Center for Nanophase Materials Sciences

Scientific Vision and Progress Report

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Linda Horton, CNMS Project Director
and Deputy Scientific Director

50th BESAC Meeting
February 23, 2004

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

CNMS Oak Ridge National Laboratory
Center for Nanophase Materials Sciences

UT-BATTELLE

Outline

- **CNMS Timeline, Building, and Status**
- **Scientific Vision, Research Themes, Operational Organization**
- **Unique and State-of-the-Art Capabilities for Nanoscience: *Neutrons, Instruments, Theory/Modeling***
- **“Jump Starting” an Outstanding User Program, and Eventual Scope**
- **The Scientific Management and Advisory Groups Team**

CNMS Oak Ridge National Laboratory

Center for Nanophase Materials Sciences

CNMS TIMELINE

FY03 June 19-20: First SAC meeting

FY03 July 18: CNMS GROUNDBREAKING

FY03 July 22: CALL FOR PROPOSALS for "jump start" user-initiated nanoscience research program

- Use existing ORNL facilities and expertise
- Information distributed by E-mail and Web site

FY03 August: Begin CNMS construction

FY04 February 19: BES Operations Budget Review

FY05 Complete construction: April 05 (cleanroom Jan 05)

FY05 Beneficial Occupancy (CD-4a): April 05
Office/lab furnishings in place; begin moving some "jump start" user research into CNMS building

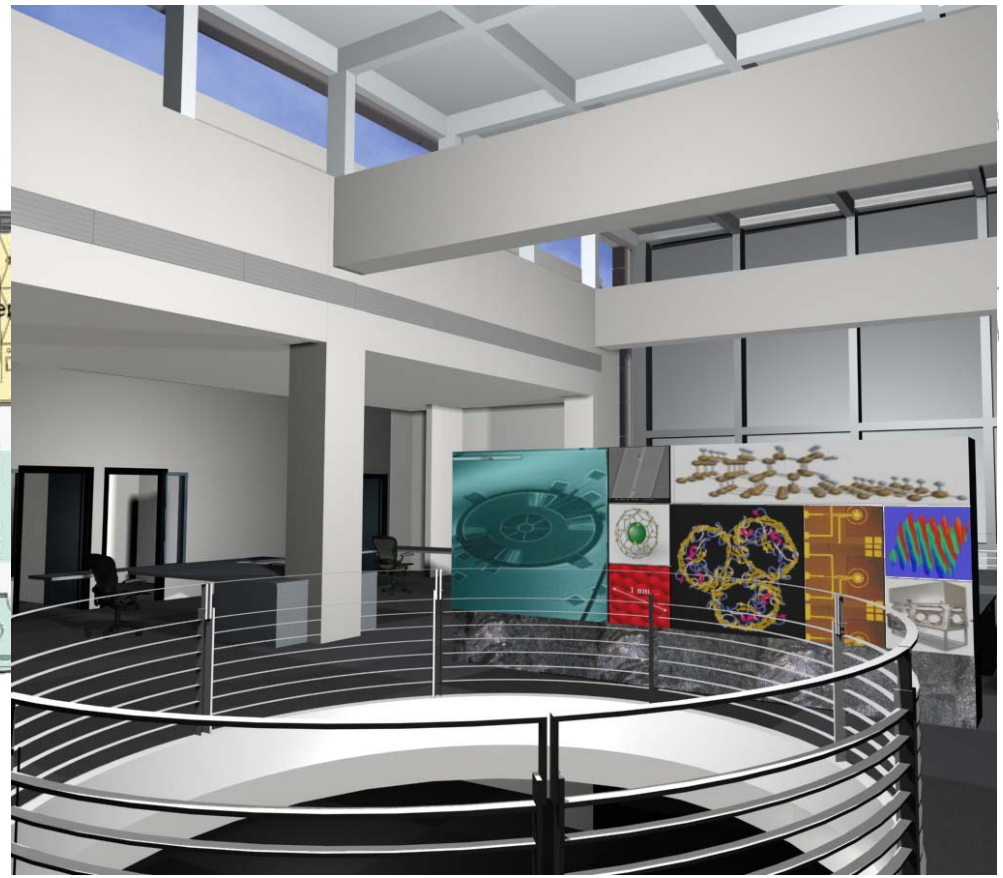
FY06 First full-year operating budget: October 05
User operations in all Scientific Theme areas

FY06 CNMS Project completion: September 06
Initial technical equipment installed & accepted (CD-4b)

Building and Support Facilities

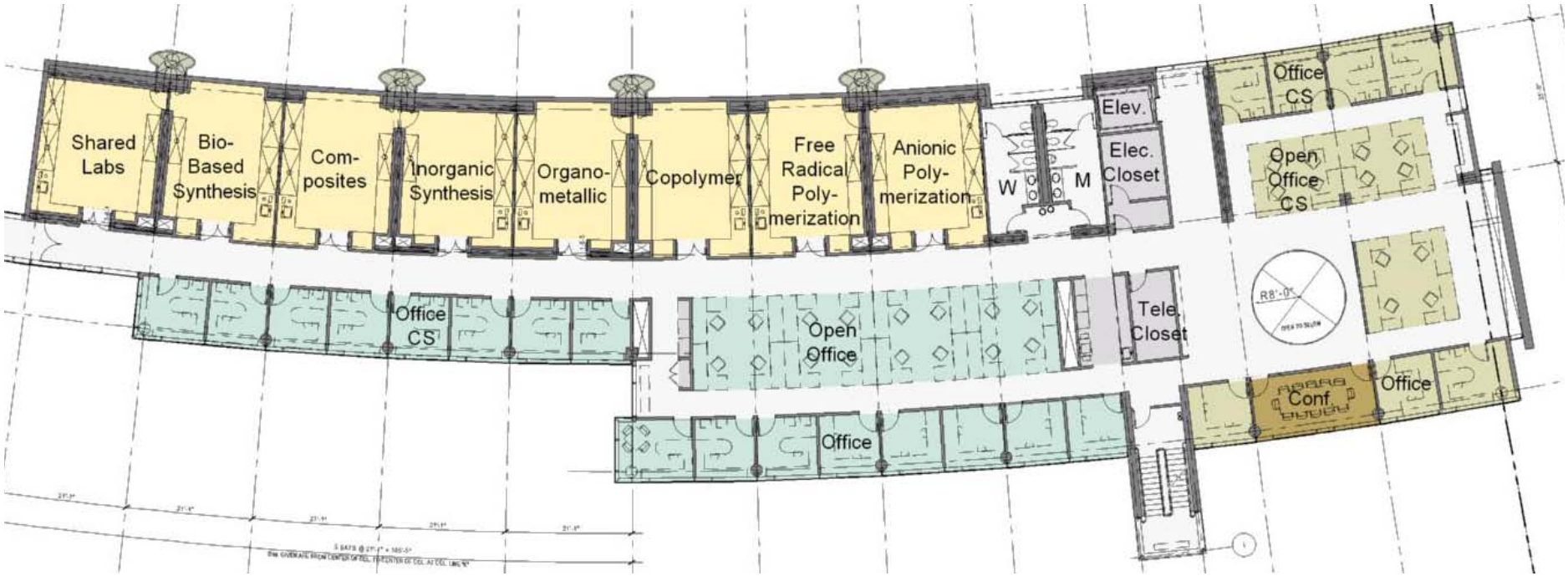
- **80,000 gsf: Four levels + Nanofabrication Research Lab (NRL, ~10,000 sf)**
- **32 "wet" & "dry" synthesis / characterization labs (25' x 20' modules)**
- **Office space for 190 staff and visitors: *Immediately opposite labs to maximize collaborative, multidisciplinary, and educational interactions***
- **Nanomaterials Theory Institute: Offices + lab to access terascale computing facilities of ORNL Center for Computational Sciences (CCS)**
- **CNMS 1st floor (adjacent to NRL): High-resolution scanning probes**
- **NRL: Clean and environmentally controlled rooms; electron microscopes; nanoscale patterning (e-beam writer / lithography); facilities for manipulation and integration of soft & hard materials**

Architecture to Maximize Collaborative, Multidisciplinary and Educational Interactions



Uppermost level (of four) at CNMS

Architecture to Maximize Collaborative, Multidisciplinary and Educational Interactions



