The New England Nanomanufacturing Center for Enabling Tools

Korea-US Nano Forum, October 14-15, 2003 Seoul

Three Dimensional Nanomanufacturing: NSF Workshop Report and Activities at the New England Nanomanufacturing Center for Enabling Tools (NENCET)

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Northeastern UNIVERSITY

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NSF Workshop on Three Dimensional Nanomanufacturing: Partnering with Industry

- The 2-day workshop served as a forum between industry, small business, and academia to address approaches to overcoming nanomanufacturing barriers and challenges.
- Invited experts from industry provided input and perspective to NSF on current nanomanufacturing research and challenges.
- Over 100 experts and grantees from small business and academia gathered for this workshop to advise NSF on research needs for the future.

Speakers from the following companies:

Motorola, Intel, Hewlett-Packard Laboratories, Lucent Technologies, Coventor Inc., General Electric Co., NexPress, Inc., General Motors, 3M, Triton Systems, Nanogen, Millennium Pharmaceuticals, Inc., Microtec, Ardesta, Roger Grace Associates, ARCH Venture Partners, LARTA, NIST, National Center for Manufacturing Sciences (NCMS)

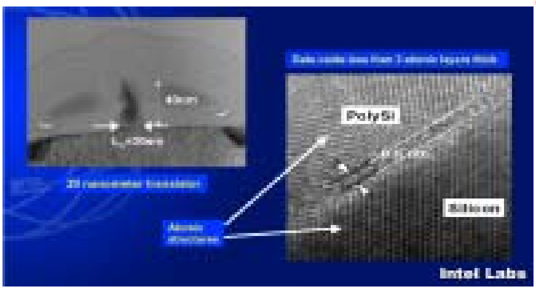
All workshop presentations are available at:

www.nano.neu.edu/nsf_workshop.html

NENCET

Panel and Attendee Input

- What is the current state of the art?
- Where are we headed?
- What are the barriers?
  - Technical
  - Cultural/Infrastructure
- What should be done to help accelerate nanomanufacturing success?

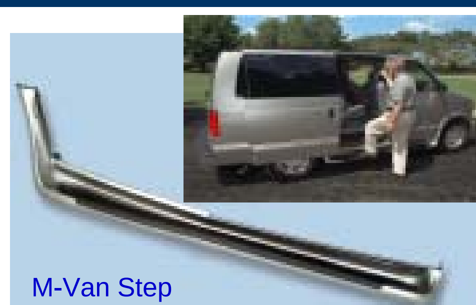


What is the Current State of the Art? Commercial Products

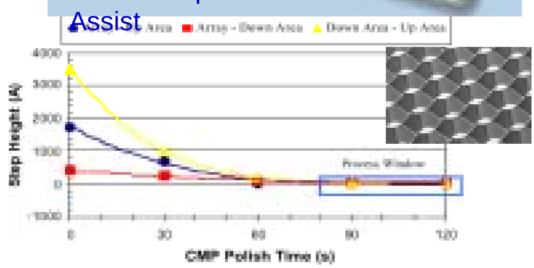
GM: Thermoplastic nanocomposites for automotive components

Triton: Nanocomposite air pouch for athletic shoes, packaging, and chemical-biological protective clothing

