The National Nanotechnology Initiative and Industrial Nanotechnology Impact

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Scientific User Facilities Division
Office of Basic Energy Sciences
Office of Science
U.S. Department of Energy

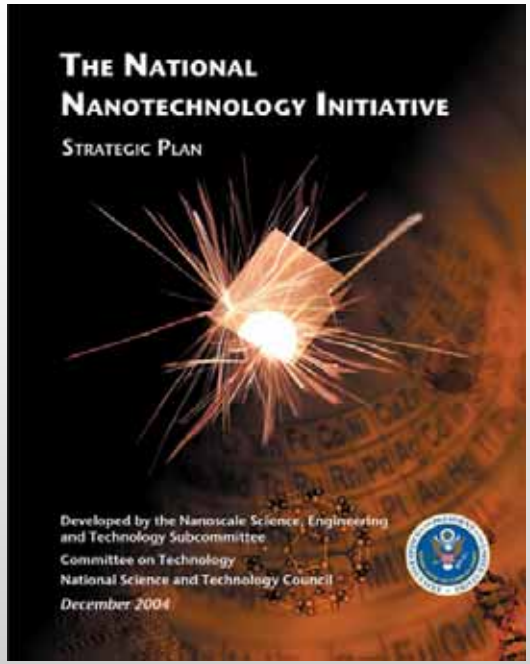
NSTI Nanotech 2007, Santa Clara, CA *May 21, 2007*

Outline

- *About the National Nanotechnology Initiative*
  - *What is it?*
  - *What does it do?*
  - *What's the budget?*
- *Industry impacts and NNI activities*
  - *Nanotechnology impact areas*
  - *Small business programs*
  - *Standards*
  - *Infrastructure for nanoscience and nanotechnology*
  - *Results at facilities: industry research highlights*

What is the National Nanotechnology Initiative?

- The NNI is an interagency program that coordinates Federal nanoscale research and development activities and related efforts among various participating entities (currently 26)
- The NNI began in 2001 and its activities were codified and further defined in the 21st Century Nanotechnology Research and Development Act (Dec. 2003)
- Planned federal NNI expenditures are over $1.4 billion in FY 2008



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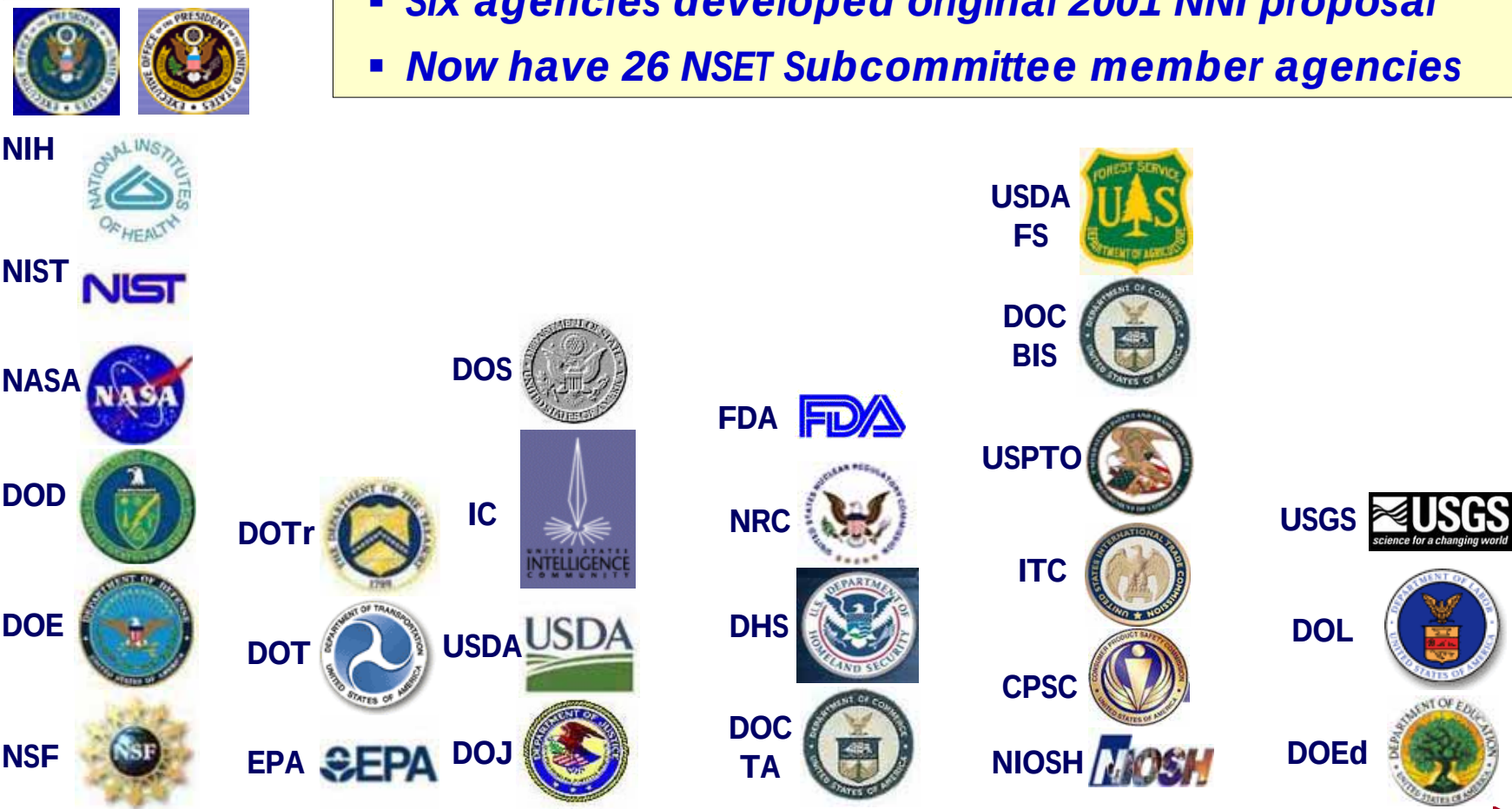
Participating Agencies in the NNI

- *Six agencies developed original 2001 NNI proposal*
- *Now have 26 NSET Subcommittee member agencies*



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The NNI definition of "nanotechnology"

What is "nanotechnology"?