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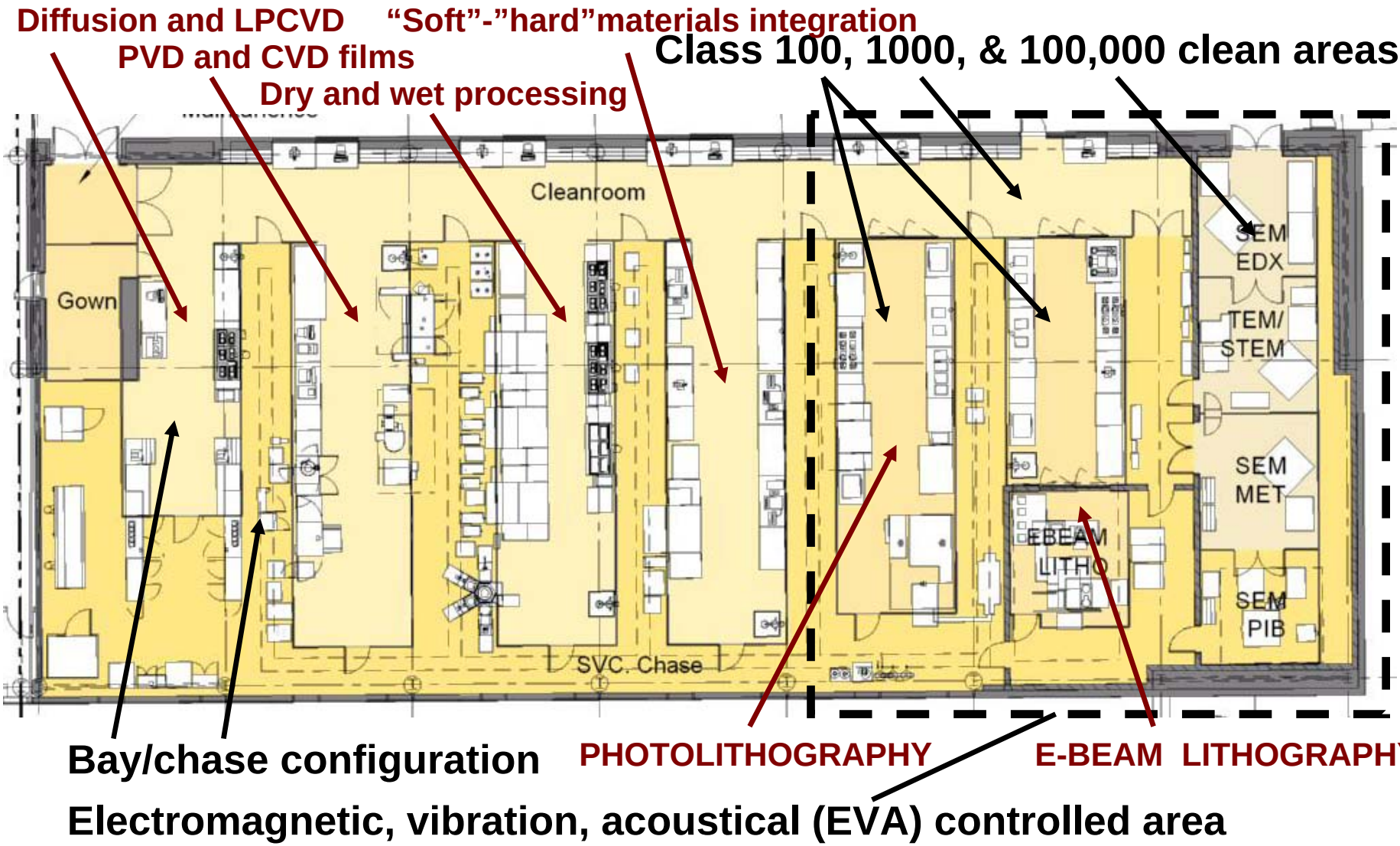
Nanofabrication Research Laboratory



CNMS: September....

CNMS: December....

Steel!!

Rebar cage

"The pit"

CNMS: February....

First elevated concrete slab

CNMS on the SNS Site: Feb 19, 2004

Vision and Plan for OUTSTANDING SCIENCE

Vision and Plan for Outstanding Science

Center for Nanophase Materials Sciences

- **Co-located with the Spallation Neutron Source (SNS) and the Joint Institute for Neutron Sciences (JINS) on ORNL's "new campus"**

- **JINS: Meeting rooms, classrooms, and support facilities for research visitors and students**

- **SNS: Provides access to *unique neutron scattering capabilities for nanoscience***

- **CNMS: Provides urgently needed capabilities for materials *synthesis and characterization*; *nanofabrication*; *theory and modeling*; and nanomaterials *design***

The CNMS Concept:

Exploit scientific synergies

to accelerate discovery in nanoscale science

Our Vision and Plan for the CNMS

Create *an environment* to accelerate discovery and drive technological advances

- Nanoscale science is highly integrative: Bring together
  - the best *ideas* and the best *instruments*
  - a highly *interactive* and *multidisciplinary* user research community
- Developed in partnership with the national scientific community

How Will we Create this Environment?

[1] ***Exploit synergies with two rapidly emerging ORNL strengths, for national scientific leadership***

- **NEUTRON SCATTERING (Spallation Neutron Source)**

  Support development of neutron scattering *techniques and sample environments* needed to understand nanoscale phenomena

- **LEADERSHIP COMPUTING (Center for Computational Sciences)**

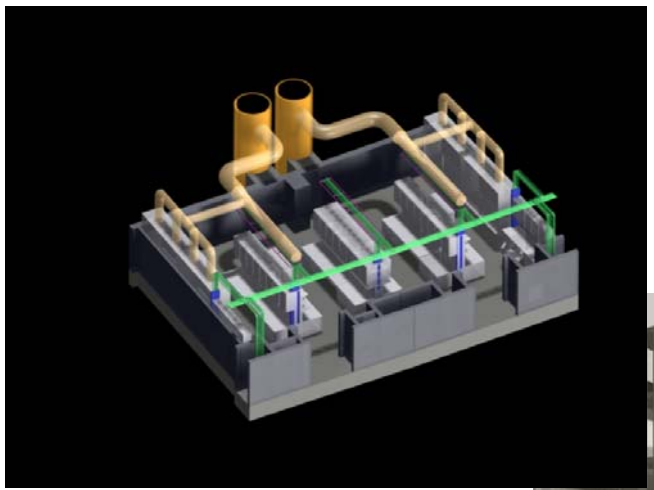
  Address grand challenges of *computational nanoscience* through the CNMS' *Nanomaterials Theory Institute*

[2] ***Address the need for a new generation of nanoscience instruments***

- **COMBINE nanoscale imaging with *simultaneous* sample-characterization and manipulation capabilities**

Operate CNMS to reliably deliver these unique capabilities to the national user community

CNMS supports a FOCUSED research agenda with a HIGH level of demand



Directly Engaging the Scientific Community

2nd CNMS Planning Workshop

Breakout Sessions

Purpose and Results

- **Define Candidate Research Focus Areas and Equipment Needs**
  - **Greatest Challenges to Scientific Understanding**
  - **Greatest Opportunities for New Technololgy**
- **Desired CNMS mode(s) of operation**

Scientific Themes for CNMS

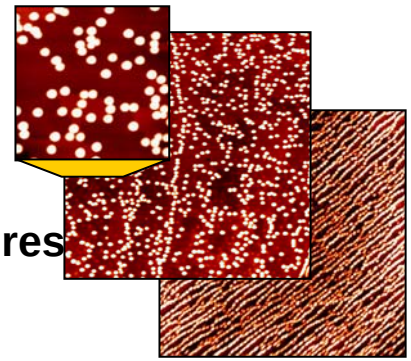
*CNMS' research is organized under **seven related scientific themes**, selected to address **grand challenges to understanding** and **nanotechnology needs***

Macromolecular Complex Systems

Synthetic (polymeric) and bio-inspired materials

Functional Nanomaterials

Nano- tubes, wires, dots, composites; artificial oxide film structures



AFM images of Fe nanodots and nanowires on flat and stepped NaCl surfaces (edge length 750 nanometers)

Nanoscale Magnetism and Transport

Reduced and variable dimensionality; quantum transport

Catalysis and Nano-Building Blocks

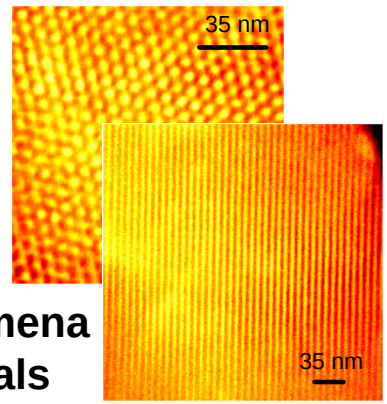
Highly selective catalysts; nanoscale synthesis & organization

