The NSF Nanoscale Science and Engineering Center for High-rate Nanomanufacturing

www.nsec.neu.edu

CHN

Northeastern UNIVERSITY

UMASS LOWELL

UNIVERSITY of NEW HAMPSHIRE

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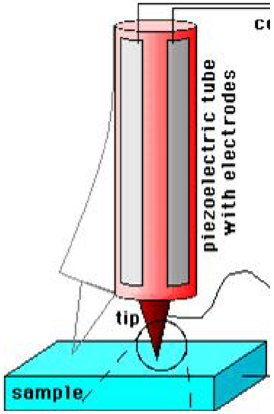
Outreach Universities: Michigan State University

Collaboration and Outreach: Museum of Science-Boston, City College of New York, Hampton University, Rice University, ETH, University of Aachen, Hanyang University, Inje University, The Korean Center for Nanoscale Mechatronics and Manufacturing (CNMM), Taipei University, University of Hyogo

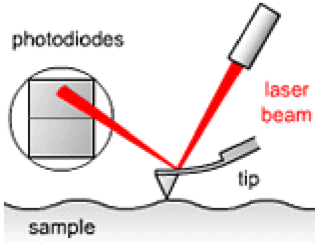
Nanoscience

Past and present:

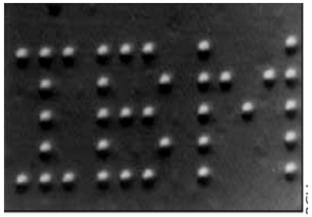
Manipulation of few atoms and SWNTs



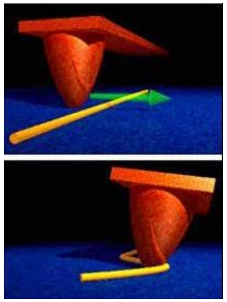
STM
1981



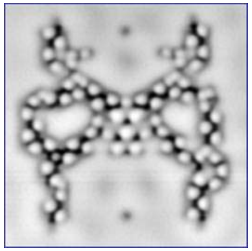
AFM
1986



STM manipulation of atoms
1989



AFM manipulation of a SWNT
1999



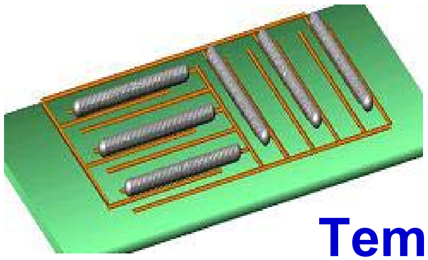
Molecular logic gate
2002

Source: IBM

Nanomanufacturing

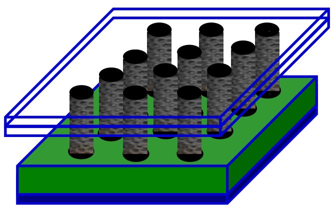
Future:

Manipulation of billions of atoms and SWNTs

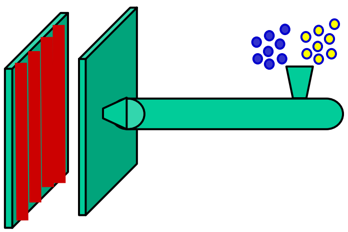


Templates

2004

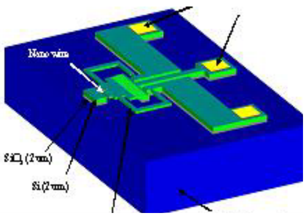


2005



High rate
High volume

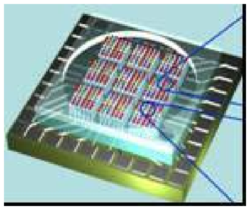
2006

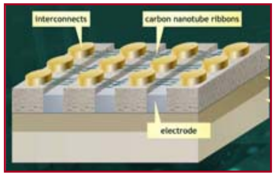


Reliability

2007

Biosensor





Memory device

Informed public and workforce

Environmentally benign processes

What are the Critical Barriers to Nanomanufacturing?

- **Barrier 1. How can we assemble and connect different nano-scale elements?**

  e.g., How do forces affect the orientation of nanoscale structures and interaction of surfaces? And how do we control these forces?

- **Barrier 2. How can we process nanoscale structures in a continuous or high rate manner?**

  e.g., How do the interfacial behavior and forces required to assemble, detach, and transfer nanoelements differ at high rates and over large areas?

- **Barrier 3. How can we test for reliability? How can we efficiently detect and remove defects?**

  e.g., How can we selectively remove defects without disturbing assembled nanoelements?

- **Barrier 4. Do nanoproducts and processes require new economic, environmental, and ethical/regulatory assessment and new socially-accepted values?**

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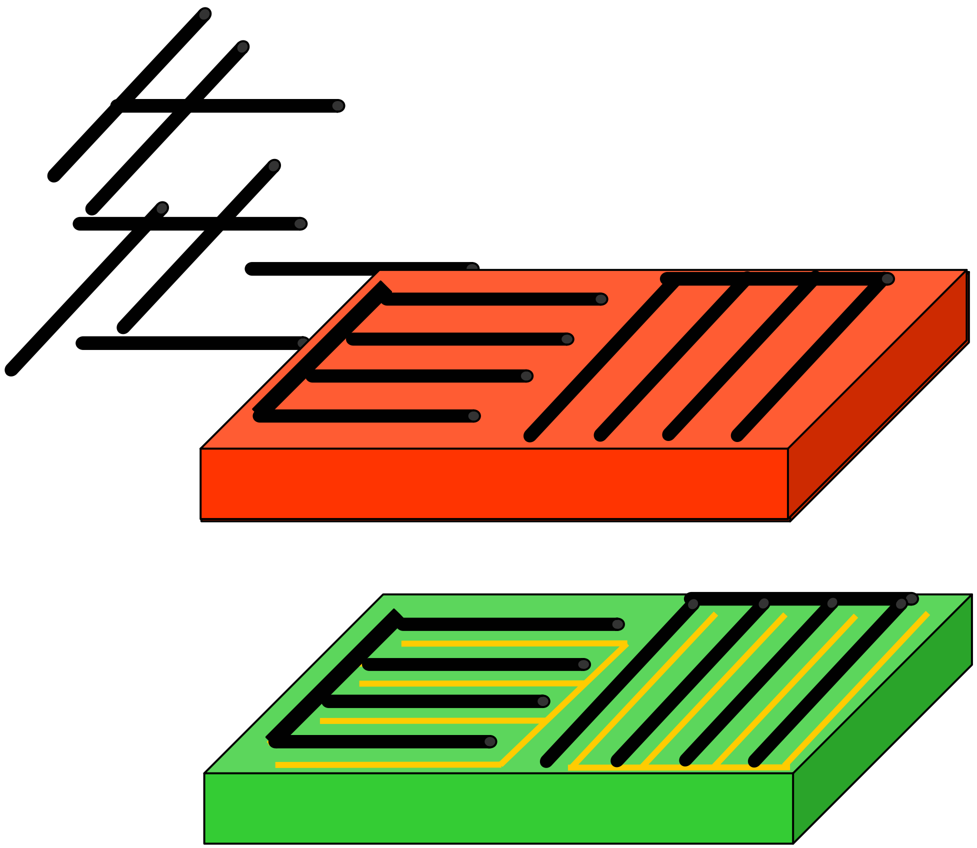
CHN Vision: Guided Self Assembly

High-rate/High-volume Guided Self-Assembly of Nanoelements



- **State of the Art:**
  - **Pure self-assembly produces regular patterns**
- **Challenge:**
  - **Nanotemplates enable guided self assembly**

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Partnerships

Industry

- Wolfe Laboratories, Inc.
- Foster-Miller
- Nantero
- Rosseter — Rosseter Holdings Ltd
- intel
- tsi
- PI
- Motorola — intelligence everywhere
- zyvex
- SCFluids Incorporated
- Draper Laboratory
- Arthur D Little
- Environ
- tyco Electronics
- M/A-COM
- Massachusetts Technology Collaborative
- Konarka technologies

Students / Faculty ↑ CHN

Facilities / Researchers ↓ CHN

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Faculty / Researchers / Students ↔ Government Labs