- ***Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications…***
- ***Nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale***

- ***With reference to the NNI, the term is meant to broadly encompass nanoscale science, engineering, and technology***
- ***Not just another step towards miniaturization; fundamental differences in physical, chemical, and biological behavior at this level compared to bulk materials or individual atoms/molecules***
  - ***quantum phenomena***
  - ***dominance of surfaces***
  - ***self-assembly***

The National Nanotechnology Initiative: Vision and Goals

- ***The vision of the NNI:*** ***a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry***

- ***Four goals for nanoscale science, engineering, and technology, as described in the NNI's annual budget supplements and Strategic Plan:***
  - *Maintain a world-class research and development program*
  - *Facilitate technology transfer*
  - *Develop educational resources, a skilled workforce, and the supporting research infrastructure and tools*
  - *Support responsible development of nanotechnology*

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So how does the NNI actually work?

- **Management** → **EOP + Agencies**
  - Establishment of nanotechnology as high priority R&D area
  - Budget creation, funding allocation to agencies, & spending
  - Negotiations with Congress
- **Coordination** → **NSET Subcommittee**
  - Coordinates development of strategic plan for NNI
  - Providing mechanisms for interagency communication and coordination on nanotechnology R&D
- **Reporting** → **NNCO**
  - Publishes reports on behalf of the NSET and the NNI for use by Congress, academia, industry, and the public
  - Serves as public point of contact for NNI

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Some interagency NNI activities facilitated by NSET and NNCO

- ***Consolidated reporting* on nanoscale science, engineering, and technology efforts across the federal complex**
- ***Cross-cutting workshops, publications, strategic planning, and information exchange* among both research and regulatory bodies**
- ***Coordinated interactions* with state and regional efforts, international bodies, industry, and others**
- ***Joint development of tools, methodologies, and facilities*, such as the Nanotechnology Characterization Laboratory established by the National Cancer Institute of NIH in collaboration with NIST and FDA**
- ***Joint grant solicitations*, such as an annual call regarding environmental and human health effects of manufactured nanomaterials led by EPA and involving NSF, NIEHS, and NIOSH**

Industry interactions and input to NNI

- *Presentations at business-oriented conferences and ongoing discussions with industry representatives such as the NanoBusiness Alliance (meeting with NSET 1/30/07)*
- *Consultative Boards on Advancing Nanotechnology (CBANs) serve as a mechanism to facilitate input from industry*
- *Existing CBANs with various industry groups, via agreements with professional or trade associations:*
  - *Chemicals*
  - *Electronics*
  - *Industrial Research*
  - *Forest Products*

NNI activities and documents inform agencies, and report outcomes, and serve as resources

Supplement to the President's FY 2007 Budget

Environmental, Health, and Safety Research Needs

NSET Subcommittee working groups

- *Focused interest and expertise in topical areas*
- *Four working groups established:*
  - *Nanotechnology Environmental and Health Implications (NEHI)*
  - *Nanotechnology Innovation and Liaison With Industry (NILI)*
  - *Global Issues in Nanotechnology (GIN)*
  - *Nanotechnology Public Engagement and Communications (NPEC)*
- *Additional informal task forces and subgroups as needed*

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The NNI budget in the FY 2008 request

- ***Federal NNI expenditures have steadily grown from the initiative's start in FY 2001. From OSTP's "one-pager" associated with the FY 2008 budget request:***

National Nanotechnology Initiative (dollars in millions)

	2001 Actual	2007 Estimate *	2008 Proposed	Dollar Change 2001 to 2008	% Change 2001 to 2008
NSF	150	373	390	240	160%
DoD	125	417	375	250	200%
DoE **	88	293	332	244	277%
HHS **	40	175	208	168	420%
Commerce (NIST)	33	89	97	64	194%
NASA	22	25	24	2	9%
EPA	5	9	10	5	100%
USDA **	0	7	8	8	NA
Homeland Security	0	1	1	0	NA
Justice	1	1	1	1	0%
Transportation	0	1	1	1	NA
TOTAL	**464**	**1,391†**	**1,447**	**983**	**212%**

* The amounts included as 2007 Estimates reflect the 2007 request levels, with the exception of the numbers for the Departments of Defense and Homeland Security, which are the enacted levels.

** 2007 and 2008 funding levels for: DoE includes the Offices of Science, and Energy Efficiency and Renewable Energy; HHS includes NIH and NIOSH funding; and USDA includes CSREES and Forest Service.

† 2007 estimate includes about $100 million in Congressional earmarks at DoD that are outside the NNI plan.

NNI areas of investment (Program Component Areas)

- Fundamental Nanoscale Phenomena and Processes
- Nanomaterials
- Nanoscale Devices and Systems
- Instrumentation Research, Metrology, and Standards for Nanotechnology
- Nanomanufacturing
- Major Research Facilities and Instrumentation Acquisition
- Societal Dimensions (EHS, ELSI, Education)

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FY 2008 budget request by PCA

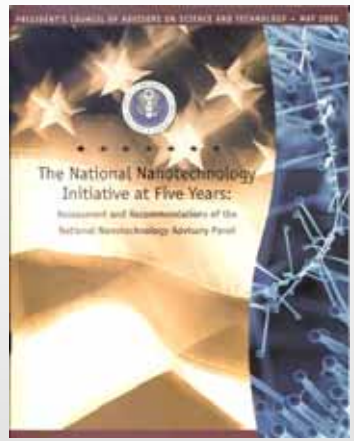
Table 3
Planned 2008 Agency Investments by Program Component Area
(dollars in millions)