Nanomaterials Theory Institute: Theory, Modeling, Simulation

Grand challenges of "computational nanoscience": Multi-scale modeling; nanomaterials design; virtual synthesis

Nanofabrication Research Laboratory

Controlled synthesis & directed assembly; linking nanoscale phenomena to the macroscale; functional integration of "soft" and "hard" materials



Ordered nanoporous silica synthesized using an organic template

Nanoscale Imaging, Characterization, and Manipulation

Unique instruments and methods to characterize and manipulate nanostructures, with simultaneous imaging and environmental control

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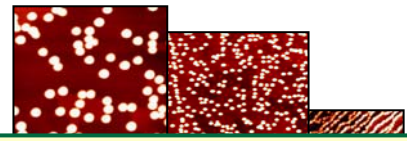

CNMS' 7 Themes are not independent,

but are scientifically and operationally related

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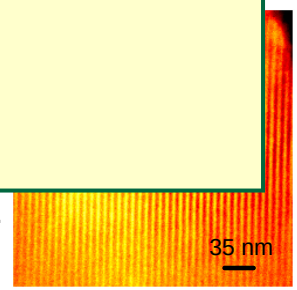
Controlled synthesis & directed assembly; linking nanoscale phenomena to the macroscale; functional integration of "soft" and "hard" materials



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Nanoscale Imaging, Characterization, and Manipulation

Unique instruments and methods to characterize and manipulate nanostructures, with simultaneous imaging and environmental control

UNIQUE and State-of-the-Art Capabilities for Nanoscience

New Research Capabilities: Unique Instruments

TWO CLASSES of INSTRUMENTS for NSRCs

- ***Critical*** **to support the scientific research agenda, often expensive, but** ***not unique***
  - **NANOSCALE: HR-SEM, E-beam writer, nanomaterials synthesis, …**
  - **Can be purchased, together with maintenance contract**

- ***Truly unique*****, offering** ***new research capabilities***
  - **Currently** ***unavailable*** **to national community (new, complex, only "β-users")**
  - **CRITICAL to ADVANCE NANOSCIENCE:** ***Simultaneous***
    - **Imaging, combined with**
    - **Properties measurements**
    - **Sample manipulation, e.g. deposition, ……**
    - **Assembly**
    - **Environmental control**
  - **Critical to** ***attract forefront user nanoscience*** **and** ***scientists***

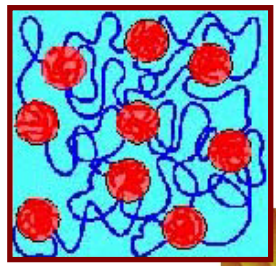
Recommendations from the SAC

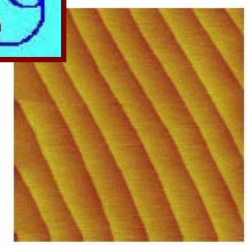
- **Recommend**: **Begin immediately to highlight and develop new *capabilities that will be world-class*. These are *the most significant draw for new users* and help stimulate new research opportunities.**

- **Recommend**: **The external community represents a significant force driving development of new facilities or enhancing capabilities at many other national user facilities. *Every effort should be made to engage external users* in the development of new capabilities.**

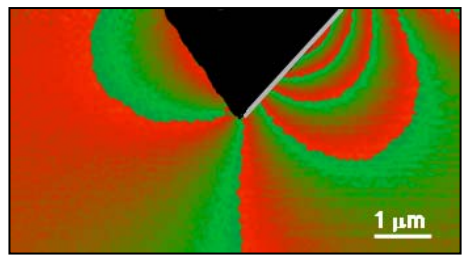
Nanoscale Imaging, Characterization and Manipulation

New techniques and instruments for imaging, characterization and manipulation of soft and hard materials, with environmental control





- **Neutron and X-ray Scattering**
  - Specialized scattering techniques and environments for nanoscience
- **UHV Scanning Probes**
  - UHV scanning probe microscopies for magnetic and quantum transport properties in nanostructured materials
- **Electron Microscopy and Spectroscopy**
  - Combine imaging with characterization and/or manipulation methods
  - Special sample environments (soft materials); in situ spectroscopy; integrated use of ambient scanning probes



Provide technicians, staff, and budget to make UNIQUE instruments RELIABLY available to the national user community

Vision for Outstanding Science

Neutron Techniques are Exquisitely Suited for Soft Materials

- **Nanoscale Challenges to Synthesis and Understanding**
  - Control of self-assembly and nanoscale structure
  - Understanding how morphology, symmetry, structure, and phase behavior relate to function
  - New approaches for rational design and fabrication of soft and hybrid materials
- **Neutron scattering opportunities**
  - **SANS** for nm-scale shape, location, and evolution
  - **Reflectometry** for molecular-scale structure near surfaces and materials interfaces
  - **H/D contrast** for component-by-component imaging on all nanometer length scales
    - > Dilute and concentrated systems
    - > "Fillers" to control block copolymer properties
    - > Proteins within complexes ("Machines of Life")
    - > Selective migration of components to surfaces
    - > Interdiffusion in solutions
    - > Atomic-level details for MD simulations

See: John Ankner and Hartmut Zabel, "Applications of Neutron Reflectivity Measurements to Nanoscience"

Vision for Outstanding Science

Unique and State-of-the-Art Measurement Capabilities for CNMS

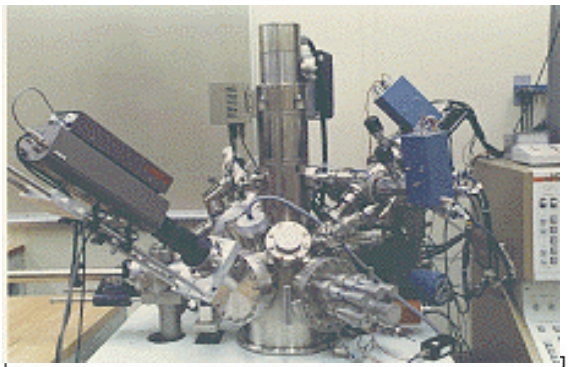
Atomically-Resolved Imaging, Manipulation and Spectroscopy

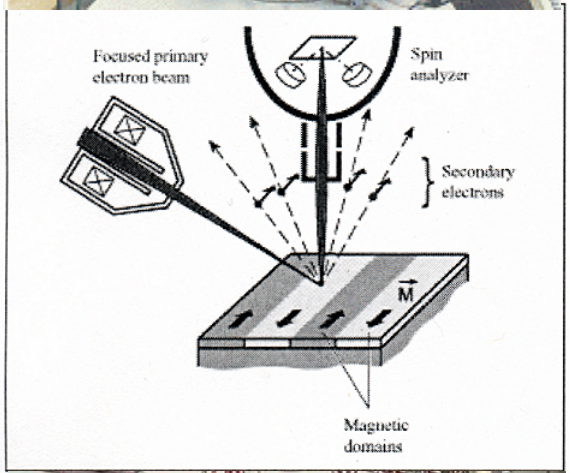
- **In-Field SEMPA (SEM with polarized analysis of current)**
- **Low-Temperature, High-Field STM (the "Ultimate STM")**
- **Four-Point-Probe STM**
- **Scanning Nano-SQUID**
- **Suite of Scanning Probe Laboratories (CNMS ground floor)**

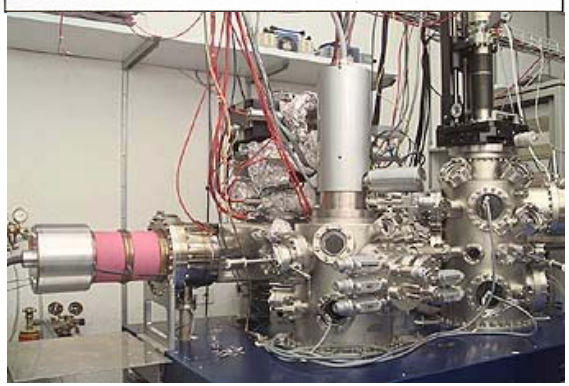
In Situ Diagnostics of Nanomaterials Synthesis

- **Spectroscopic Diagnostics Facility for Nanomaterials & Film Growth**
- **Continuous Compositional Spread (rapid nano-catalyst evaluation)**

High–Resolution Scanning Electron Microscope for (Spin)-Polarized Analysis (SEMPA)