3M: CMP fixed micro fabricated abrasive pad

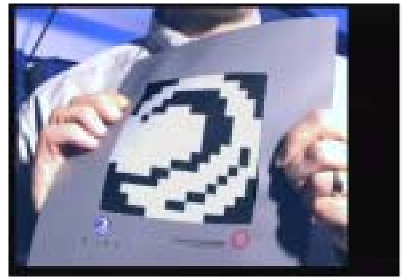


M-Van Step Assist

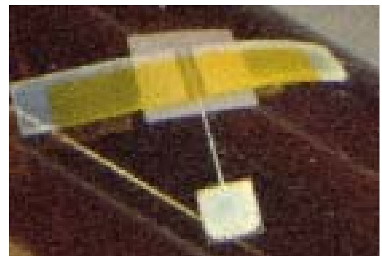


What is the current state of the art? Products in Progress

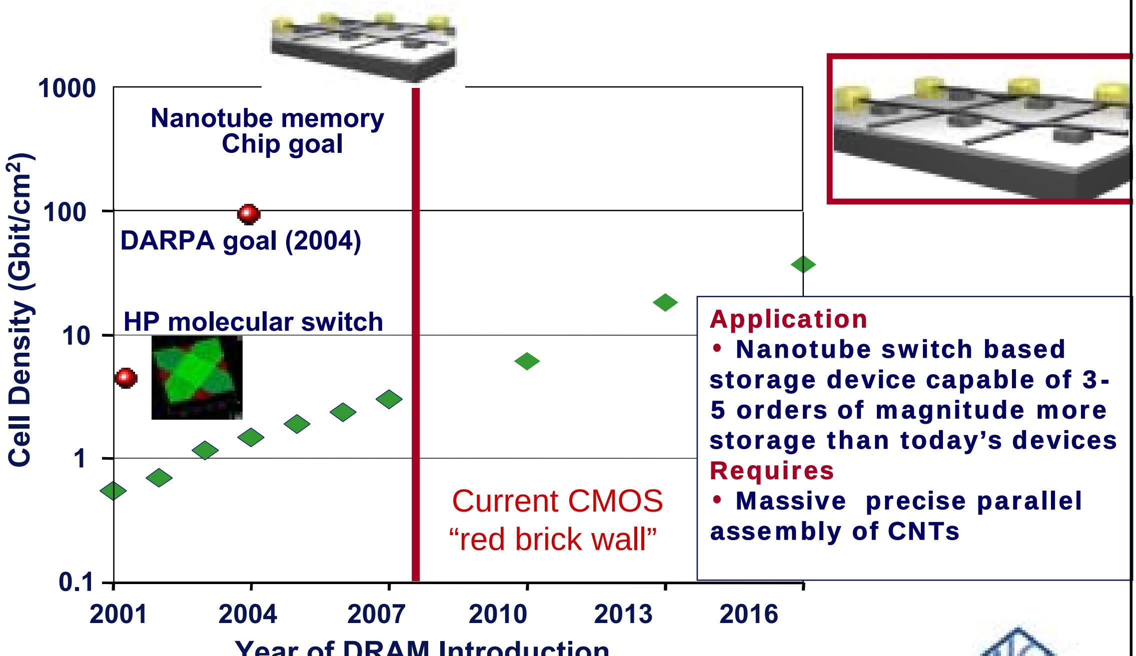
- HP: High density (6.4 Gbit/cm^2) electronically addressable memory (Molecular Switch Crossbar Circuits)
- Intel: Nano-transistors for logic technology
- Lucent: Rubber stamps and plastic circuits for electronic paper (plastic or paper display)
- Lucent: 3D microfabrication via printing on curved objects
- Lucent: Large area nanoreplication with a flexible mold
- Motorola: Nano elements of an OFET
- Triton: Nanoparticles cancer therapy
- Triton: Organic electronic materials



PNAS, **98**(9), 4835 (2001)
Science, **291**, 1502 (2001)



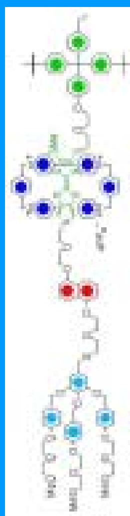
Possible Products; Nanotube Memory Chip



Application
- Nanotube switch based storage device capable of 3-5 orders of magnitude more storage than today’s devices

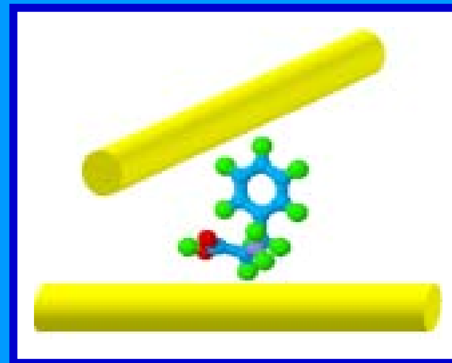
Requires
- Massive precise parallel assembly of CNTs