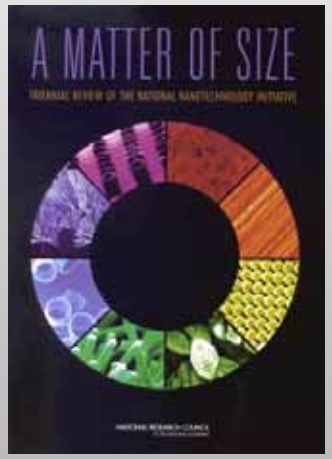
	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instr. Research, Metrology, & Standards	Nano-manufacturing	Major Research Facilities & Instr. Acquisition	Societal Dimensions	NNI Total*
NSF	142.7	60.2	51.1	14.5	26.9	31.6	62.9	389.9
DOD	179.1	91.7	70.6	8.3	1.0	23.0	1.0	374.7
DOE	85.4	99.8	13.5	26.7	2.0	100.6	3.5	331.5
DHHS (NIH)	53.3	16.5	114.9	6.7	1.7	0.1	9.7	202.9
DOC (NIST)	27.1	8.0	13.5	26.4	11.1	4.5	6.0	96.6
NASA	1.0	12.0	10.0	0.0	1.0	0.0	0.0	24.0
EPA	0.2	0.2	0.2	0.0	0.0	0.0	9.6	10.2
USDA (CSREES)	0.4	0.8	1.5	0.0	0.1	0.0	0.2	3.0
DHHS (NIOSH)	0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.6
USDA (FS)	1.7	1.5	1.0	0.2	0.2	0.0	0.0	4.6
DHS	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.0
DOJ	0.0	0.0	0.1	0.8	0.0	0.0	0.0	0.9
DOT (FHWA)	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.9
TOTAL*	491.8	290.7	277.4	83.6	44.0	159.8	97.5	1,444.8

* Totals may not add due to rounding.

External reviews of the NNI

- *PCAST is designated as the National Nanotechnology Advisory Panel and is called upon to assess the NNI every two years; their first report was issued 5/05*





- *The National Research Council of the National Academies is to provide a triennial review of the NNI; their first such report was published late in 2006*

- *NSET has made efforts to evaluate and address the recommendations of the PCAST and NRC reports as appropriate*

Industry impacts and NNI activities

- *"Nanotechnology" is not a monolithic industry, but a set of enabling capabilities*
- *What are the implications for industry?*
  - *Novel or enhanced properties of materials (arising from control of material structure at the nanoscale via controlled growth, self-assembly, patterning, assembling with nanoscale precision, etc.)*
  - *Incremental improvements in products (textiles), disruptive new technologies (quantum computing), cleaner or cheaper methods of manufacture (tailored catalysts)*
  - *Impacts ranging over a very diverse set of application areas, from drug delivery to lightweight structural materials to water purification to electronics to self-cleaning coatings to sporting goods… and many more*

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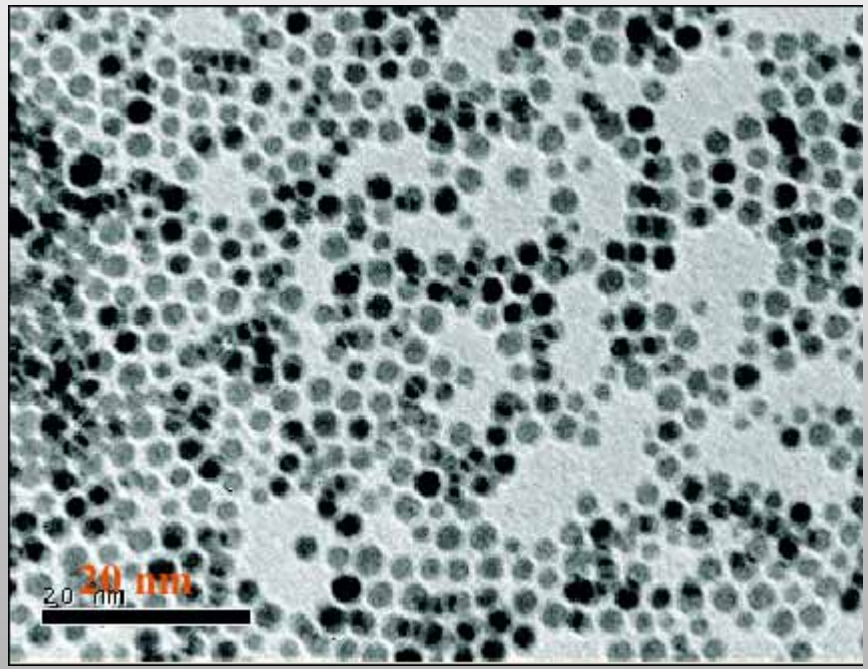
Potential Nanotechnology Impact Areas in Energy & Environment

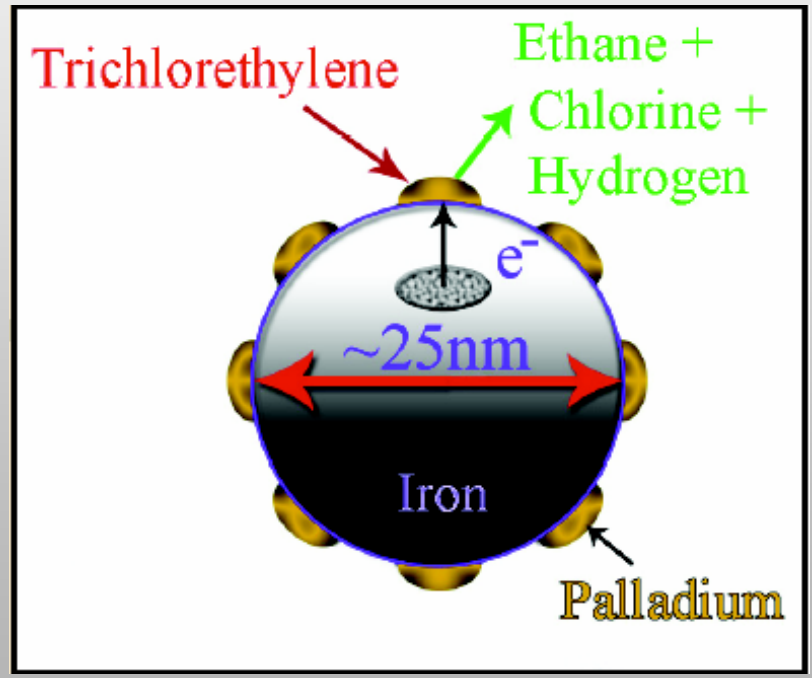
- **Energy**
  - hydrogen storage
  - solid-state lighting
  - low-power displays
  - fuel cells
  - battery materials
  - solar power
  - catalysis
  - weight reduction
  - propellants and explosives
  - nanoscale energy (ATP motors, etc.)
- **Environment**
  - sensors
  - remediation
  - emissions reduction
  - membranes and separations
  - coatings
  - green processing
  - radioactive waste containment, etc.