Faculty / Researchers / Students ↔ Universities and other Outreach

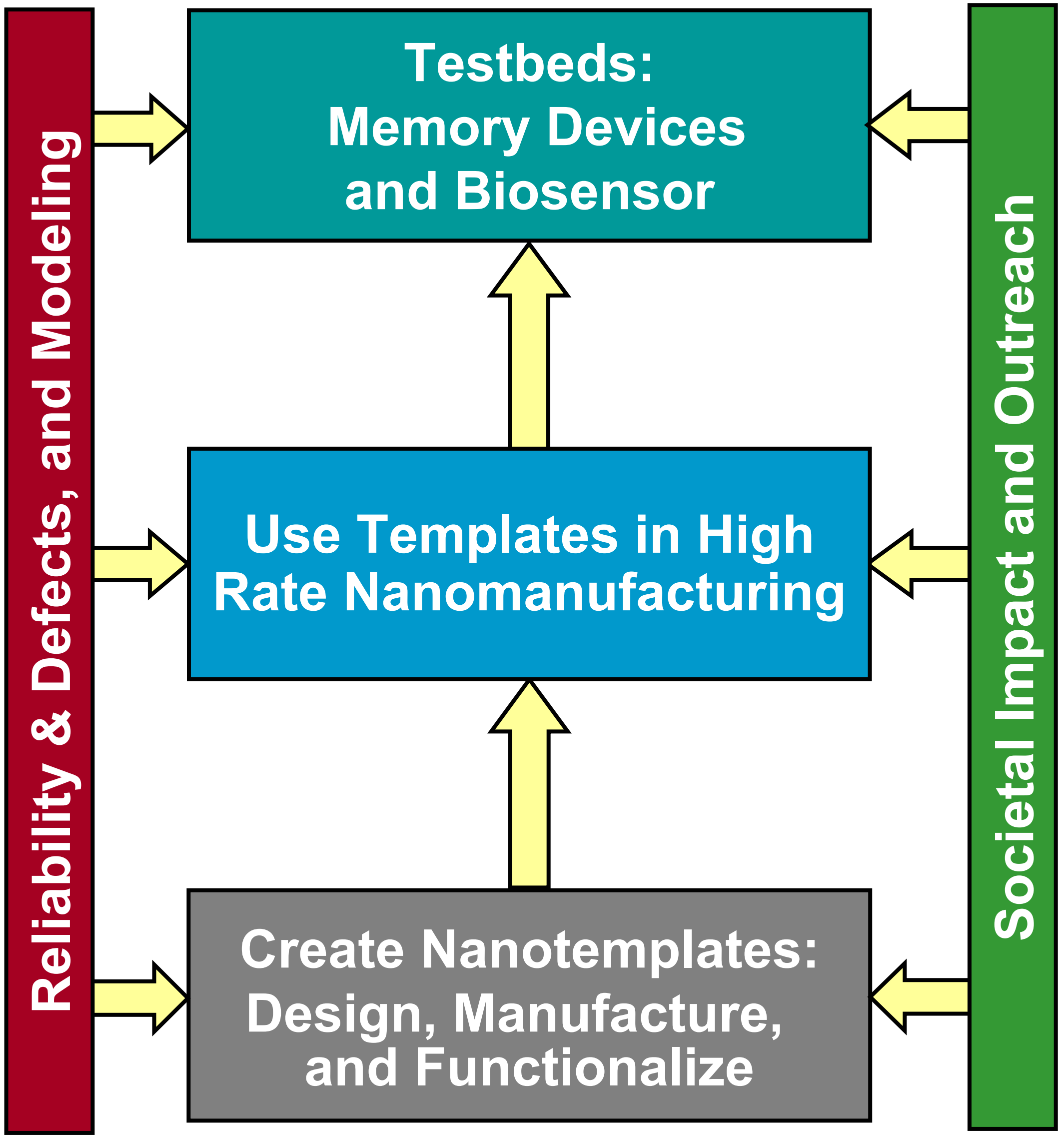
Government Labs

- Lawrence Livermore National Laboratory
- ARL

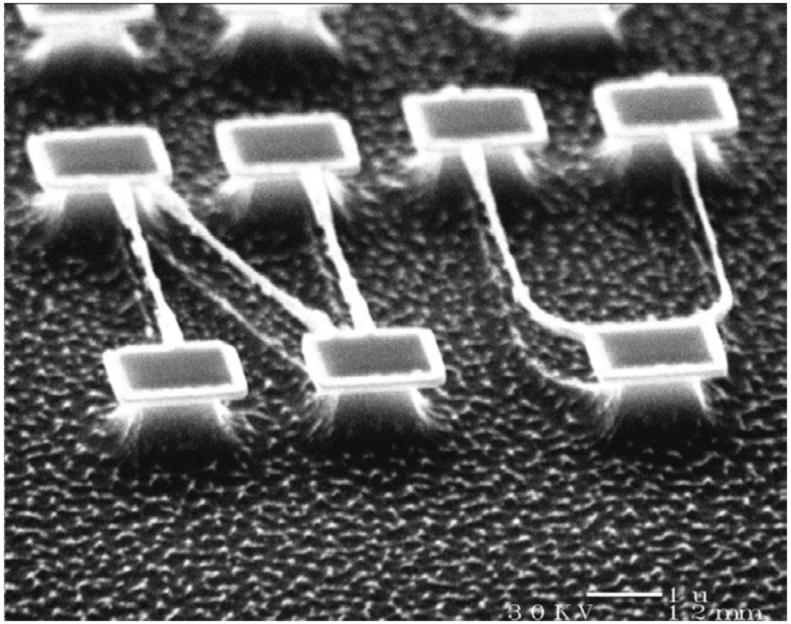
Universities and other Outreach

- Hampton University
- 臺北醫學大學 Taipei Medical University
- 仁濟大學校
- Museum of Science
- City College CCNY New York
- Himeji Institute of Technology
- Swiss House for Advanced Research and Education (SHARE)
- AMO GmbH, Huyskensweg 25, D-52074 Aachen, +49-241-8867-200
- Micro Biochip Center

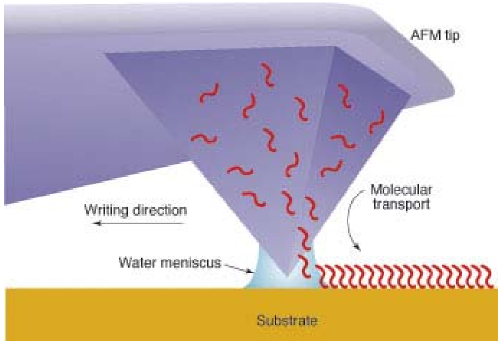
CHN's Path to Nanomanufacturing

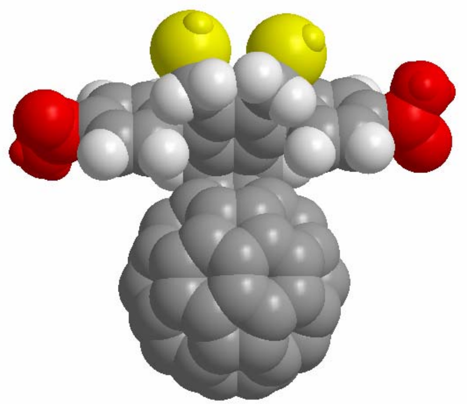


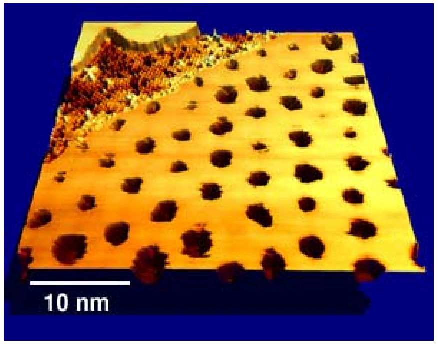
Nanotemplate Pattern Fabrication

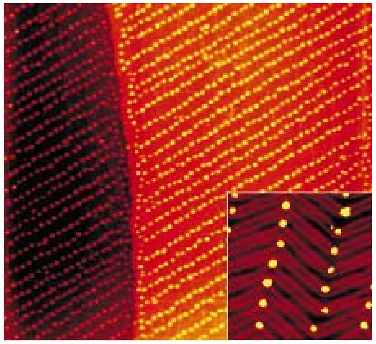


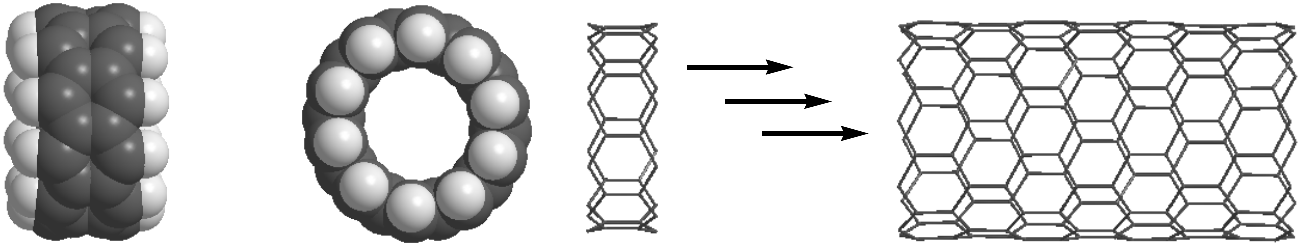
E-beam lithography: gold wires suspended over silicon (Northeastern U., 2004)