Example of Work in Progress; Molecular Electronics, HP



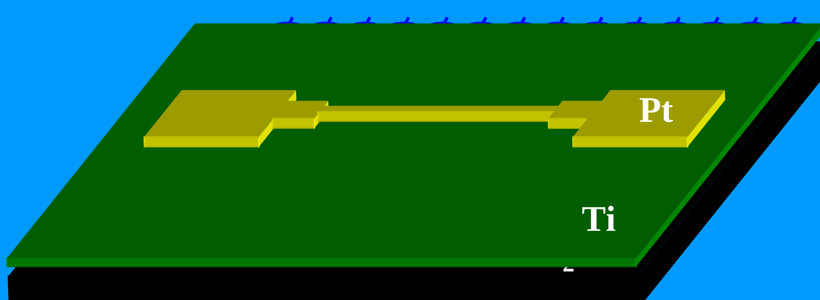
Roxtaxane
F. Stoddart, UCLA

Utilizes Switchable Molecules



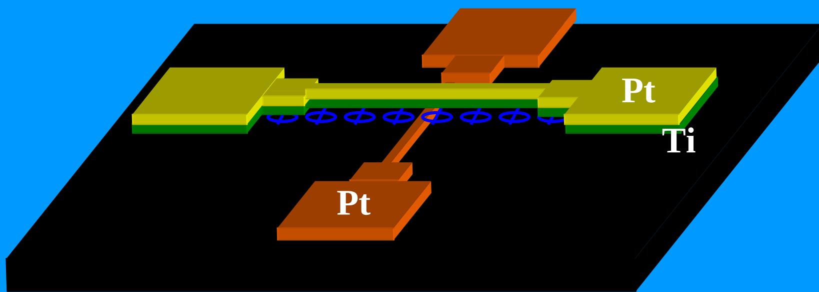
- It's small
- It functions
- It's cheap

Nanoscale Molecular Devices



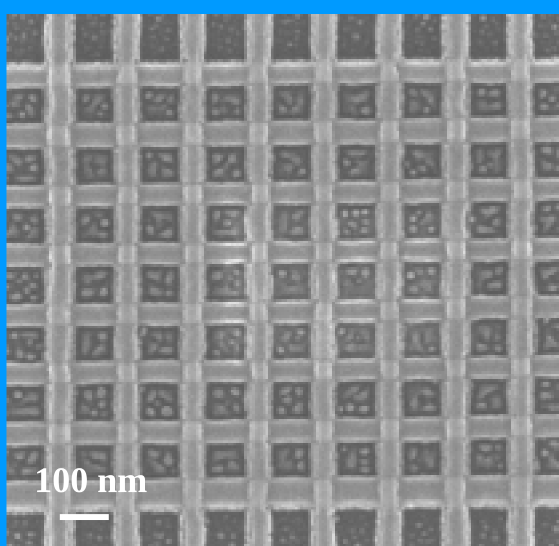
US Patent# 6407443

Nanoscale Molecular Devices



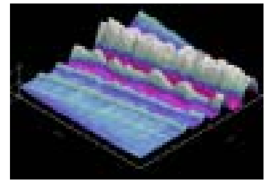
US Patent# 6407443

Molecular Crossbar Circuits

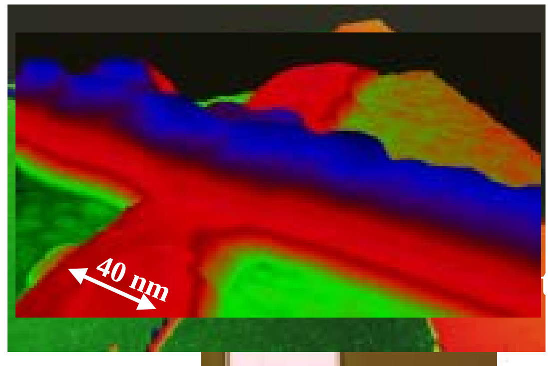


Where are we headed?

- Development of processing methods for fabrication of nanomaterials
  - New materials with unique properties
  - Environmentally friendly nanomanufacturing processes
  - Process models



- Heterogeneous, multi-scale materials/device integration and assembly.



What are the barriers? Technical

- **Assembly of 3D heterogeneous systems**
  - Low rates of 3D manufacturing
  - Alignment and registration - multilayers and interconnects
  - Interconnection at three dimensions, various length scales, different materials, and functionalities
  - Packaging
- **Quality**
  - Low reliability and yield are key issues for nanoscale devices that need to be solved
  - Reproducibility and repeatability of nanomanufacturing
  - Control of contamination and development of fault /defect tolerant devices
  - Control of morphology to produce an engineered structure.