Treatment of Contaminated Groundwater with Iron Nanoparticles

- *Fe nanoparticles with Pt or Pd degrade trichloroethylene (TCE) – up to 96%*
- *break down a wide variety of contaminants*
- *high reactivity due to large surface area (~33.5 m2/g)*
- *injectable, for soil and groundwater remediation*



electron micrograph of Fe nanoparticles



schematic of remediation process

W. Zhang et al., Lehigh (funding from NSF, EPA)

NNI agency funding for small businesses

- ***Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs include nanotechnology-specific topics and nanotechnology components within other topics***

Table 8
2005 Agency SBIR and STTR Awards
(dollars in millions)

	SBIR	STTR	NNI Total
DOD	28.0	13.8	41.7
NSF	12.1	2.2	14.3
DHHS (NIH)*	11.1	5.2	16.3
DOE	7.7	0.4	8.1
NASA	6.0	0.0	6.0
EPA	1.0	n/a	1.0
USDA	0.0	n/a	0.0
DOC (NIST)	0.1	n/a	0.1
TOTAL	**65.9**	**21.5**	**87.4**

* NIH SBIR and STTR funding are included in its NNI totals.

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Suitable Standards are Critical For Nanotech Development and Commercialization

- Commercial progress in nanotechnology requires standards based on solid science and engineering
  - Imperative for best technologies to be incorporated into internationally-developed specifications and standards
  - Standards not so founded can constrain innovation and entrench inferior technologies
  - Documents on consensus specifications serve as highly informative and instructional information for advancing field
- Standards are key to addressing the highly multi-disciplinary and broad based nature of nanotechnology—cross-sectorial standards typical
  - across scientific fields including biochemistry, molecular biology, engineering, physics, chemistry, medicine,…
- Standards on nomenclature, measurement, and environment, health, and safety (EHS) are a high priority

International Standards Organizations

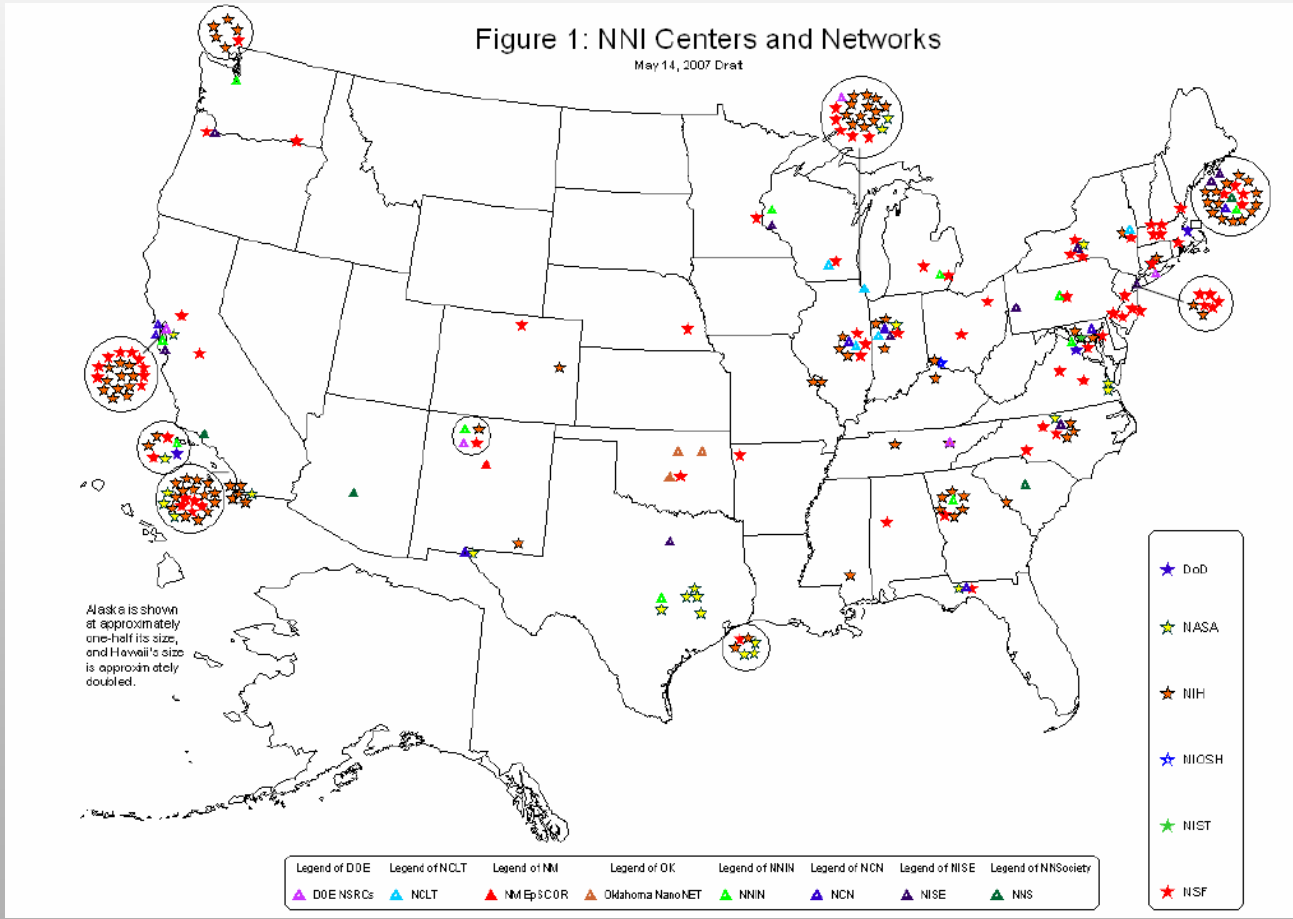
National Body International Standards Organizations