Controllable diameter
Controllable length

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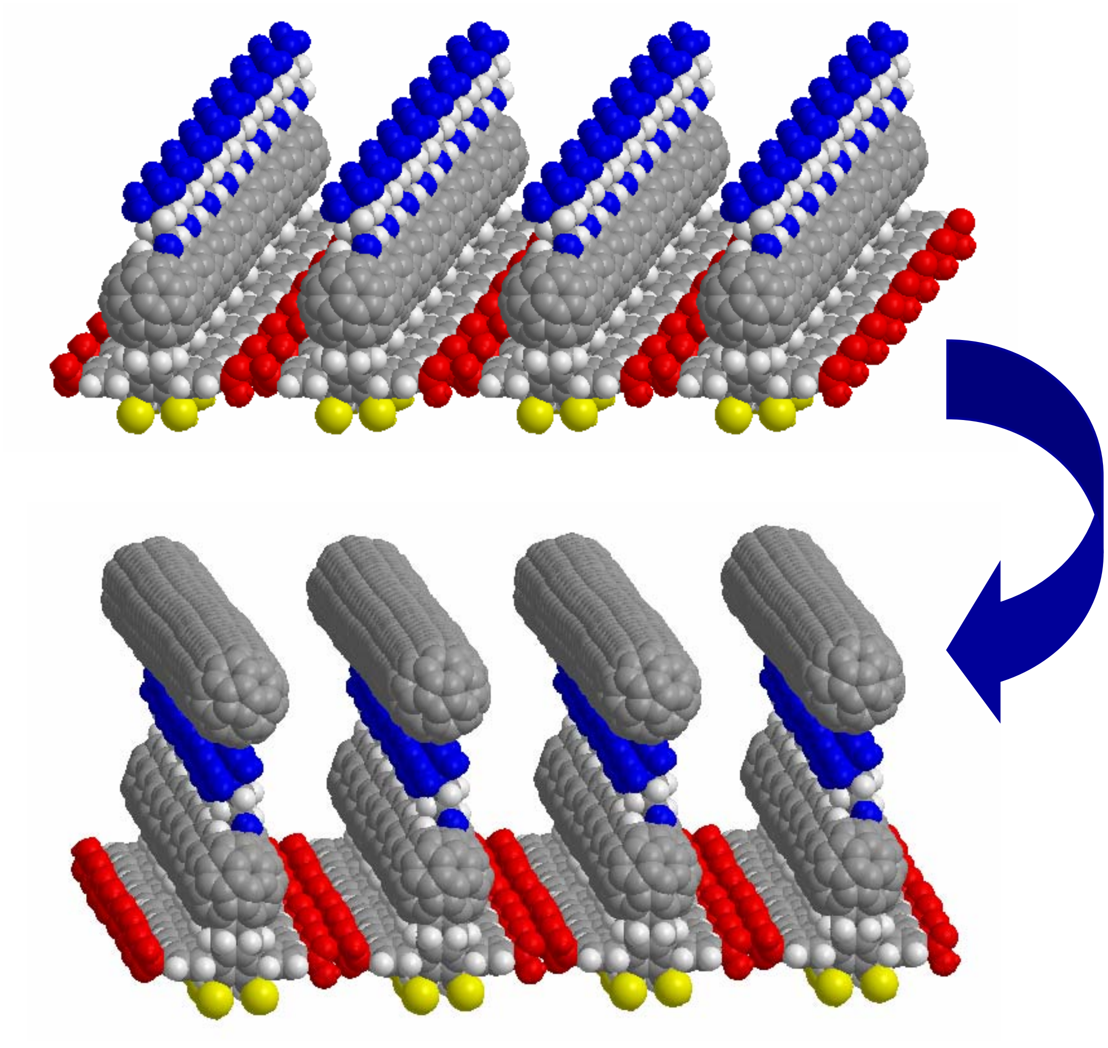
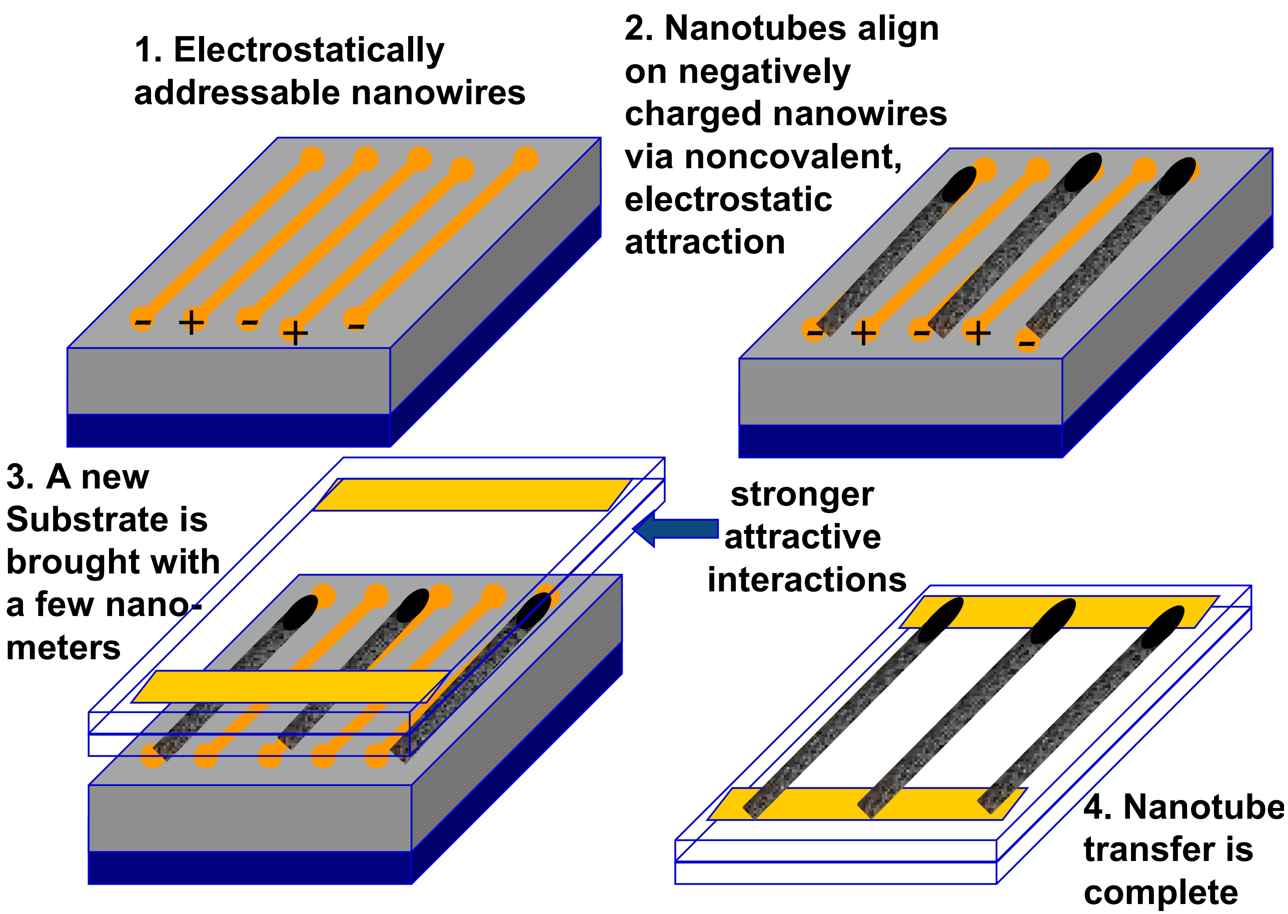
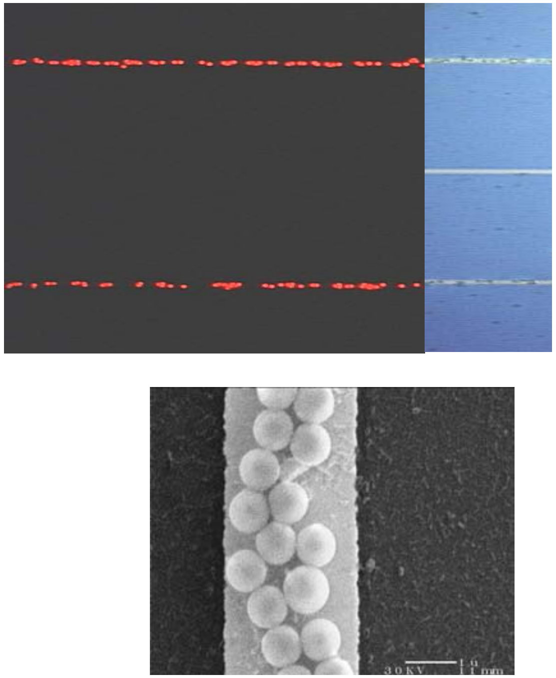
Challenge: Use the Nanotemplates for 2-D Assembly