What are the barriers? Technical

- **Modeling**
  - Limited understanding of fundamental physics
  - Lack of component specifications, material specifications, reliability models, simulation models
- **Materials**
  - Cost and availability of materials for scale up
- **Metrology of nanodevices**
  - Lack of real time characterization methods
- **Requirement for manufacturing processes that are robust under commercial environments (not Class 1 clean rooms)**

What are the barriers? Cultural/Infrastructure

- **Infrastructure**
  - Lack of standards, instrumentation, and tools
  - Lack of affordable infrastructure (facilities, equipment, design tools, skilled personnel)
  - Lack of nanotechnology roadmaps
- **Cultural**
  - Limited knowledge of nanomanufacturing processes within traditional manufacturing community
  - Education needed for both scientists and engineers
  - IP issues
  - "Nano-fear"

How to accelerate nanomanufacturing success?

- **Funding and Resources**

- **Spread roles, risks, and rewards among industry, academia, and government, motivate & reward risk taking**
- **Existing approaches**
  - Government funding (e.g., GOALI, STTR, ATP projects)
  - Research centers of excellence programs at universities that include small and large business participation
- **Additional approaches**
  - Support more applied academic researchers to bridge the gap to meet industrial needs
  - Government-Industry support of university associated incubator programs.
  - Expand national R&D infrastructure with not for profit applied research centers emulating CSEM or Fraunhofer Institutes.

How to accelerate nanomanufacturing success?

- **Communication**
  - Constant feedback and information dissemination between industry and academia
  - Creation of user groups
  - Workshops
  - Connecting small companies with VC (e.g., Matchmaker)
- **Integration between academia and industry**
  - Education and clarification on IP issues
  - Exchange of industrial workers with faculty and students
  - Better consideration of technology scale-up issues by academia
- **Application focus required to accelerate development**

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Research Activities at the New England Nanomanufacturing Center for Enabling Tools (NENCET)

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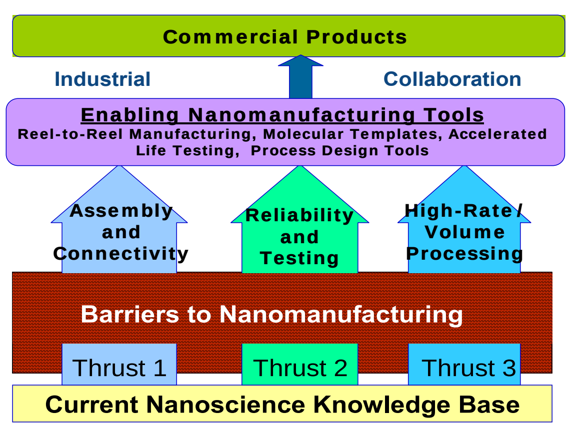
Overcoming Barriers to Commercialization

- To move scientific discoveries from the laboratory to commercial products, a completely different set of fundamental research issues must be addressed.

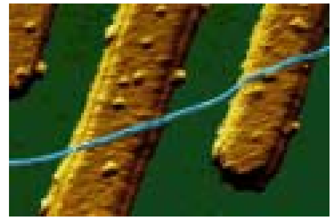
- The field of nanomanufacturing is incredibly broad,
- Nevertheless, three critical and fundamental technical barriers to manufacturing surface repeatedly:

(1) Smart tooling (guided self-assembly using nano templates) and wiring
(2) High-rate/high-volume processing.
(3) Reliability and testing



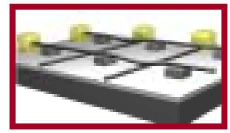
NENCET

Nanotube Memory Chip



- Potential $100 billion market
- Non-volatile memory
- Nanotube based storage device capable of 3-5 orders of magnitude more storage
- Memory accessible at orders of magnitude faster than silicon chips.

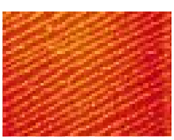
- Breakthroughs needed for:
  - Large-scale precise, economic assembly of CNTs
  - with specific orientation and functionality
  - with connection to the micro/macro level
  - at high rate and volume



