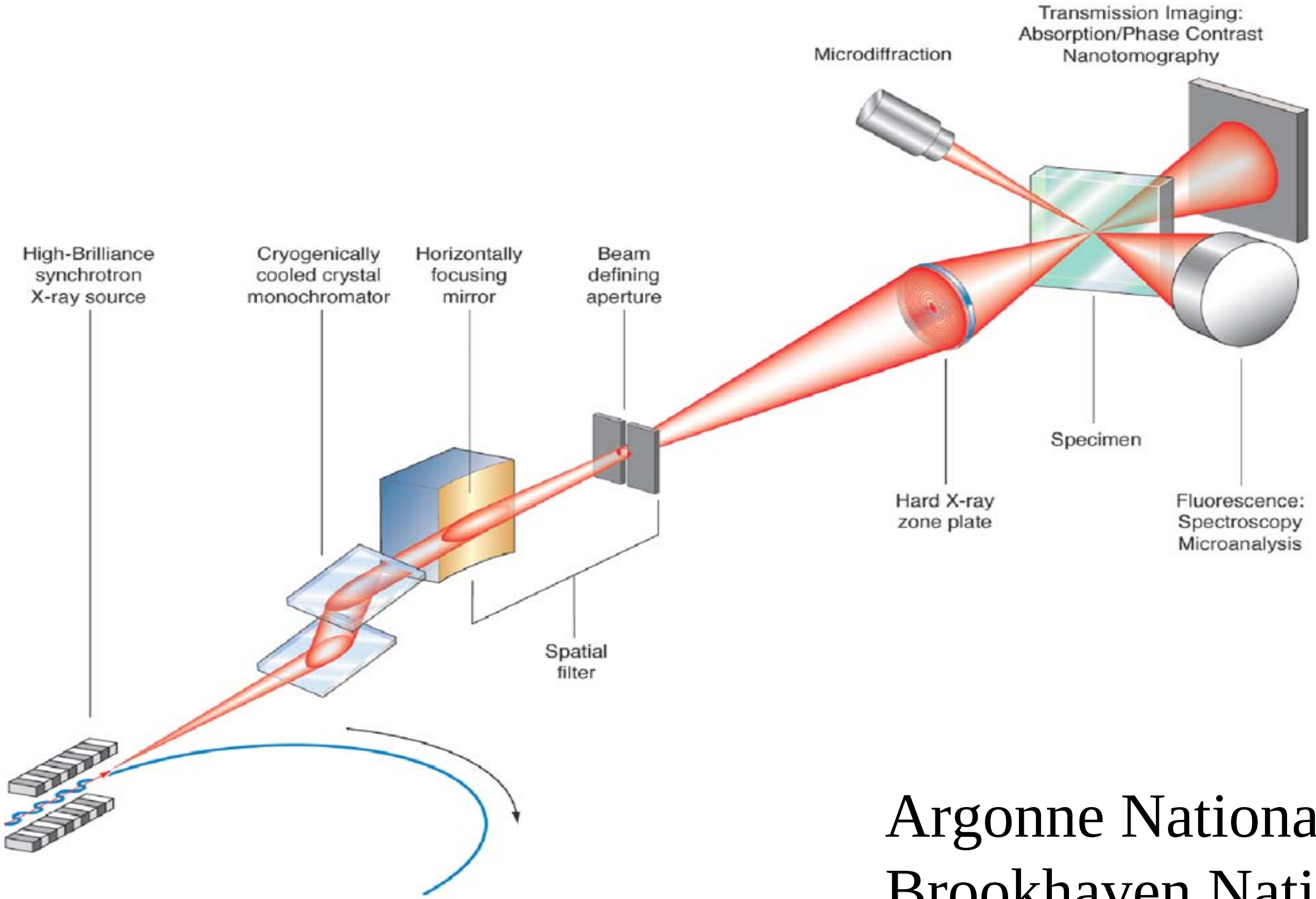
Feed throughs
Provide Electrical and Mechanical Connection

Experimental insert:
Designed for each experiment removable w/o disturbing optics.
Structural support for experiments

Module loading (4” Port)
- Easily inserted
- Stage is integral to module
  (side entry or transfer)

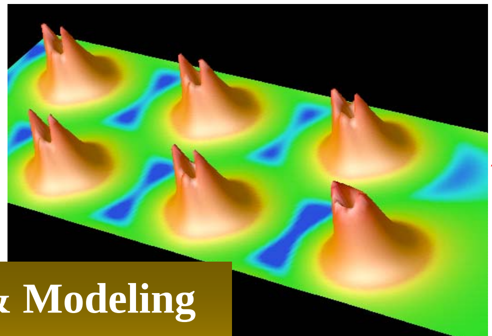
Courtesy Robertson, Twesten, Petrov & Zuo