Functionalizing the [60]fullerene array produces a nanotemplate that can be used to selectively bind nanoelements including single-walled carbon nanotubes

Challenge: Use the Nanotemplates for 2-D Assembly





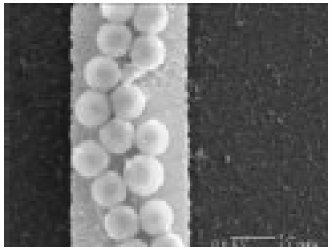
Guided self assembly of particles onto Au wires (Busnaina, NEU, 2003)

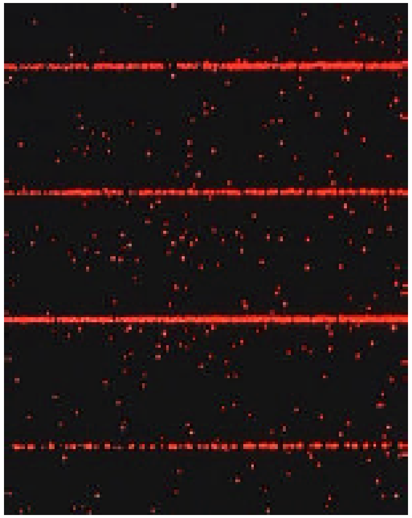
Challenge: Use the Nanotemplates for 2-D Assembly

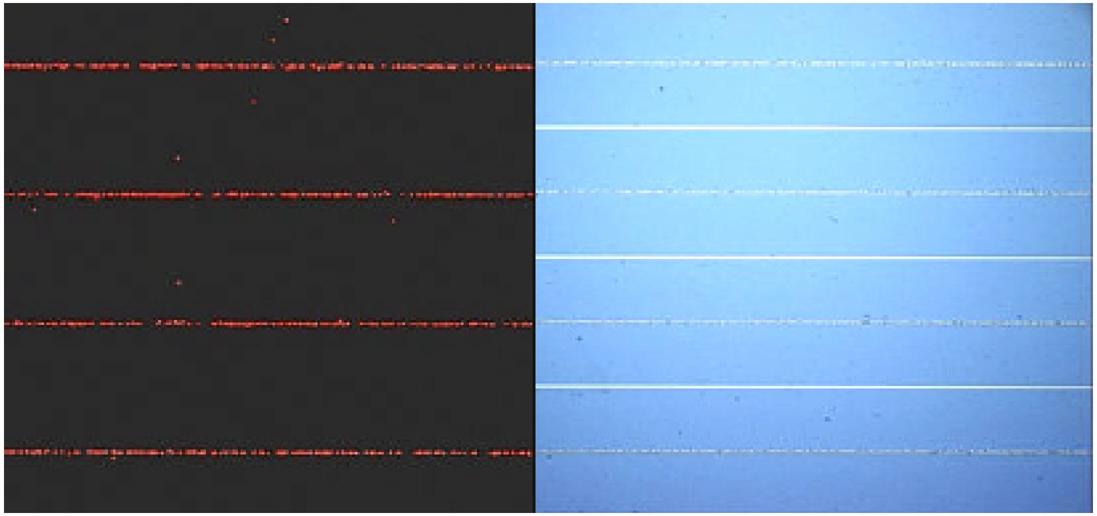
Controlled Assembly of Submicron Particles

Gold surface has higher Hamaker Constant than Silicon surface and induces higher adhesion force on PSL particles.

Particles deposited anywhere else can be removed by flow rinse.





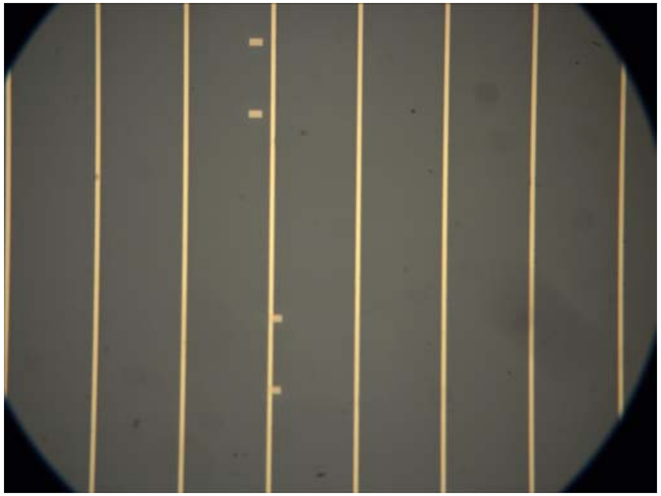


Assembly without cleaning Control　　Assembly with cleaning Control

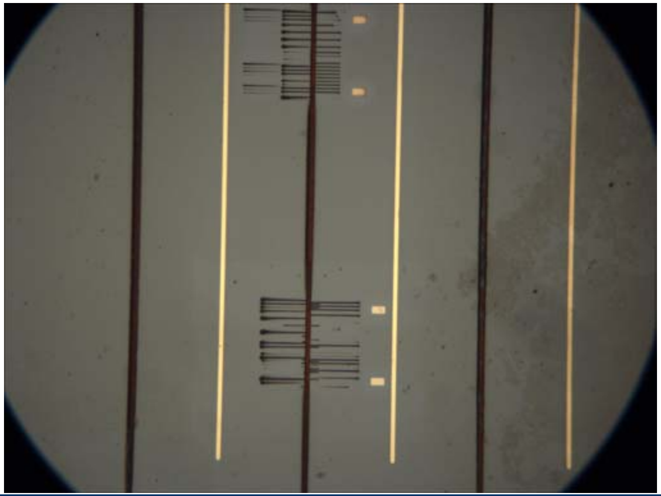
Selective removal of 800 nm particle on Nanotemplates