Treaty-Based International Standards Organizations

Standards Development Orgs. With Global Reach

NNI infrastructure includes many centers and networks

- **User facilities available to the entire research and development community include the National Nanotechnology Infrastructure Network (NNIN), supported by NSF, which includes 13 university sites, and the five DOE Nanoscale Science Research Centers (NSRCs) at National Laboratories.**



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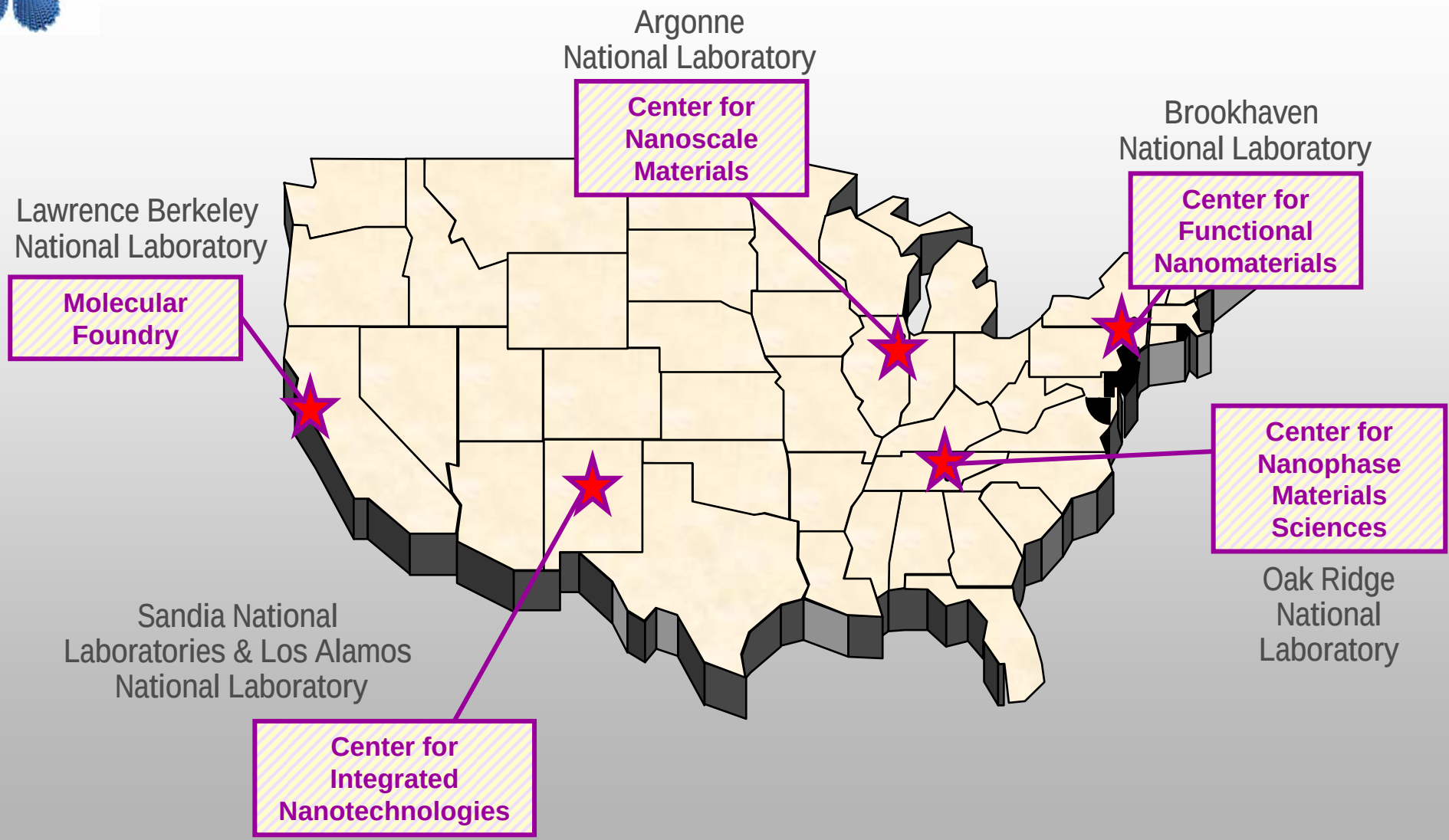
The Five Department of Energy (DOE) Nanoscale Science Research Centers (NSRCs)



Four of the Five NSRCs are in operation

Center for Functional Nanomaterials
(Brookhaven National Laboratory)
- just completing construction

Molecular Foundry
(Lawrence Berkeley
National Laboratory)

Center for Nanoscale Materials
(Argonne National Laboratory)

Center for Nanophase Materials Sciences
(Oak Ridge National Laboratory)