In-situ Synchrotron Beamlines for nanoscale characterization



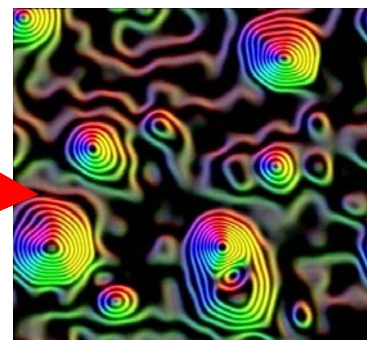
Argonne National Lab
Brookhaven National Lab

NSRC's: Interdisciplinary Arena for Nanoscience Research



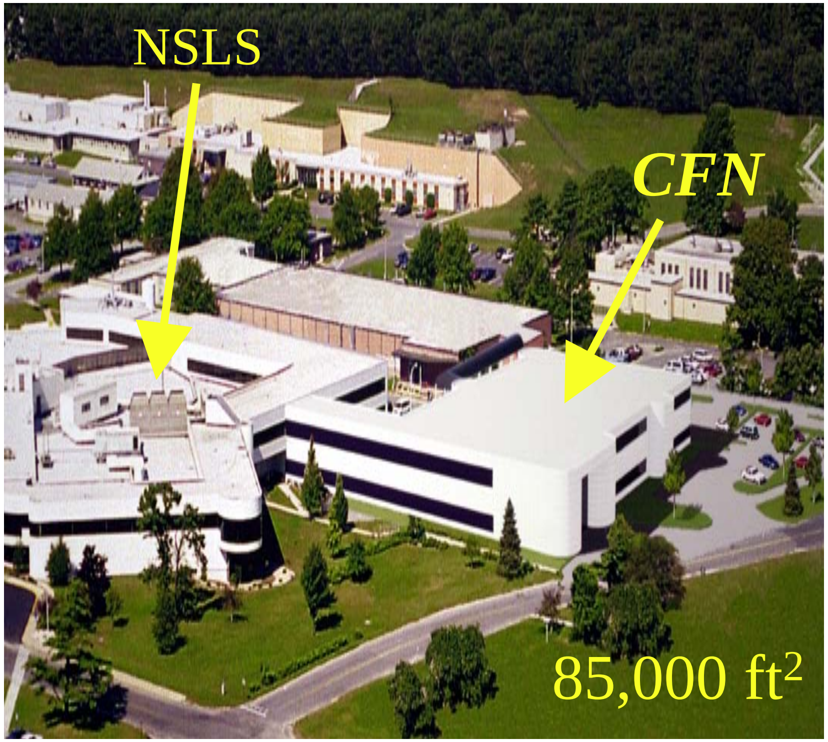
Theory & Modeling
Electronic structure
Dynamics
Kinetics
Multi-scale

Synthesis
Lithography - e-beam, optical, soft
Nanotubes and nanowires
Nanocrystals
Bio-macromolecules



Characterization
Scanning Probes
Electron Microscopies
Synchrotron-based x-ray spectroscopies, imaging and diffraction
Neutron scattering and diffraction

Center for Functional Nanomaterials



$81M - Construction and Cap. Equip.
$18M - Operating

NSLS - Endstations
Sub-micron diffraction, SAXS
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, PEEM, SPLEEM
Theory & Computation
LAPW, Plane Wave Pseudo Potl., Quantum Chem.,
QMC, MD, and SMP computing

Opportunities and Challenges

Understand nanoscale behavior - functionality

Tune and control functionality - materials by design

Synthesis - optimization & environment and health impact

Coupling to macro-environment - Application & devices

Construction start dates of the NSRC's

Summer '03

Center For Nanophase Materials Sciences at ORNL

Spring '05

Center For Functional Nanomaterials at BNL

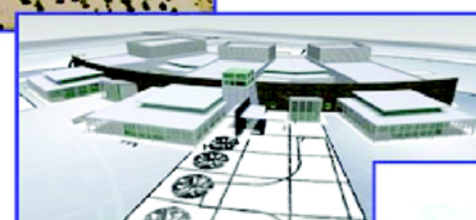
Spring '04

Molecular Foundry at LBNL

Spring '04

Center for Nanoscale Materials at Argonne

Spring '04



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

NSRC Jumpstart User Program

All NSRC’s are now accepting proposals and users

- Center for Functional Nanomaterials at Brookhaven National Laboratory
  - http://www.cfn.bnl.gov/
- Center for Nanophase Materials Sciences at Oak Ridge National Laboratory
  - http://www.cnms.ornl.gov/
- Molecular Foundry at Lawrence Berkeley National Laboratory
  - http://foundry.lbl.gov/
- Center for Integrated Nanotechnologies at Sandia National Laboratories (Albuquerque, NM) and Los Alamos National Laboratory\
  - http://cint.lanl.gov/
- Center for Nanoscale Materials at Argonne National Laboratory
  - http://nano.anl.gov/