Guided Assembly

CNT on 2 micron Au wires, black wires are positive charged and yellow negative

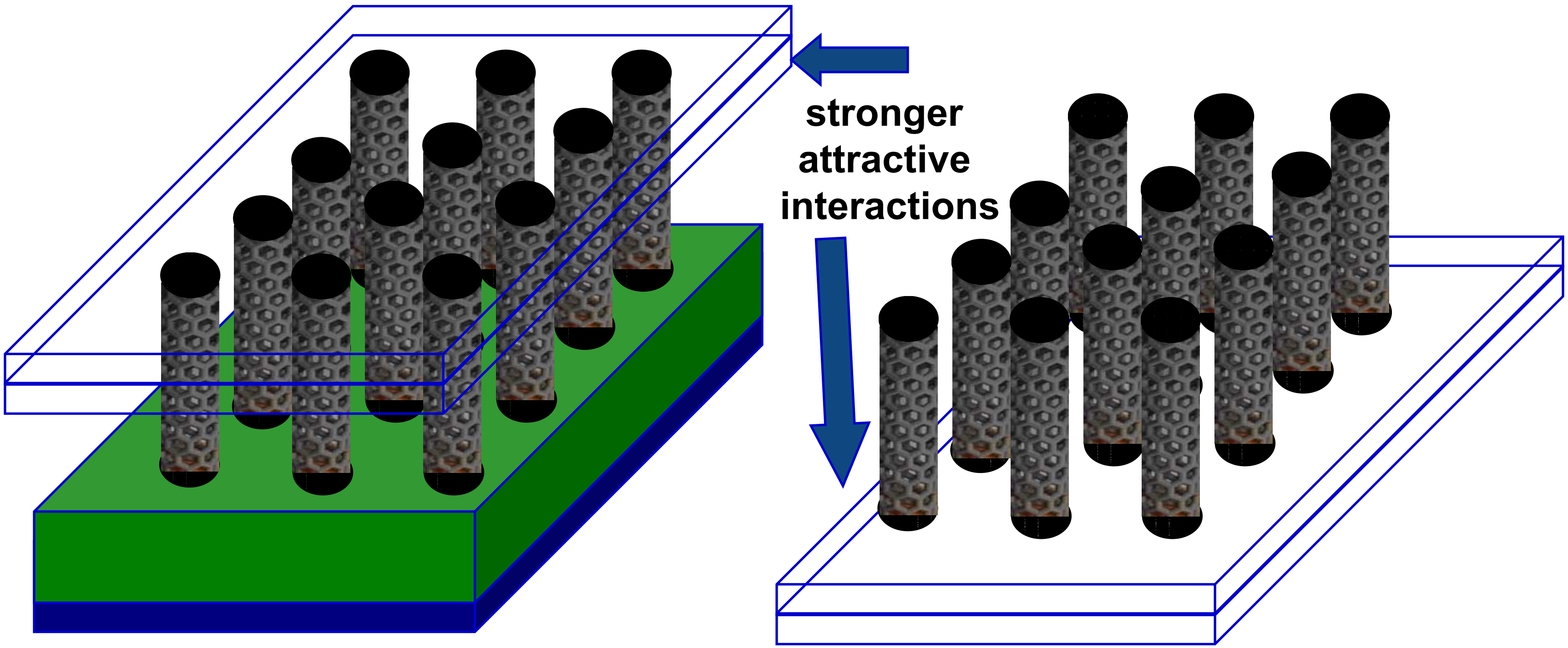


50nm nanowires (nanotemplates) connected to 2 micron wires (nanowires cannot be seen in optical microscope)



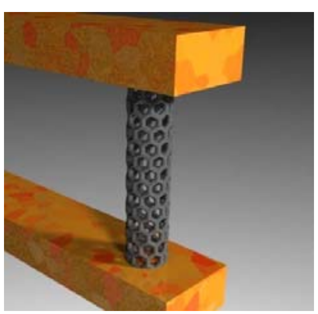
After CNT self-assembly, 50nm nanowires are covered with CNTs, which makes the nanowire wider and can be seen in optical microscope

3-D Assembly of Nanotube Interconnects



5. A new substrate with stronger attractive interactions is brought into contact

6. Nanotube transfer is complete



Possible applications: Nanotube interconnect and magnetic media

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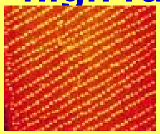
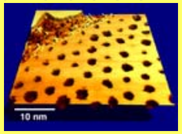
Guided Self-Assembly of Polymer Melts at High Rates

Approach

- Use nanotemplates in high rate environment

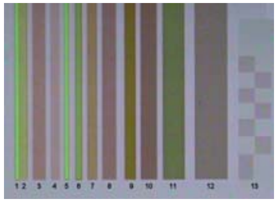
Nanotemplates used as tooling surface in high rate process