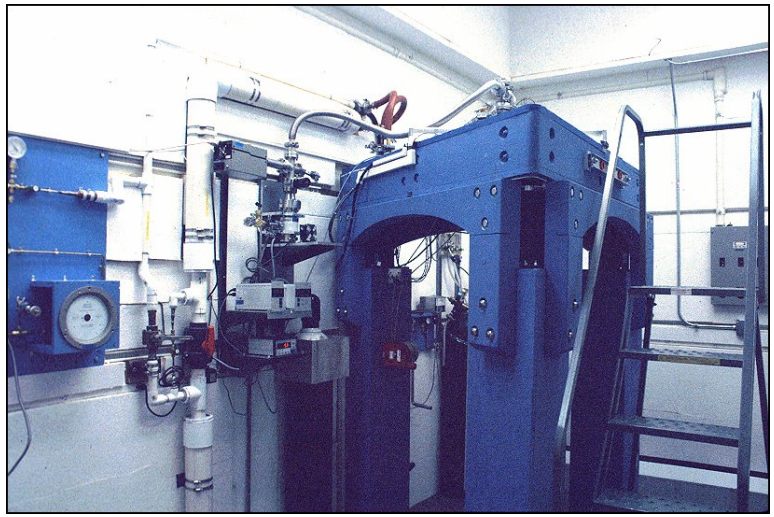


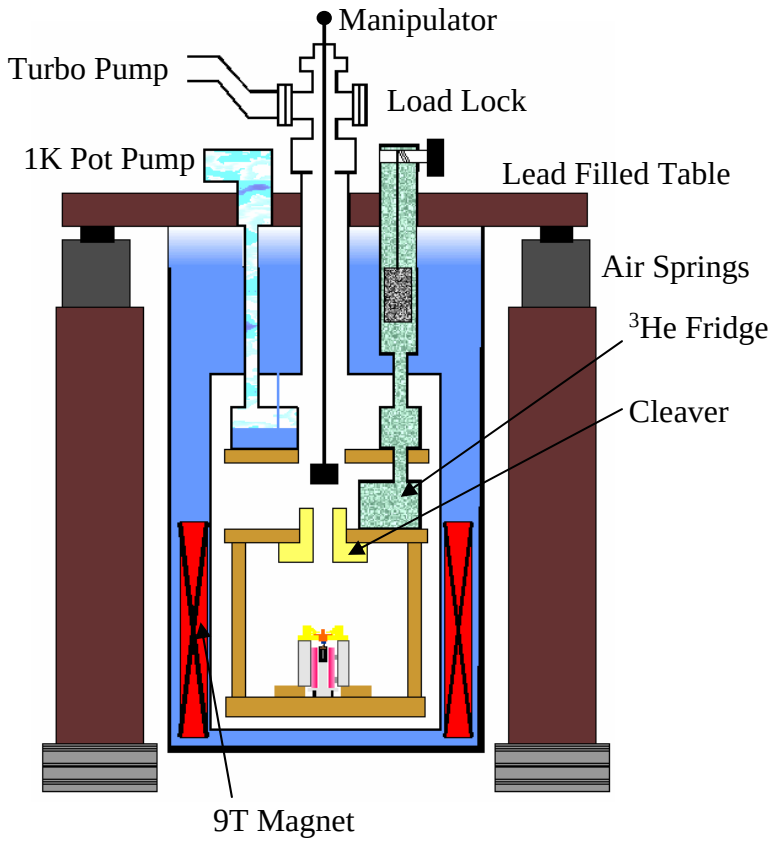
- **Scientific Drivers**
  - **Direct high-resolution (nanometer-scale) imaging of magnetic domain structure**
  - **Investigation of spin-switching and spin dynamics under magnetic field**
  - **Correlation between chemical and magnetic inhomogenieties with SAM and SEMPA**
  - **Elemental analysis of nanostructures via scanning Auger microscopy**
  - **Areas Impacted: Nanoscale magnetism**
    Complex oxides
- **Proposed Capabilities**
  - **UHV sample environment and sample preparation system; T = 50 K → 1000 K**
  - **True UHV electron column with 15-nm spatial resolution**
  - **Spin detector based on the spin-polarized LEED detector**
  - **Operates with in-plane magnetic field of 300 mT (to be improved to 800 mT)**

The "Ultimate STM"

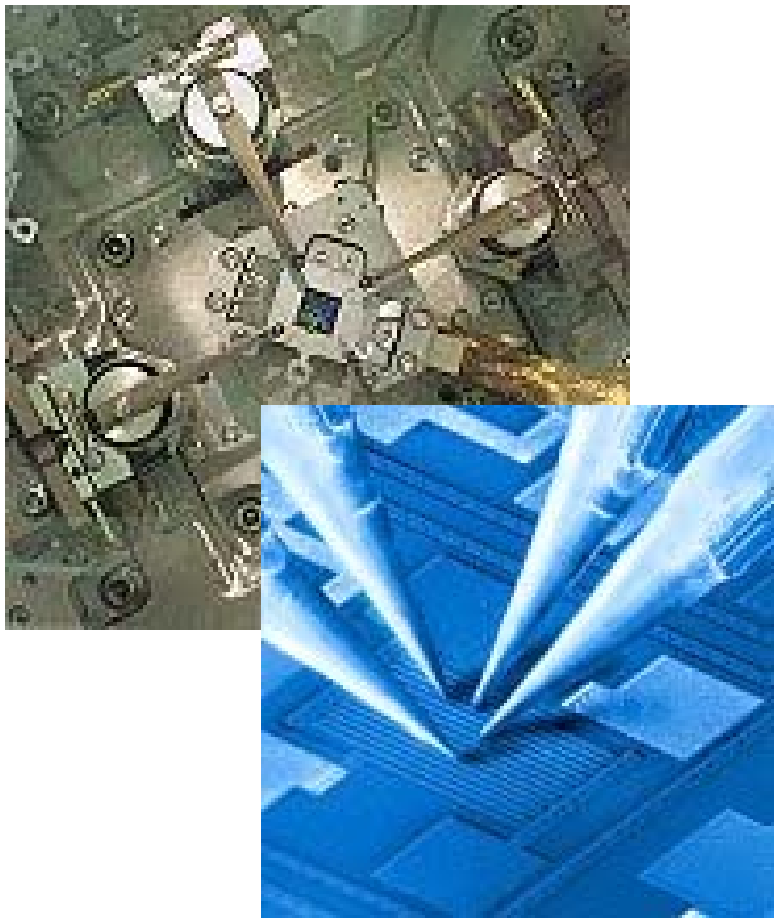
- Single-atom or -molecule spectroscopy
- Atomically-resolved spectroscopy maps
  (Requires vertical resolution of <0.0001 nm, ~100X better than commercial instruments.)
- k-space mapping of electronic structure
- The temperature and magnetic field range to study the quantum response of nano-objects
- Optical access to the sample in magnetic field, for probing and exciting atoms or molecules
- Sample rotation (STM) in the magnetic field
- Flexibility to convert this STM to a magnetic scanning microscope with atomic resolution

- 300mK < T < 150K
- B_{max} ~ 9.0 Tesla
- Sample exchange from RT
- Cryogenic UHV Sample Cleavage