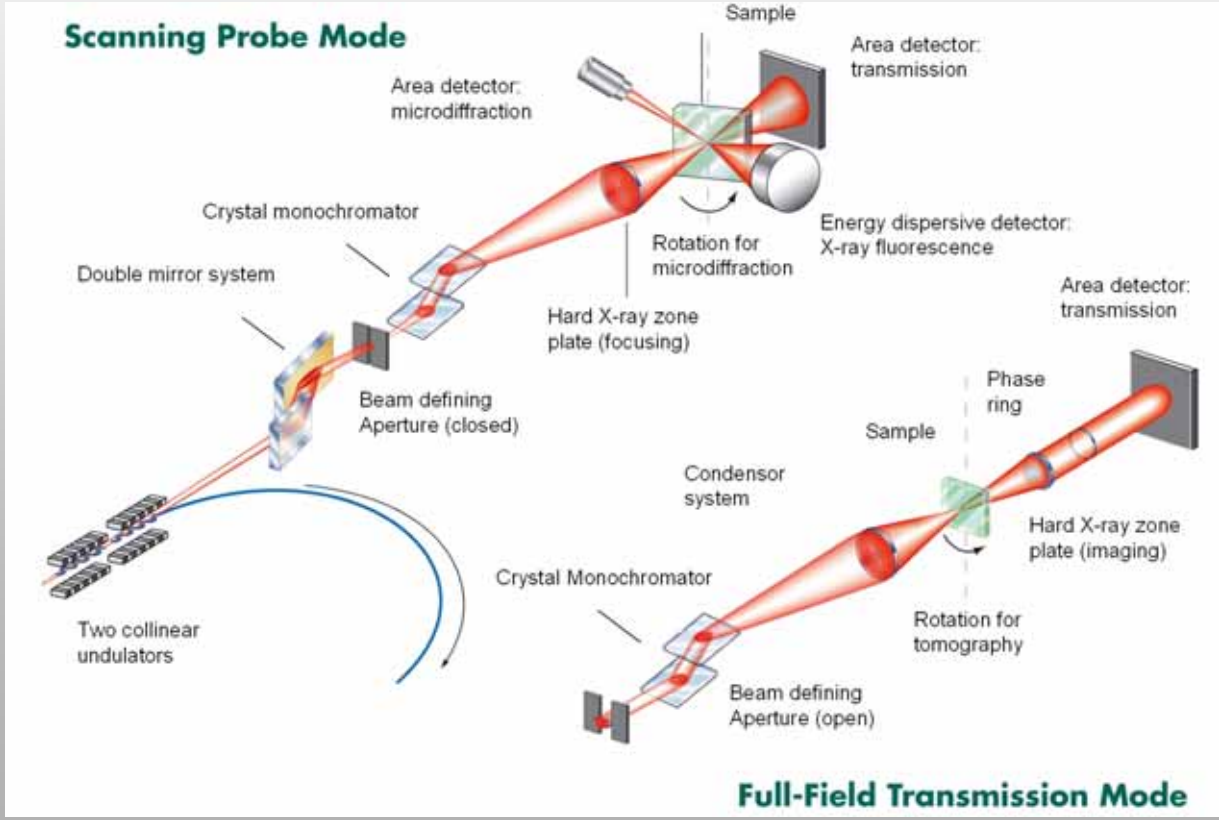
Center for Integrated Nanotechnologies
(Sandia & Los Alamos National Labs)

Nanoscale Science Research Centers: Basic Info

- *Research facilities for synthesis, processing, analysis, and characterization of nanoscale materials*
- *Provide specialized equipment, unique tools, and dedicated scientific and support staff that are difficult for individual institutions to put in place and maintain*
- *Operated as user facilities and available to all. Access determined by peer review of proposals. No cost for precompetitive, non-proprietary work leading to publication; cost recovery for proprietary work.*
- *Co-located at DOE National Laboratories with existing major user facilities (synchrotron radiation light sources, neutron scattering facilities, other specialized facilities) to provide characterization and analysis capabilities*

Unique tools: x-ray synchrotron beamlines with nanoscale resolution

- Unique instruments to study individual nanostructures
- Quantitative structure, strain, orientation imaging
- Sensitive trace element and chemical state analysis



- Joint nanoprobe effort between CNM and the Advanced Photon Source at Argonne National Laboratory
- Similar efforts underway via CFN and the National Synchrotron Light Source at Brookhaven National Laboratory

Examples of industry research at NSRCs

CNMS 2003-010: G. Blanchet (DuPont Corp.)

Tailoring Electronic Properties of Polyaniline/SWNT Composites

- Plastic Electronics
  - For organic large-area flexible displays, low-cost memory, disposable or wearable electronics
  - Polyaniline - A printable, environmentally-stable, conducting polymer with reversible conductivity depending upon doping, for plastic substrates
  - SWNT/ PANI composites become highly conductive (3 S/cm) at extremely low nanotube concentrations
    - 4 orders of magnitude improvement
    - PANi/SWNT devices outperfom devices with Au electrodes

- How does nanotube orientation affect carrier injection in PANi/SWNT composites?
  - Need to examine the morphology of the nanotube network inside the polymer and relate it to conduction
  - Need to understand if SWNT induce charge transfer at the SWNT/PANi interface or at the SWNT/PANi/semiconductor interface

- Will use and help develop new SEM imaging and I-V tools developed at ORNL

OAK RIDGE NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

CNMS
Center for Nanophase Materials Sciences

Examples of industry research at NSRCs

Molecular Foundry at LBNL

Polymers Facility – R. P. Meagley, Intel Corporation

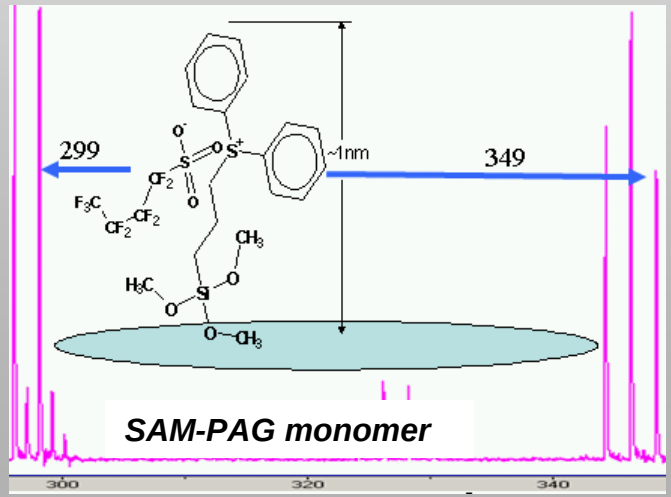
1st SAM-Photo-acid generator (PAG) *monolayer light sensitive catalyst precursor @ interface-to correct profile at base of feature*
1st Preorganized Resist -*precise base & switch placement: smooth speed*
1st Poly-PAG *polymeric light sensitive catalyst precursor*
1st Nano Si & Ge LDI-TOF-MS 4/19/05- *nanoparticle mass & structure assay*