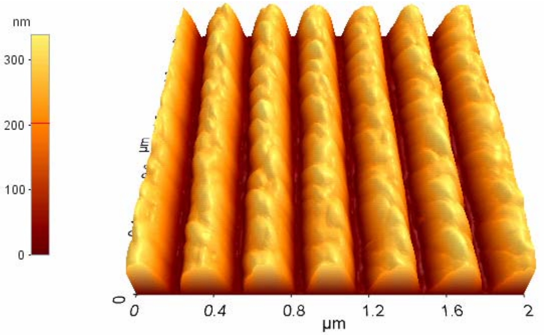




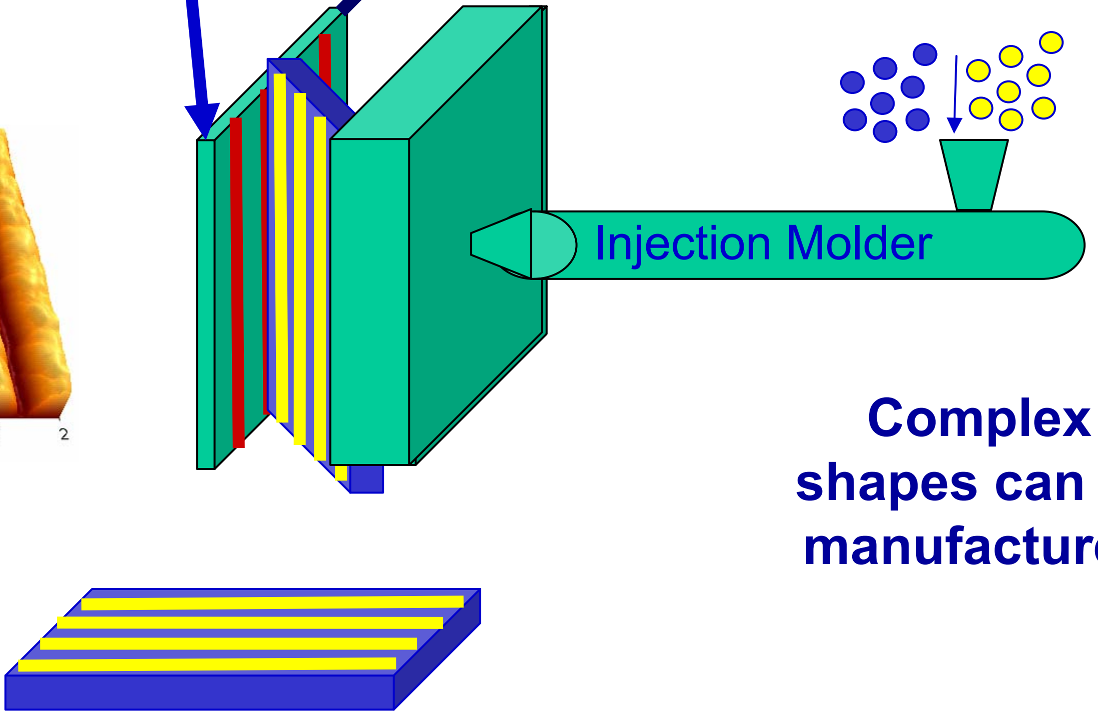
microinjection molding machine

3-D templates Made at our partner University in Japan





Polymer A + B
Block copolymers



Complex shapes can be manufactured

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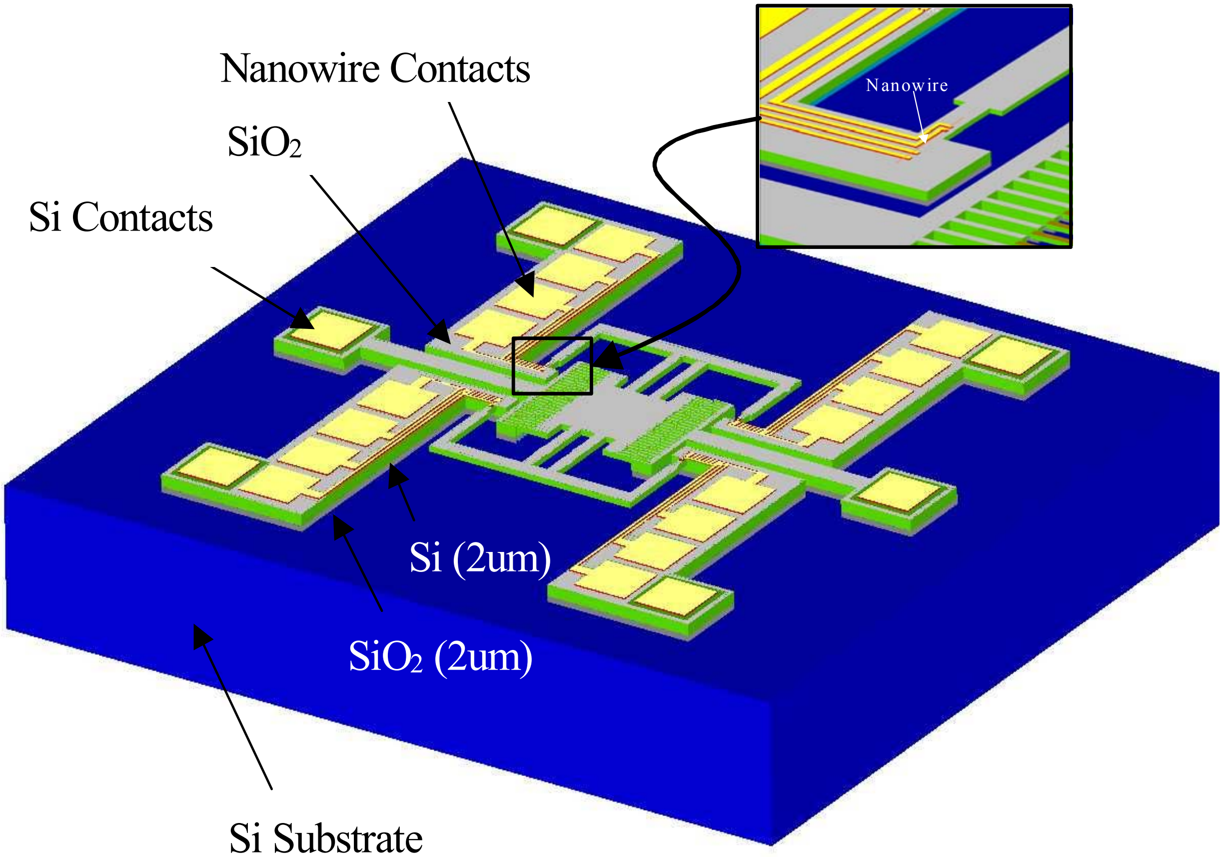
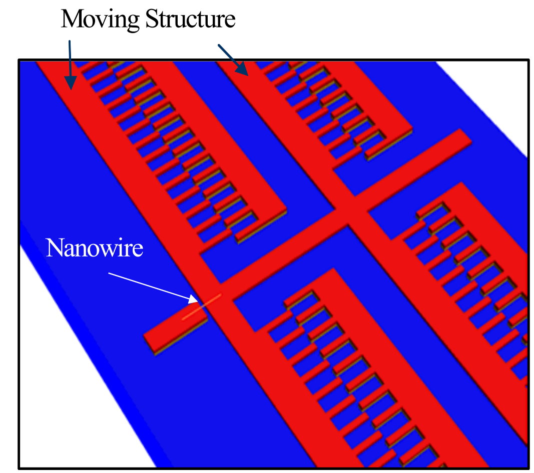
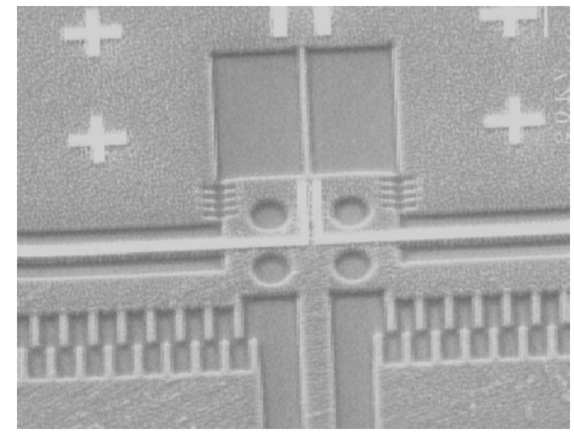
MEMs Nanoscale Characterization and Reliability Testbed





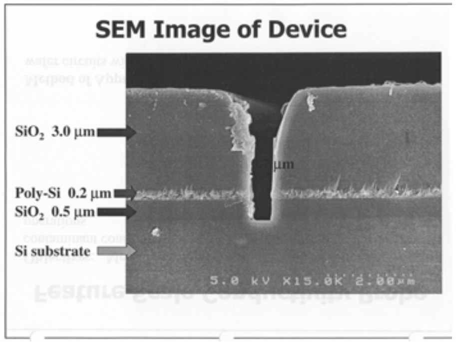


Innovative MEMS devices characterize nanowires (also nanotubes, nanorods and nanofibers) and conduct accelerated lifetime testing allowing rapid mechanical, electrical, and thermal cycling during UHV SPM observation

Defects in Nanomanufacturing

State of the Art (Semiconductor Industry)

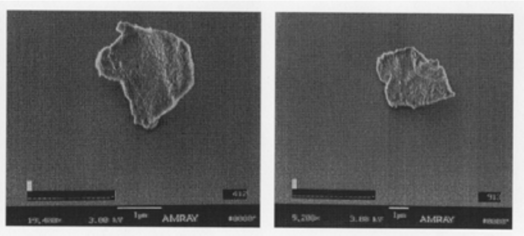
- Particulate, ionic, and organic contaminants
- Cleaning is applied over a large area
- Non selective removal
- Removal of defects: ~ 100 of 400 processing steps



Photoresist particles trapped in submicron trench (Micron Technology)

Challenges In Nanomanufacturing

- Need to worry about the above and other defects
- Need selective impurity and defects removal (e.g., oxygen)
- Chemistry plays a larger role
- Need to understand the adhesion of surfaces, particles, and nanoelements in a variety of conditions and situations
- Cleaning nanostructures without destroying them



Particles generated in a W CVD process (Busnaina, NEU, 1998)