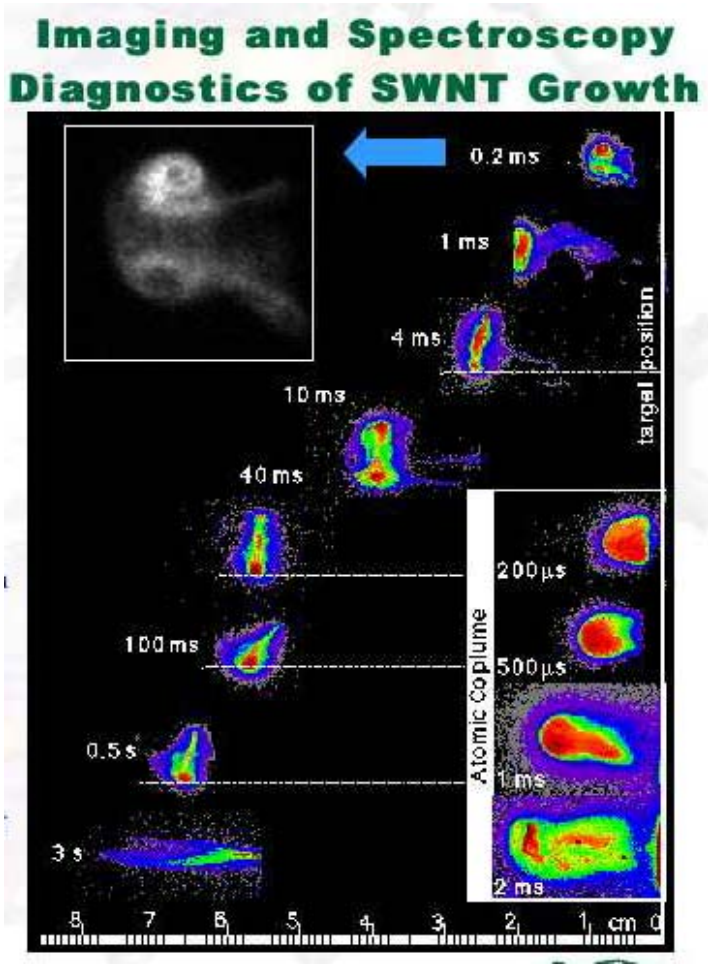


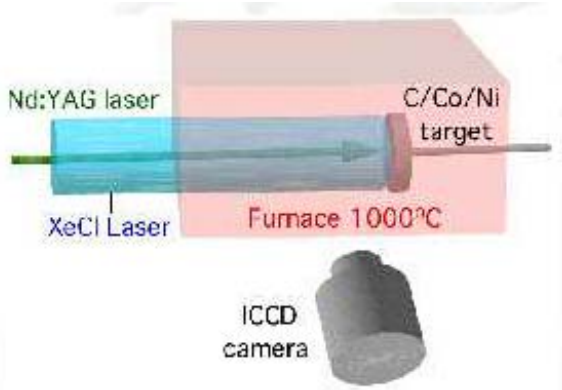
Four-point Probe STM with SEM:
Manipulation & Transport in Nanoscale Systems

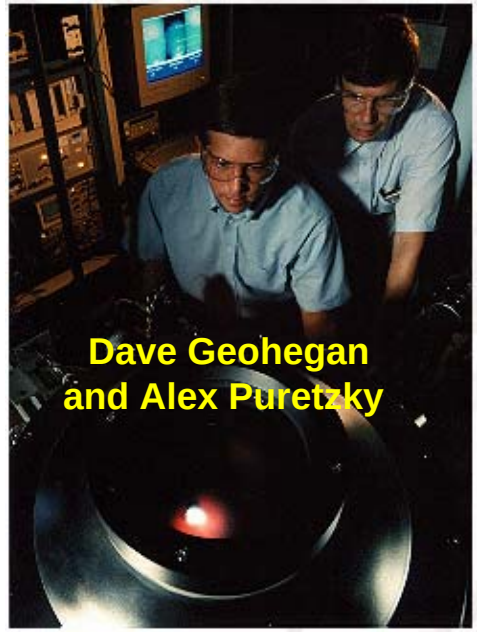


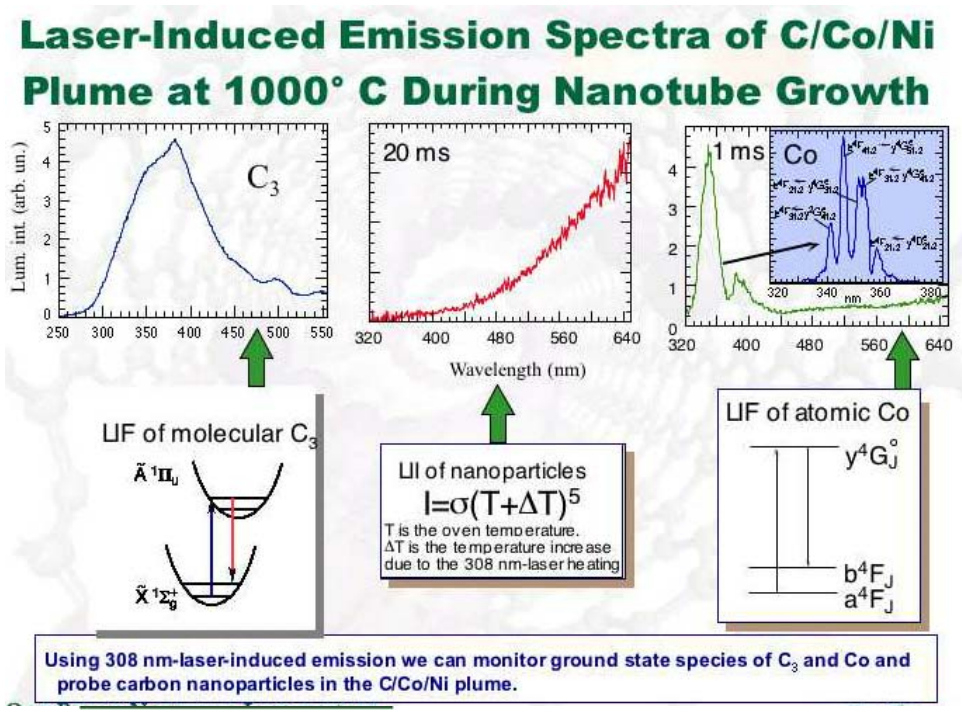
- **Scientific Drivers**
  - Temperature-dependent quantum **electrical transport of nanoscale objects on surfaces**
  - **Manipulation** of individual nano-objects
  - **Fabrication** and **characterization** of nanoscale devices
  - Spintronics / spin injection / spin transport
- **Proposed Capabilities**
  - **Four probes operate independently**, tip separation < 100 nm
  - Integrated SEM with resolution < 10 nm permits accurate positioning of four tips relative to each other and to nanofeatures of interest
  - 20 K < T < 600 K
  - UHV-capable (5 x 10^{-11} Torr)
  - Integrated sample preparation / handling
  - **Nanofabrication: STM tip-stimulated chemical vapor deposition (CVD)**

In situ Spectroscopic Diagnostics of Nanomaterials Growth





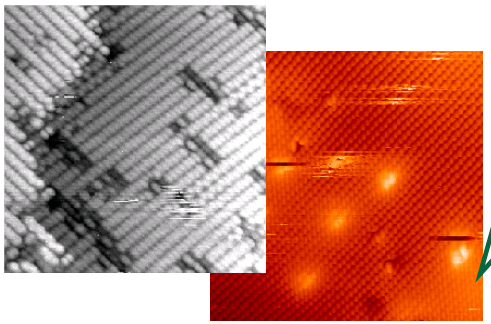




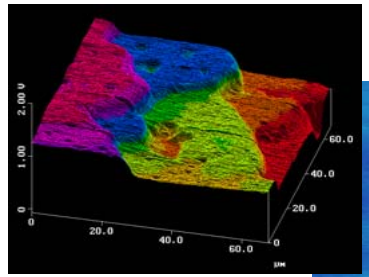
Spatially Resolved Characterization:

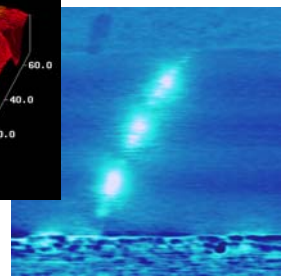
Atoms, Spins, Charge and Transport with Atomic Resolution