Chemical Amplification limits? *Speed enhancement & size reduction by resist components preorganization*

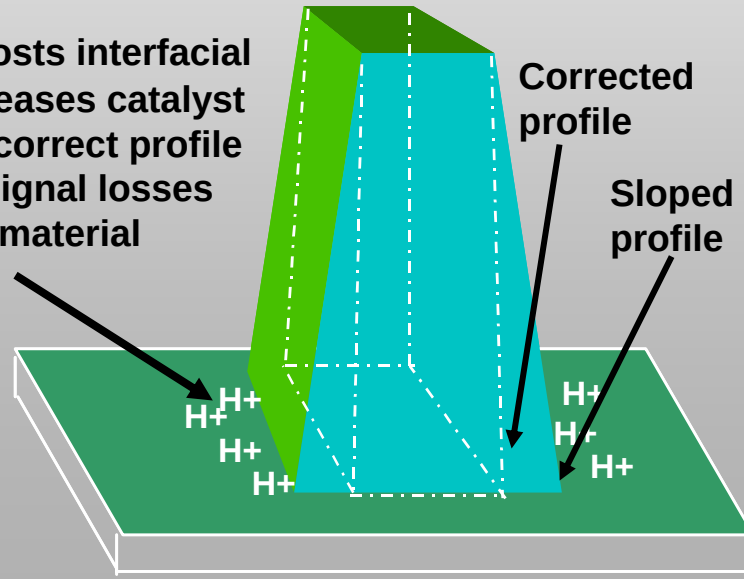
- *Speed vs. roughness*
- *Catalytic turnover vs. volume*
- *Transparency vs. switching speed*
- *Dissolution contrast vs. developer*

nm interfacial & structural control!

MS/MS: ***size & structure assay***



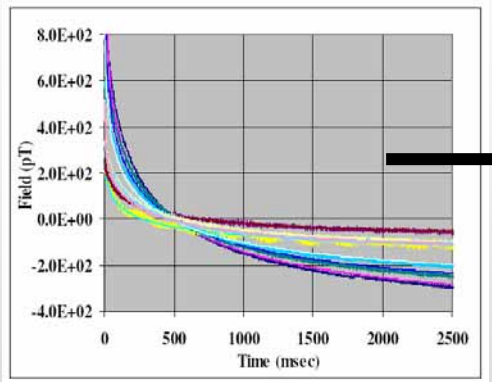
SAM-PAG: **boosts interfacial resist gain & increases catalyst concentration to correct profile slope from light signal losses through depth of material**



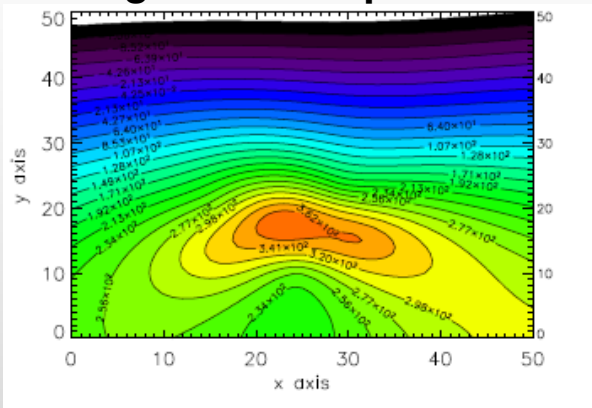
Examples of industry research at NSRCs

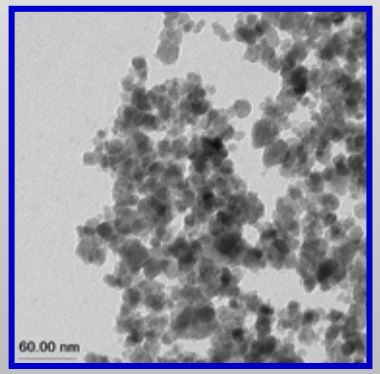
- ***Senior Scientific LLC is a startup developing magnetic detection techniques for cancer, organ rejection, and Alzheimer's plaques; their technology:*** ➔

7-channel SQUID signal of Néel relaxation

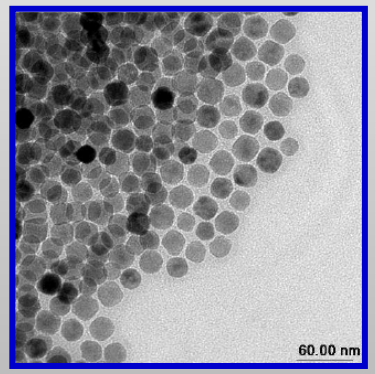


Map of binding of superpara-magnetic nanoparticles





Commercially available particles are too small, irregularly shaped, polydisperse, and agglomerated. Less than 5% contribute to signal (the others are too small).



CINT developed particles are larger, lower polydispersity, and >50% are of the appropriate size and contribute to signal.

- ***Role of CINT (at Sandia and Los Alamos National Laboratories):***
  - ***Custom nanoparticle synthesis with optimal sizes, narrow polydispersity, magnetite composition and structure***
  - ***Developing coatings to allow particles to cross the blood-brain barrier***

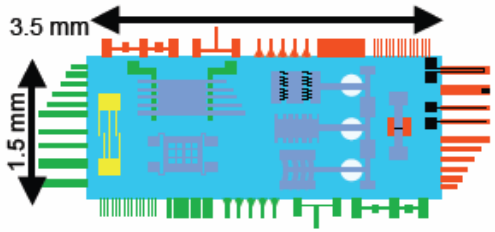
Novel approaches for rapid, reproducible measurements and synthesis

New Tools: Discovery Platforms™

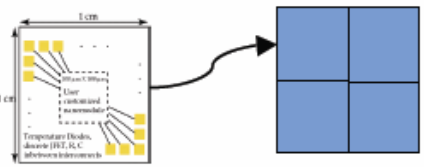
Standardized modular, micro-laboratories—designed and batch fabricated for:

