The NSF Nanoscale Science and Engineering Center for High-rate Nanomanufacturing
www.nsec.neu.edu

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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
Future:
Manipulation of billions of atoms and SWNTs

- Templates
- High rate
- High volume
- Reliability
- Biosensor
- Memory device

Informed public and workforce
Environmentally benign processes

2004
2005
2006
2007
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?
State of the Art:
- Pure self-assembly produces regular patterns

Challenge:
- Nanotemplates enable guided self assembly
CHN’s Path to Nanomanufacturing

Testbeds: Memory Devices and Biosensor

Use Templates in High Rate Nanomanufacturing

Create Nanotemplates: Design, Manufacture, and Functionalize

Reliability & Defects, and Modeling

Societal Impact and Outreach
Nanotemplate Pattern Fabrication

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

Controllable diameter
Controllable length
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

1. Electrostatically addressable nanowires
2. Nanotubes align on negatively charged nanowires via noncovalent, electrostatic attraction
3. A new Substrate is brought with a few nanometers
4. Nanotube transfer is complete

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

6. Nanotube transfer is complete.

Possible applications: Nanotube interconnect and magnetic media.

3-D Assembly of Nanotube Interconnects
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

3-D templates
Made at our partner University in Japan

Injection Molder

Complex shapes can be manufactured

Polymer A + B
Block copolymers

microinjection molding machine
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

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

Removal of oxygen by photo-surgery

(Tomanek, MSU, 2004)
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
Ultimate scaling beyond CMOS to $\text{Tb/cm}^2$ 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

Electrodes (~100nm with 300 nm period)

Nanotemplate will enable single CNT electromechanical switch

(Nantero, 2004)
Education for Nanomanufacturing

- Nano Courses
- Colloquia Workshops
- Industrial Co-ops and Internships (600 employers)
- Museum of Science (Boston)
- General Public
- Teachers as Researchers
- Curriculum Development Symposia
- Undergraduate Students
- Industry-based Projects
- K-12 Teachers
- K-12 Students
- Nanotechnologies
- UG Research Projects
- K-12 Outreach Programs
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.
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.