CNMS ground floor: Scanning Probe Laboratories Suite

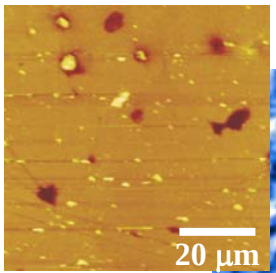


STM: Electronic structure



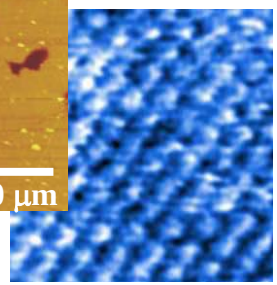


Transport

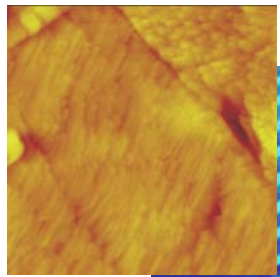


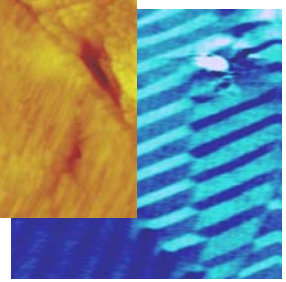
ZnO

NaCl

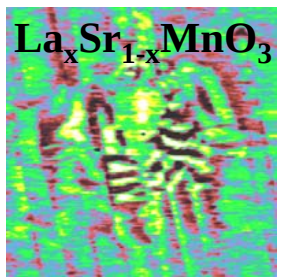


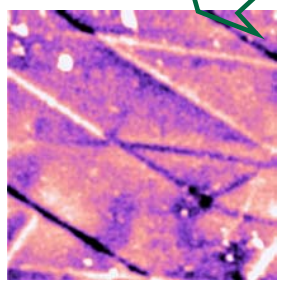
AFM Topography



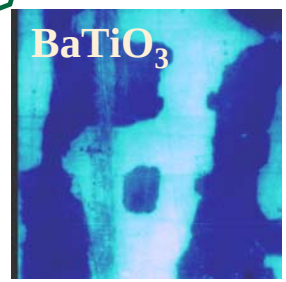


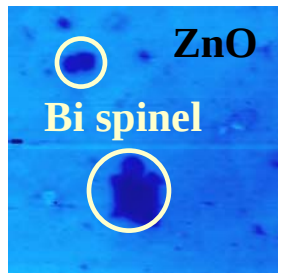
Piezoresponse Force Microscopy





Magnetic Force Microscopy

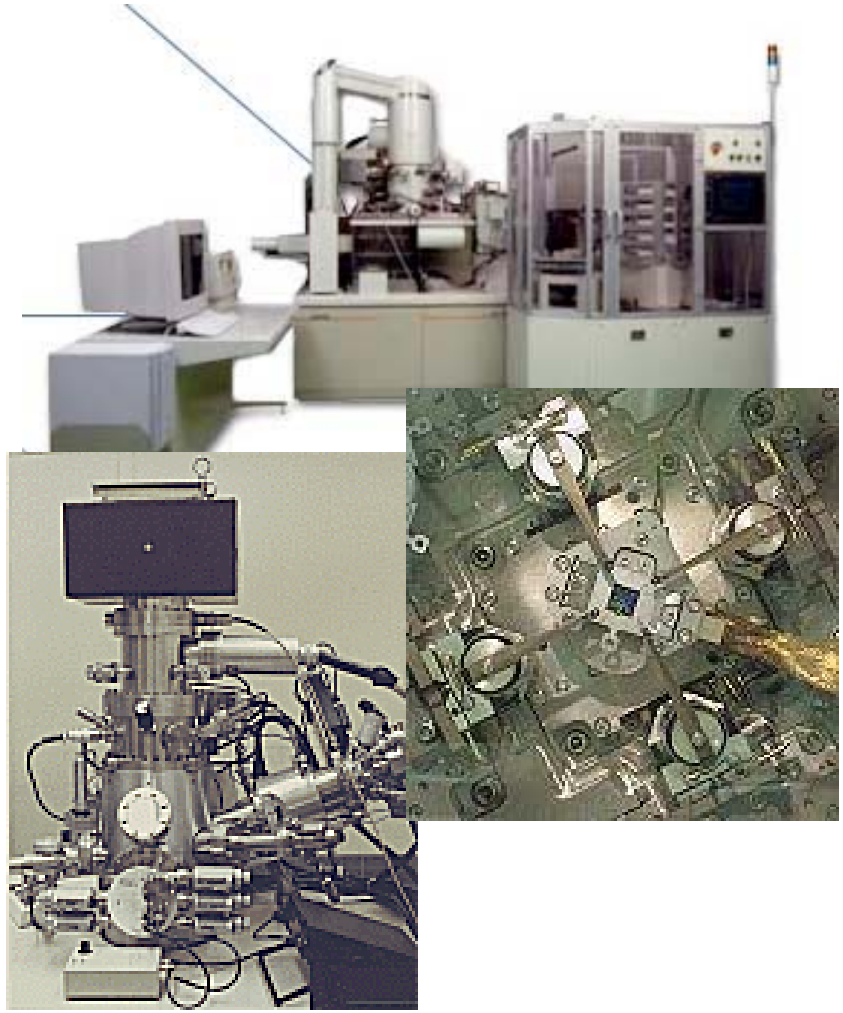




Potential imaging

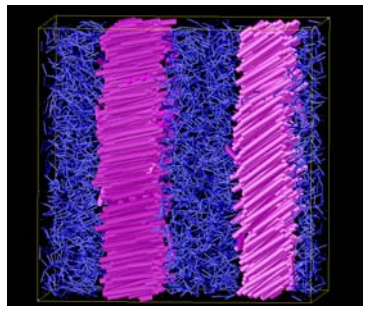
Ordering of CNMS Technical Equipment has Begun

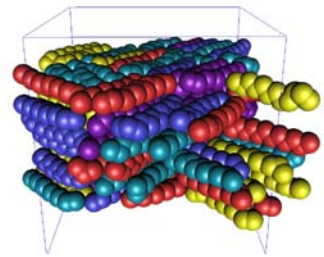
- **E-beam lithography system (order placed)**
- **SEMPA – order placed**
- **4-probe STM/SEM (bids under review, order expected in March)**
- **2 other pieces of clean room equipment are ordered and will be delivered in FY04**
  - **Used/refurbished equipment!**

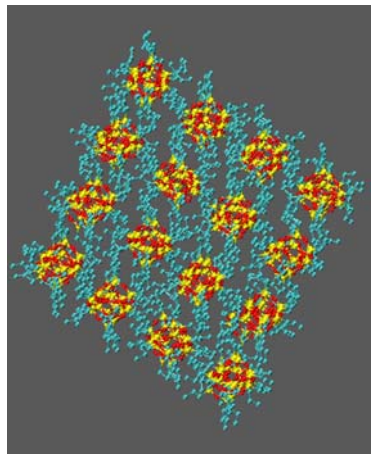


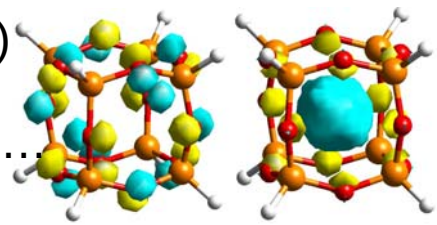
Vision for Outstanding Science

Unique Instruments: Perfecting the "Computational Multiscope"









- **Current capability of computational nanoscience**
  - Excellent clarity for some systems at specific levels of description
    - Electronic structure scale, atomistic simulation scale, etc.
    - Analogous to a different lens at each length scale
  - *Moving from one scale to another* requires "changing out the lens": switching to fundamentally different technique
- **Nanomaterials Theory Institute (NTI) of CNMS**
  - Develop scale-spanning methods and combine with leadership-class computing at ORNL's CCS
  - Create a "computational multiscope"
    - Seamless clarity at length and time scales from electronic to macroscopic
    - Virtual synthesis, virtual experiments, device design,…
- **Enable this vision at the NTI by utilizing expertise of**
  - ~40 theorists and computational chemists, physicists, materials scientists at ORNL (esp. NTI & CCS user support)
  - Users working with NTI & CCS staff, Guest (visiting) Scientists, ORNL and shared postdocs, graduate students, …

"Jump Starting"
AN OUTSTANDING USER PROGRAM

Initial User Program and Call for Proposals

SELECTION OF RESEARCH AREAS

- **CNMS Planning Workshops: Expected strongest user interest**
- **Major strengths of current ORNL / BES research programs**
- **Support for**
  - **Controlled synthesis research**
  - **Broad range of imaging and characterization**
  - **Theory, modeling, and simulation**
- **User research initiated in 5 of 7 CNMS Scientific Themes**
  - **Some aspects of remaining two**

GOAL

- **Vibrant, interactive, productive user community *before* CNMS opens**

FY2003-2004 "Jump Start"

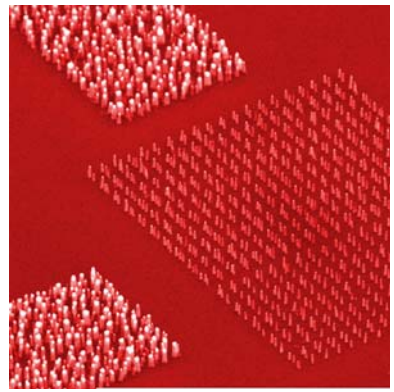
Nanoscience Research with Users

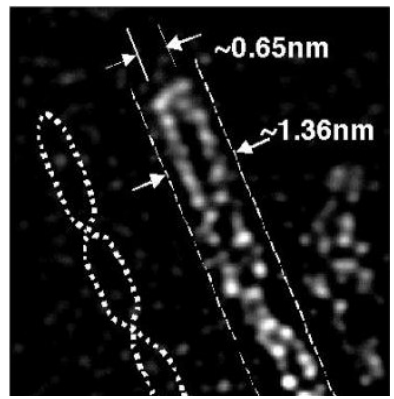
- **Design, Synthesis, and Characterization of Macromolecular Materials**
  - ***Materials Focus:*** **Polymers and biologically-derived or -inspired systems**
  - ***Grand Challenge:*** **Design and control macromolecular organization to achieve novel functionalities**
- **Controlled Synthesis and Assembly of Functional Nanomaterials**
  - ***Materials Focus:*** **Single- and multi-wall carbon (and eventually other) nanotubes and related composite materials**
  - ***Grand Challenge:*** **Understand and control synthesis and functionalization of nanotubes and related structures, to obtain materials with desired physical and chemical properties**
- **FY2004: Initiate Nanomaterials Theory Institute's *User Research Focus Laboratories* program**
  - **Development and application by users of selected, powerful computational nanoscience techniques, together with world leaders**
  - **Address key problems / issues *of users' choice* in understanding nanoscale materials and phenomena**
  - **Users run their applications "hands on" using supercomputers of ORNL's *Center for Computational Sciences* (CCS)**