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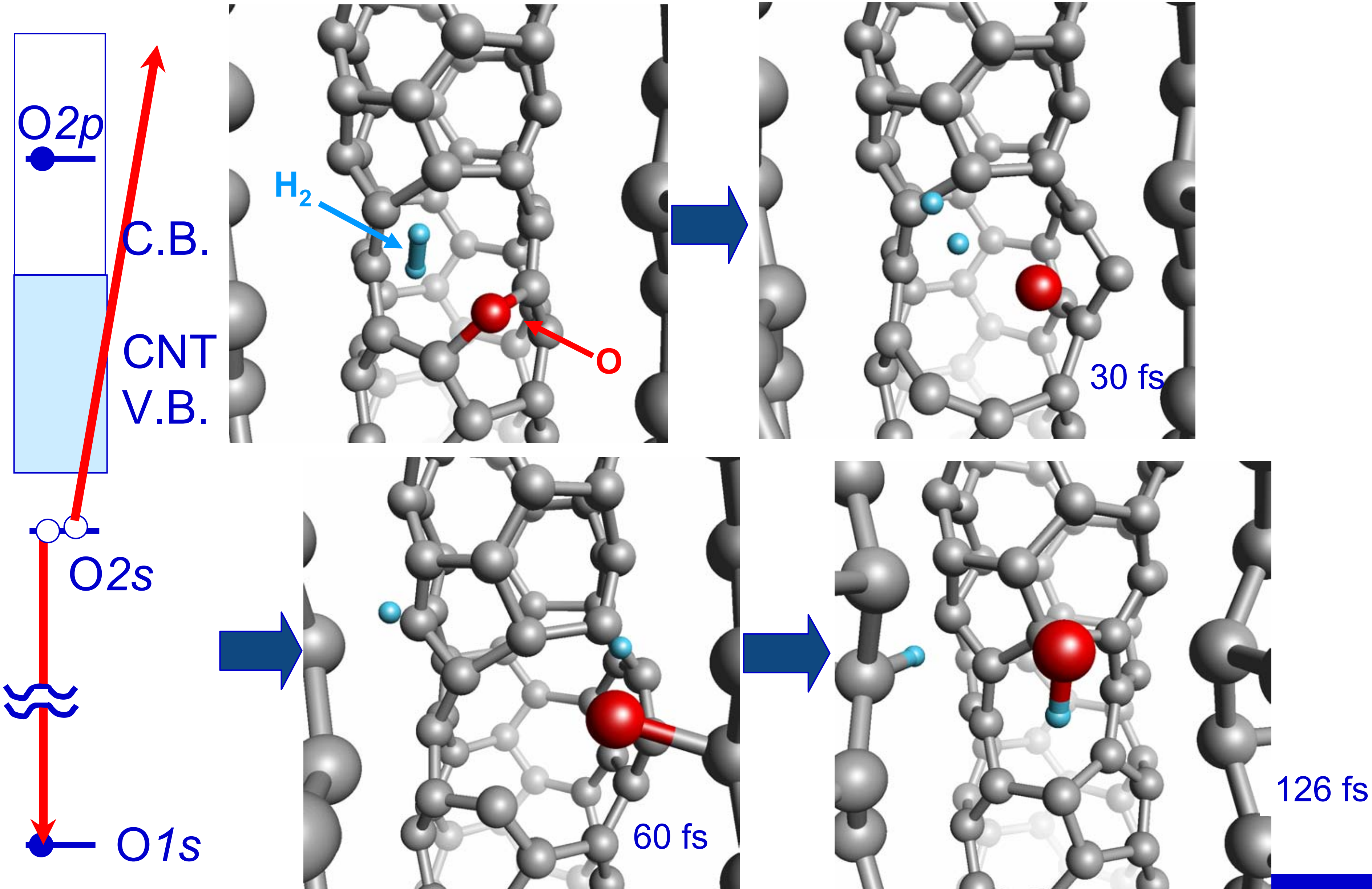
Auger decay following the O1s → 2p excitation (~520 eV)

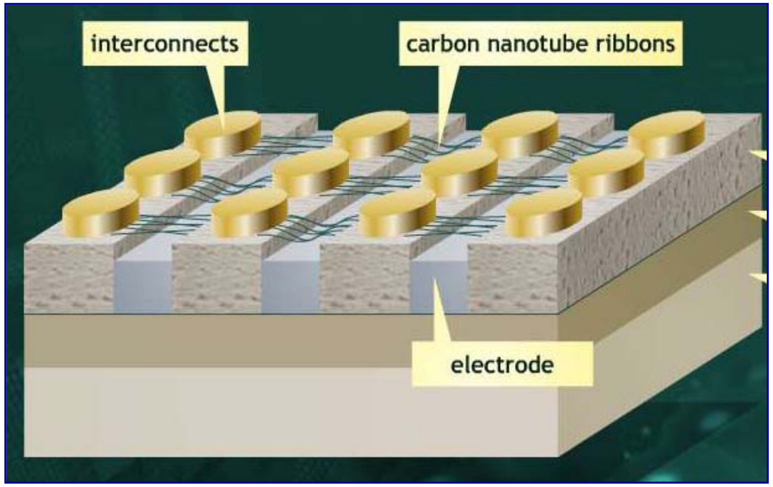


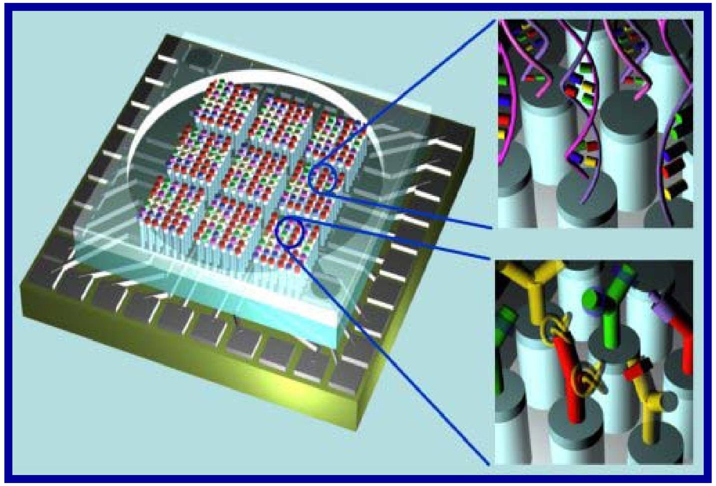
- Removal of oxygen by photo-surgery

(Tomanek, MSU, 2004)

Proof of Concept Testbeds
Research Drivers

True manufacturing success and product realization will not occur without strong industry partnership at inception





Nanotube Memory Device

- **Partner: Nantero**
- Making nanoelectronic devices using carbon nanotubes

Biosensor

- **Partner: Triton Systems**
- FDA testing on functionalized nanoparticles for cancer tumors with UML faculty

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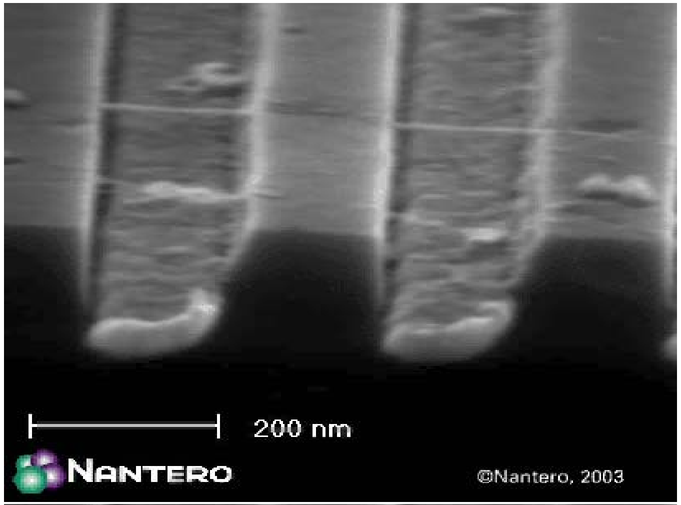
Use of Nanotemplates for Nanotube Memory Chip

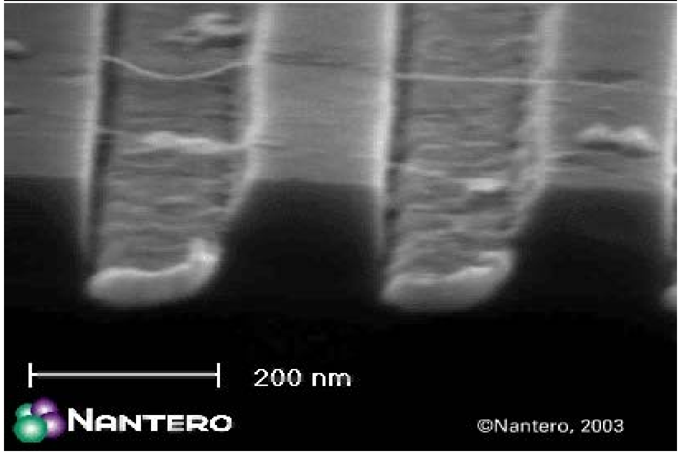
Ultimate scaling beyond CMOS to Tb/cm^2 requires breakthroughs:

➢ Large-scale precise, economic assembly of CNTs with:

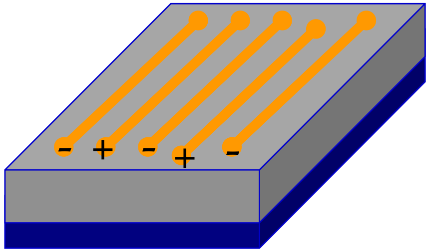
- specific orientation and functionality
- with connection to the micro/macro level
- at high rate and volume

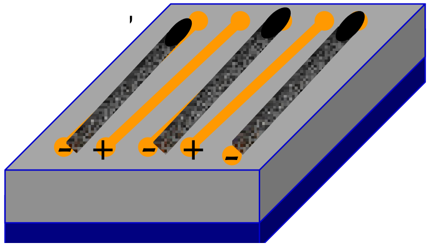
Nantero will use the developed nanotemplates with CMOS in a “hybrid” commercial testbed to reach ultimate scaling