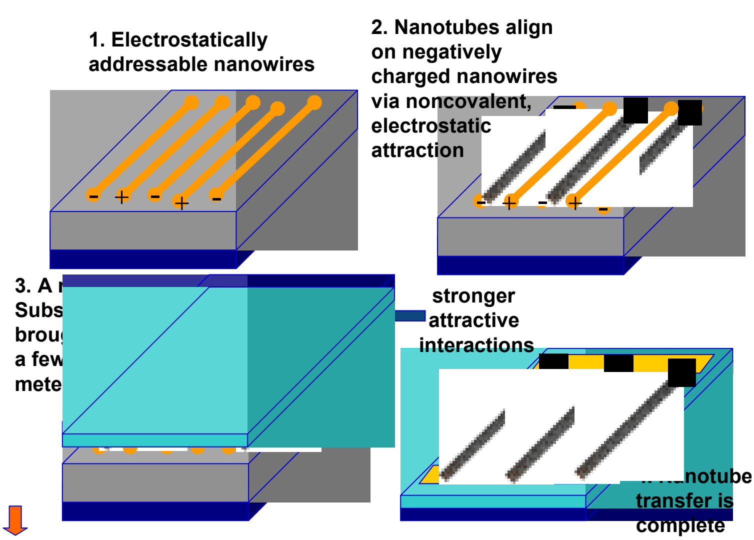
Other SWNT Scientific Roadblocks:

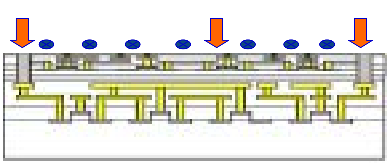
- **One size does not fit all where applications are concerned**
- **Structure-property relationships unknown. How do properties vary as a function of precise molecular dimensions?**
- **Lack of Solubility**
- **Organic Chemistry of SWNTs, Lack of chemical functionality**

How Can Nano Templates Be Used To Assemble Nanoelements (SWNT, DNA, Nanorods)?



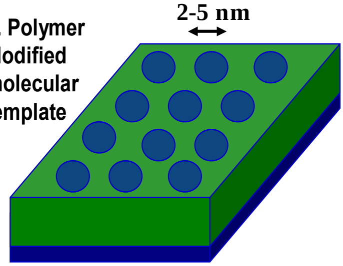
self-ordering growth of nanowires on strained interfaces



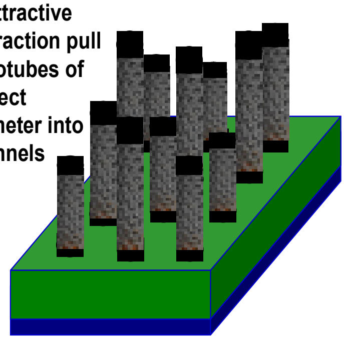


How Can Nano Templates Be Used To Assemble Nanotube Interconnects?

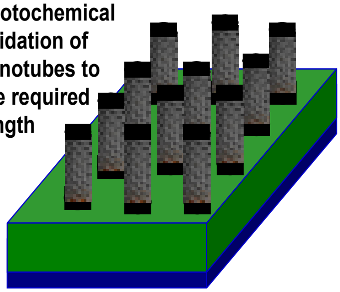
1. Polymer Modified molecular template



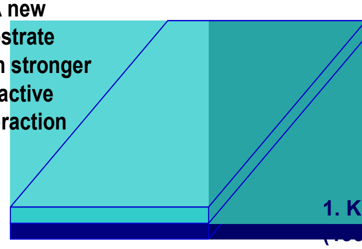
2. Attractive interaction pull nanotubes of correct diameter into channels

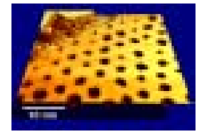


3. Chemical or photochemical oxidation of nanotubes to the required length

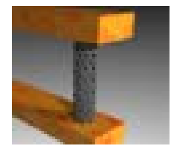


4. A new substrate with stronger attractive interaction





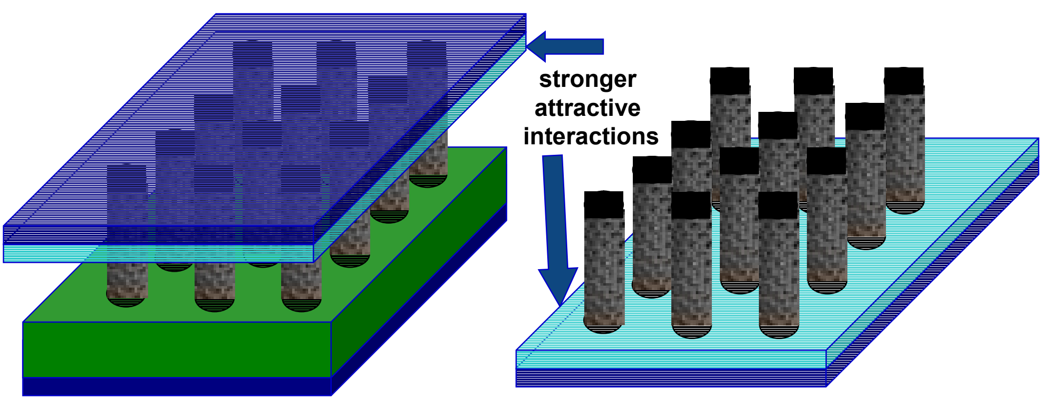
Ordered networks of misfit dislocations (2 nm islands and a 5 nm pitch) where feature sizes and densities can be varied[1].