FY2003-2004 "Jump Start"

Collaborative Outreach: Nanofabrication

- **Nanofabrication: Interim nanofabrication lab for users**
  - Training / supervision for new users
  - Skilled technicians for some tasks / users
  - Communication and enforcement of safe-use and clean-use policies
- **Nanoscale Imaging and Characterization**
  - Nanoscience user access to:
    high-resolution electron microscopy
    analysis instruments
    scanning-probe instruments
    SEMPA
    in SHaRE, High Temperature Materials Laboratory (HTML) Materials Analysis User Center, and MPI—Halle (Germany)





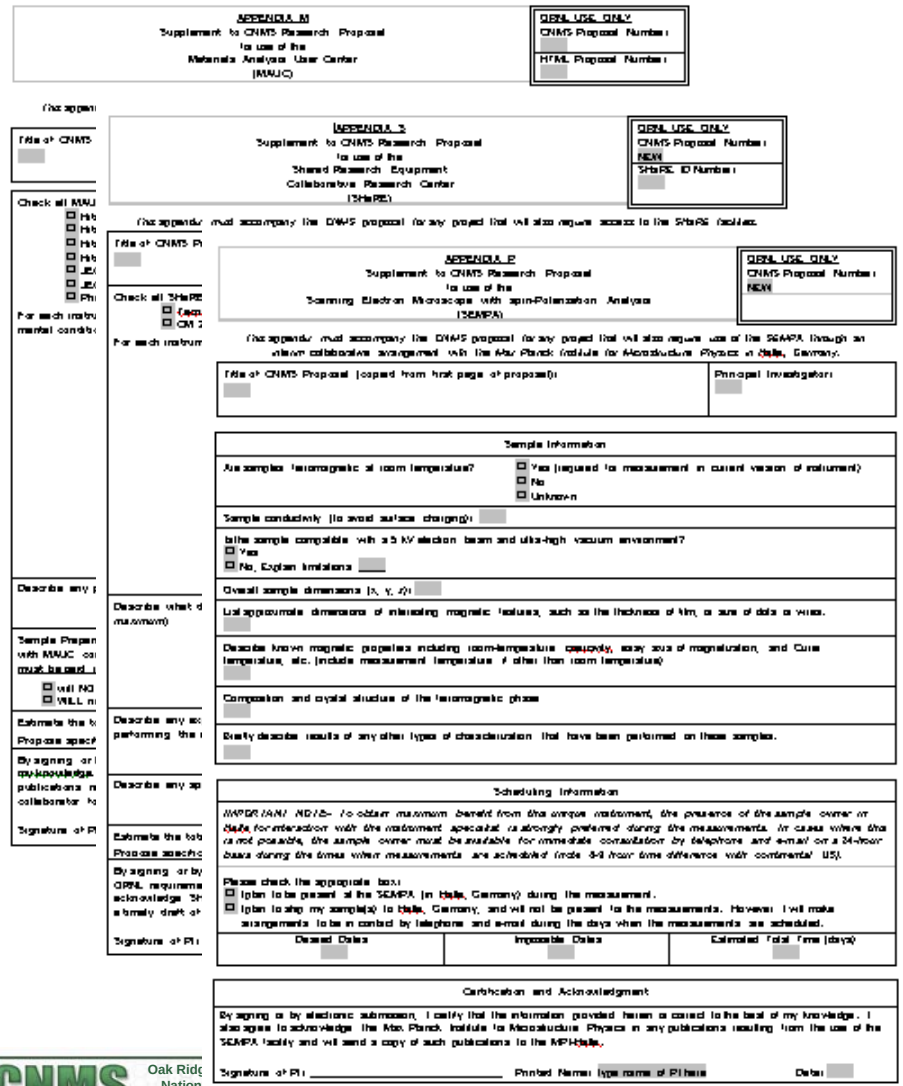
Electron microscopy reveals a double helix chain of iodine Atoms inside a carbon nanotube

Vision for an Outstanding User Program

MOAs with Selected ORNL User Facilities

CNMS will internally coordinate requests to use other ORNL nanoscience research capabilities

- **CNMS Proposal Application Form includes Appendices for access to other User Facilities**
- **GOAL: Timely, "one-stop shopping" for all needed resources**
  - **All relevant facilities within single application form**
- **MOAs and Appendices already initiated for FY03-04 "jump start"**
  - **SHaRE, MAUC, SEMPA**
- **Future: CCS, SNS / HFIR, HTML**


APPENDIX M
Supplement to CNMS Research Proposal
for use of the
Materials Analysis User Center
(MAUC)

ORNL USE ONLY
CNMS Proposal Number
HFIR Proposal Number

APPENDIX S
Supplement to CNMS Research Proposal
for use of the
Shared Research Equipment
Collaborative Research Center
(SHaRE)

ORNL USE ONLY
CNMS Proposal Number
NEW
SHaRE ID Number

APPENDIX P
Supplement to CNMS Research Proposal
for use of the
Scanning Electron Microscope with spin-Polarization Analysis
(SEMPA)

ORNL USE ONLY
CNMS Proposal Number
NEW

Title of CNMS Proposal (copied from first page of proposal)

Principal Investigator

Sample Information

Are samples ferromagnetic at room temperature?
Yes (required for measurement in current version of instrument)
No
Unknown

Sample conductivity (to avoid surface charging):

Is the sample compatible with a 5 kV electron beam and ultra-high vacuum environment?
Yes
No, Explain limitations

Overall sample dimensions (x, y, z):

List approximate dimensions of interesting magnetic features, such as the thickness of film, or size of dots or wires.

Describe known magnetic properties including room-temperature coercivity, easy axis of magnetization, and Curie temperature, etc. (include measurement temperature if other than room temperature)

Composition and crystal structure of the ferromagnetic phase

Briefly describe results of any other types of characterization that have been performed on these samples.

Scheduling Information

IMPORTANT NOTE: To obtain maximum benefit from this unique instrument, the presence of the sample owner or Hajja for interaction with the instrument specialist is strongly preferred during the measurements. In cases where this is not possible, the sample owner must be available for immediate consultation by telephone and e-mail on a 24-hour basis during the times when measurements are scheduled (note 9-9 hour time difference with continental US).

Please check the appropriate box:
I plan to be present at the SEMPA (in Halle, Germany) during the measurement.
I plan to ship my sample(s) to Halle, Germany, and will not be present for the measurements. However, I will make arrangements to be in contact by telephone and e-mail during the days when the measurements are scheduled.

Desired Dates | Impossible Dates | Estimated Total Time (days)

Certification and Acknowledgment

By signing or by electronic submission, I certify that the information provided herein is correct to the best of my knowledge. I also agree to acknowledge the Max Planck Institute for Microstructure Physics in any publications resulting from the use of the SEMPA facility and will send a copy of such publications to the MPI-Halle.