(Nantero, 2004)



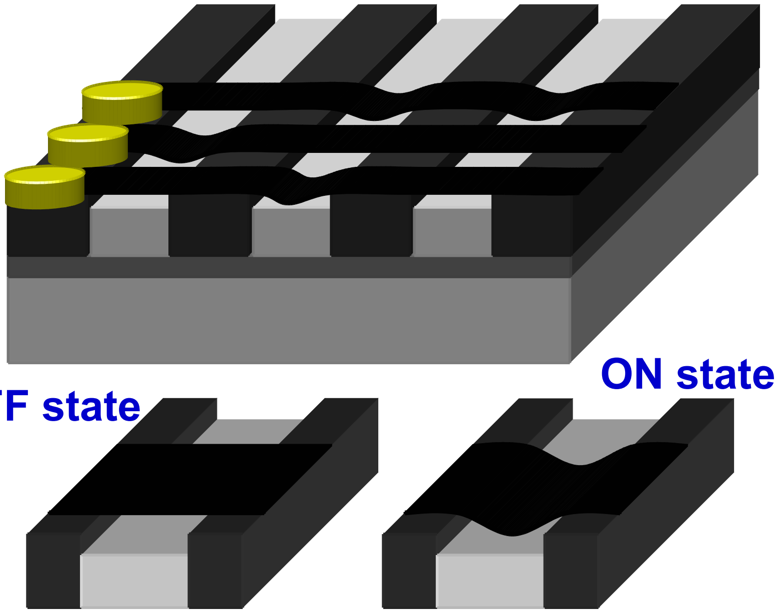


High Density Memory Chip

Current process

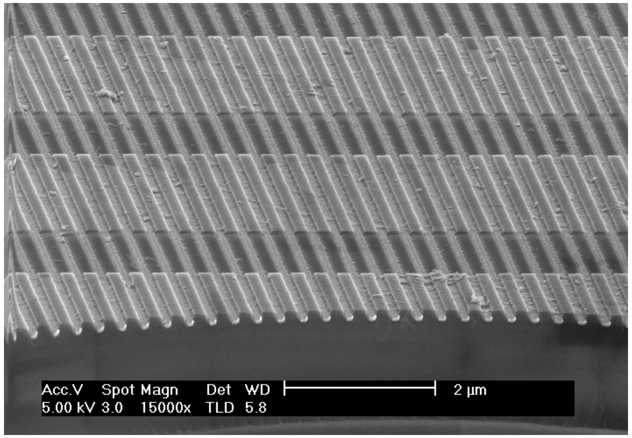
- Uses conventional optical lithography to pattern carbon nanotube films

- Switches are made from belts of nanotubes

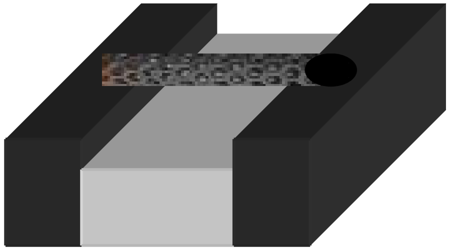


(Nantero, 2004)

Electrodes (~100nm with 300 nm period)

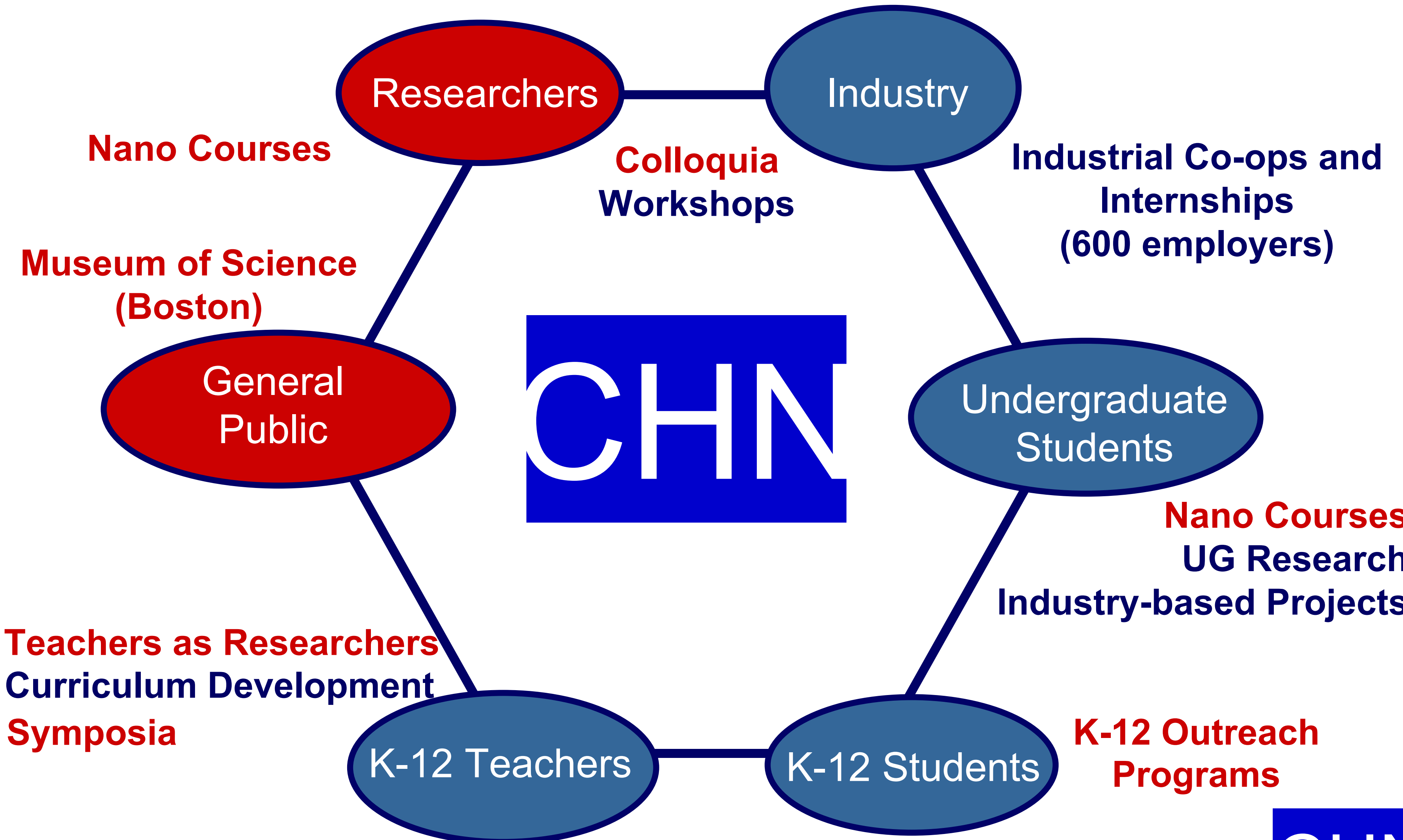


Nanotemplate will enable single CNT electromechanical switch



(Nantero, 2004)

Education for Nanomanufacturing



George J. Kostas Nanoscale Technology and Manufacturing Center

- Established through Mr. George J. Kostas generous gift, the Center Facility will be ready in February 2005.

- The center will consist of three areas, fabrication, imaging and traditional labs. The first area consists of class 10 and 100 cleanrooms and includes capability for nanolithography (FESEM, Nanoimprint, etc,.) , wet chemical processes. The second area is dedicated to imaging and characterization (SPM, STM, AFM and FESEM with a nanomanipulator), nanoparticle characterization (size and zeta potential) and surface energy analysis

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Summary

- The Center for High-rate nanomanufacturing will enable the creation of commercial products by bridging the gap between scientific research and the creation of commercial products

- The Center introduces novel science to enable high-rate/high-volume nanomanufacturing, such as:
  1. High-volume room-temperature uniform CNT synthesis
  2. Fullerene nanowires
  3. Nanotemplates for patterning polymers at high rates

- Environmental, economic, and societal impact will be addressed concurrently with the technical research tasks

- Strong partnerships with industry will accelerate commercialization

- Partnerships among universities, K-12 teachers and students, industry, and the Museum of Science (Boston) will deliver education in nanomanufacturing to the current and emerging workforce