- Integrating nano and micro length scales
- Studying the physical / chemical properties of nanoscale materials and devices
- Directly accessing wide range of CINT external diagnostic and characterization tools

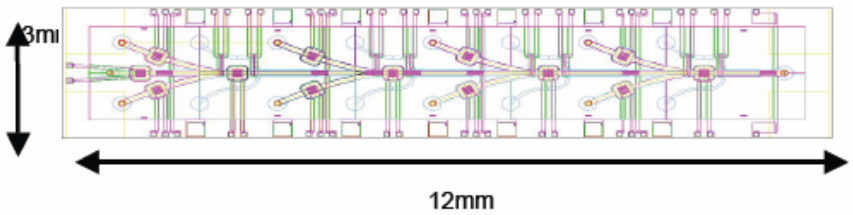
Cantilever Array Platform



Electrical Transport & Optical Spectroscopy Platform



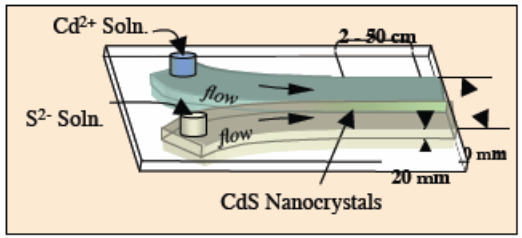
Microfluidic Synthesis Platform

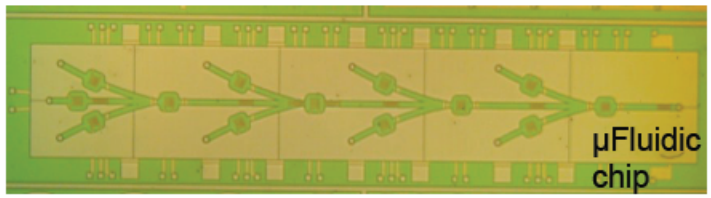


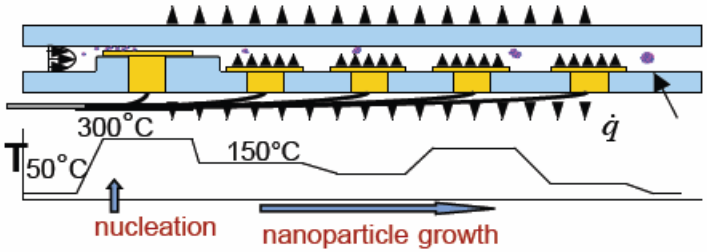
Novel approaches for rapid, reproducible measurements and synthesis

Microfluidic Synthesis Platform:

Controlled Kinetics of Nanomaterial Synthesis



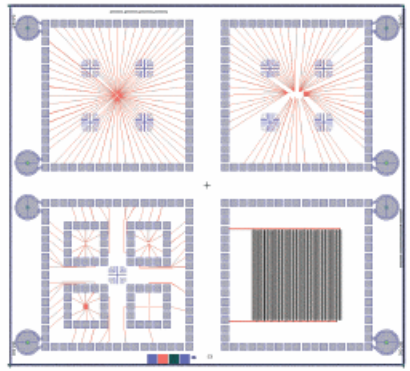




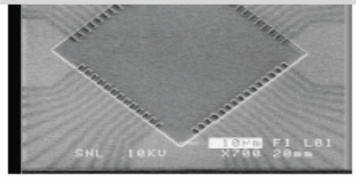
Enables fundamental studies of synthesis of novel nanomaterials.

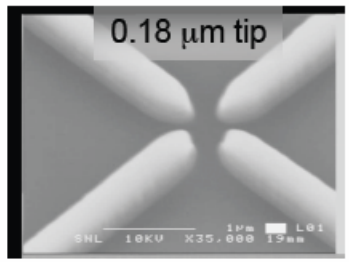
All Discovery Platforms ™ are fabricated in MESA

Optical and Electronic Transport Platform

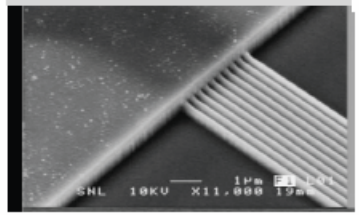


user-customizable area

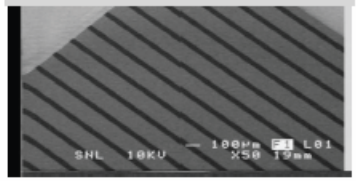




0.18 µm lines & spaces



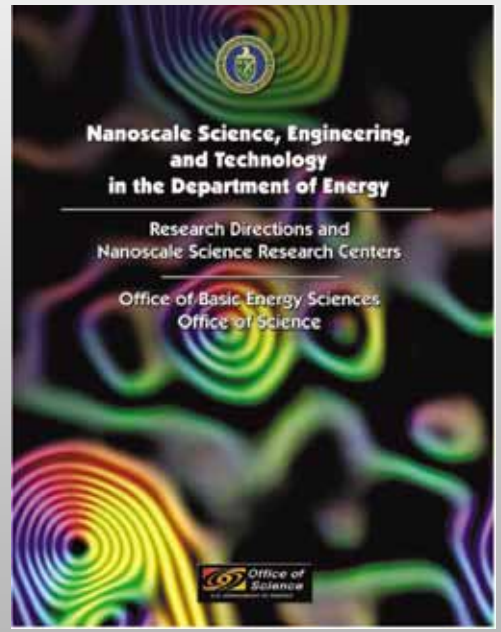
50 µm interdigitated lines & 150 µm spaces



For more information:

- **On the NNI:**
  http://nano.gov

- **On DOE nanoscience and NSRCs:**
  http://nano.energy.gov



…or visit booth #100!

Acknowledgements

Clayton Teague – NNCO director

Celia Merzbacher – OSTP; NSET co-chair

NSET subcommittee members

NNCO staff

DOE NSRC staff