Signature of PI: _____ Printed Name (type name of PI here) Date:

Enthusiastic Response to Call for Proposals

71 PROPOSALS RECEIVED

- **Most from southern and eastern United States**
- **18 states represented**

DISTRIBUTION BY SOURCE

- **50 universities**
- **6 industry**
- **10 ORNL**
  - **Some with university collaborators**
- **5 foreign**
  - **Germany, France, China**

71 total

- **41 proposals selected for support, based on external *PRC* review**
  - **~ 10 on proof-of-concept basis**
- ***All active user research proposals now listed on CNMS web site***

Research Center for Nanophase Materials Sciences

A Highly Collaborative and Multidisciplinary

U.S. DOE Nanoscale Science Research Center

2004 User-Initiated Nanoscience Research Program

Tailoring Electrical Properties:PANI/SWNT's Composites
Principal Investigator: G. B. Blanchet (Material Science & Engineering, DuPont)
Collaborators: D. Geohegan (Oak Ridge National Laboratory)

Study of Nanomagnetism in Patterned Structures Using SEMPA
Principal Investigator: J. Shi (Physics, University of Utah)

Direct Growth of Single Walled Carbon Nanotubes with Controlled Structures on Substrates for Device and Sensor Applications
Principal Investigator: J. Liu (Dept. of Chemistry, Duke University)

Optical Manipulation of Carbon Nanotubes: Differential Diffusion Through a New Chirality-Dependent Electric Dipole Response
Principal Investigator: W. R. Garrett (Physics & Astronomy, University of Tennessee)

Fabrication of Magnetic Nanowires and Nanowire Arrays Using Self-Assembling Polymer Templates
Principal Investigator: M. G. Bakker (Dept. of Chemistry, University of Alabama)
Collaborators: D. Nikles (University of Alabama)

Hybrid Composites of Facially Amphiphilic Phenylene Ethynylenes and Carbon Nanotubes
Principal Investigator: G. N. Tew (Polymer Science & Engineering, University of Massachusetts)

Hydrogenation of Carbon Nanotubes: Water as a Hydrogen Source
Principal Investigator: Y.-P. Sun (Chemistry, Clemson University)

Directed Assembly of Nanoparticles in Polymers
Principal Investigator: T. Emrick (Polymer Science & Engineering, University of Massachusetts)
Collaborators: T. P. Russell (Polymer Science & Engineering, University of Massachusetts)

Scaffolding of Biosynthetic Enzyme Systems to Nanostructured Electrodics for Controlled Synthesis of Inorganic Materials
Principal Investigator: D. Morse (Dept. of Molecular, Cellular & Develop. Biology, University of California)
Collaborators: M. L. Simpson (Oak Ridge National Laboratory)
T. McKnight (Oak Ridge National Laboratory)

Calculating Time Dependent Effects from a Modified Wang-Landau Density of States
Principal Investigator: M. A. Novotny (Dept. of Physics & Astronomy, Mississippi State University)

Ferromagnetic Domain Structures at Epitaxial Metal/Semiconductor Interfaces for Spintronics
Principal Investigator: H. H. Weitering (Physics & Astronomy, University of Tennessee)
Collaborators: L. C. Feldman (Vanderbilt University)
J. Shen (Oak Ridge National Laboratory)

High Production Rate Nanotube Synthesis Apparatus
Principal Investigator: M. W. Smith (NASA Langley Research Center)

Development of a Nanoscale Solvothermal Processes Laboratory (NSPL) for CNMS
Principal Investigator: D. J. Wesolowski (Chemical Sciences Division, Oak Ridge National Laboratory)
Collaborators: D. B. Beach (Chemical Sciences Division, Oak Ridge National Laboratory)
D. R. Cole (Chemical Sciences Division, Oak Ridge National Laboratory)
W. A. Hamilton (Chemical Sciences Division, Oak Ridge National Laboratory)

Nanostructured Composites as Tunable Dielectrics
Principal Investigator: M. E. Rogers (Advanced Materials, Luna Innovations, Inc.)
Collaborators: B. Koene (Luna Innovations, Inc.)
P. Stevenson (Luna Innovations, Inc.)
M. Vercellino (Luna Innovations, Inc.)

User Activity (mid-February)

Number of new badges requested: 16

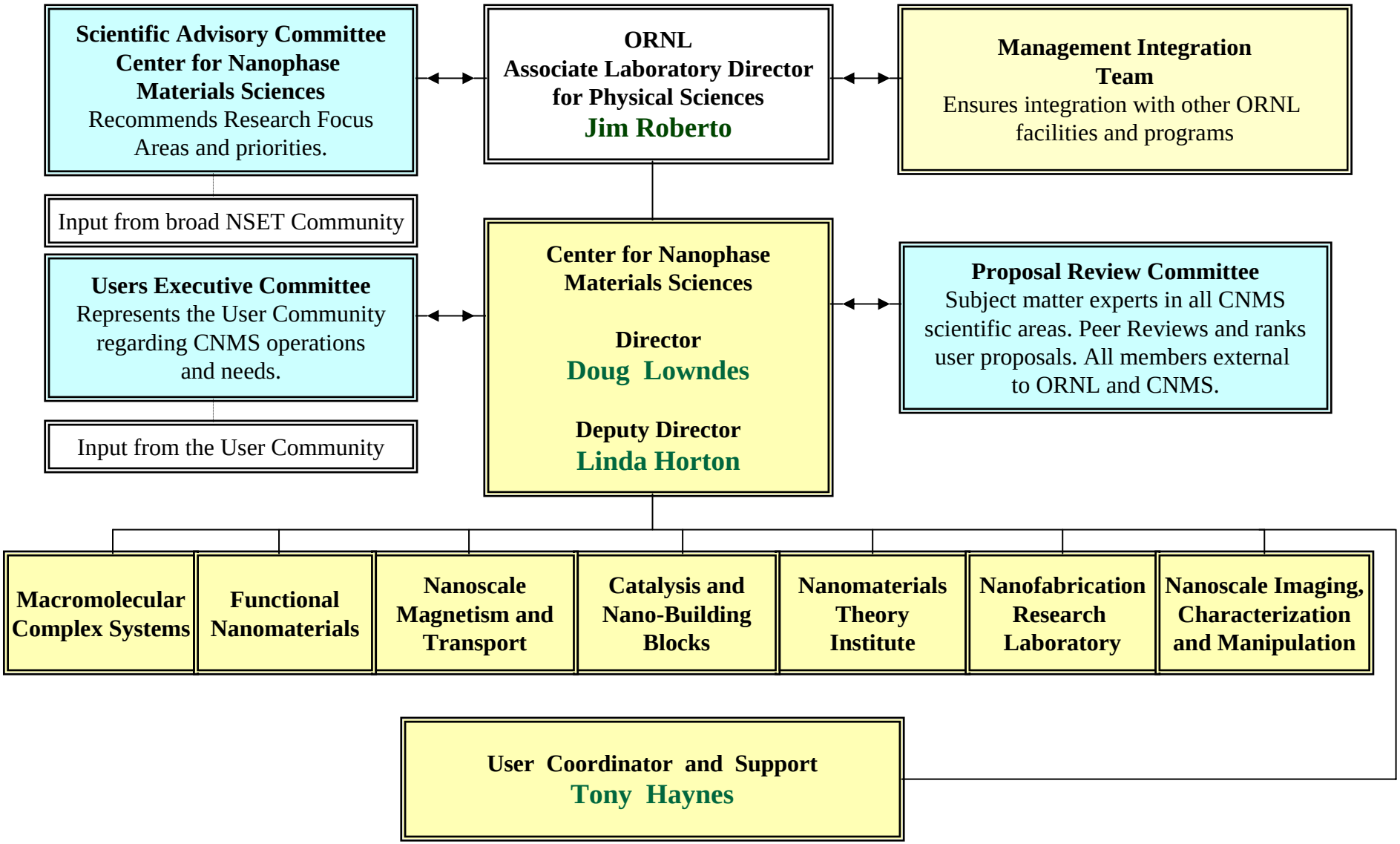
Users actively scheduling or working: > 18

The Team:
SCIENTIFIC
MANAGEMENT
and
ADVISORY GROUPS

CNMS Project Scientific Leadership Team

- **Doug Lowndes** — **CNMS Scientific Director**
- **Linda Horton** — **CNMS Project Director and Deputy Scientific Director**
- **Michelle Buchanan** — **CNMS Scientific Thrust Leader for Soft and Hybrid Materials**
- **Ward Plummer** — **CNMS Scientific Thrust Leader for Complex Hard Materials**
- **Peter Cummings** — **CNMS Scientific Thrust Leader for Theory / Modeling / Simulation (Nanomaterials Theory Institute)**
- **Mike Simpson** — **CNMS Scientific Thrust Leader for the Nanofabrication Research Lab**
- **David Joy** — **CNMS Co-Leader for Imaging, Characterization and Manipulation**
- **Ian M. Anderson** — **CNMS Co-Leader for Imaging, Characterization and Manipulation**
- **Tony Haynes** — **CNMS User Coordinator**
- **John Cooke** — **CNMS Work Proposal Manager**
- **Jim Roberto** — **ORNL Associate Laboratory Director for Physical Sciences**

Governance and Operation of the CNMS



www.cnms.ornl.gov