Possible applications: Nanotube Interconnect and magnetic media.

1. K. Pohl et al., Nature, 397, 238 (1999).

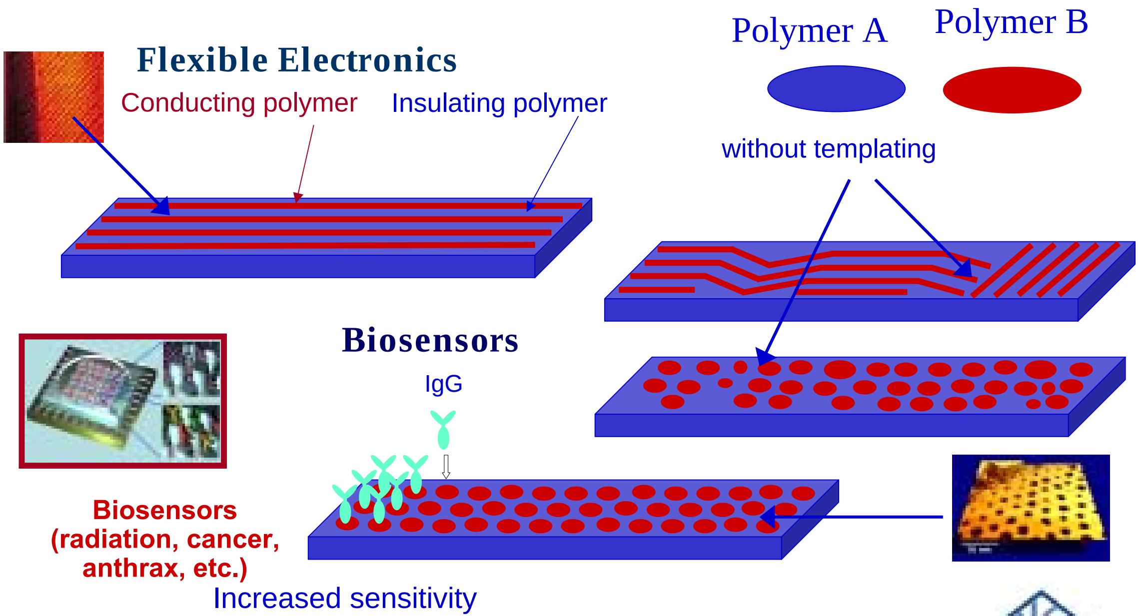
How Can Nano Templates Be Used To Assemble Nanotube Interconnects?



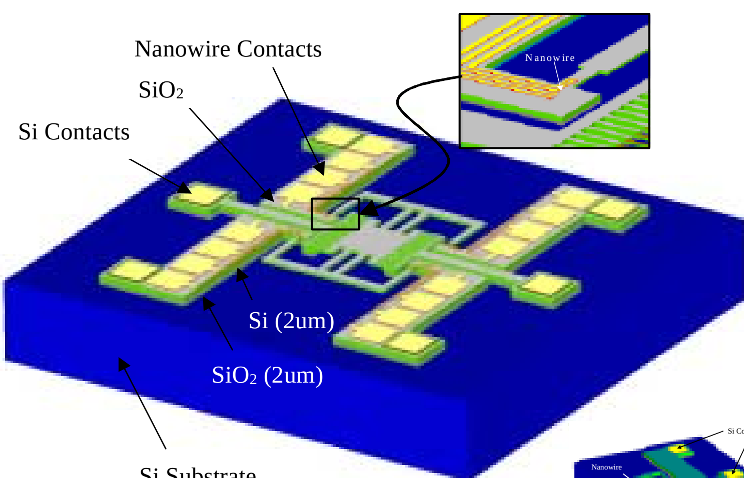
5. A new substrate with stronger attractive interactions is brought into contact

6. Nanotube transfer is complete

Flexible Nano Templates from Rigid Molecular Templates

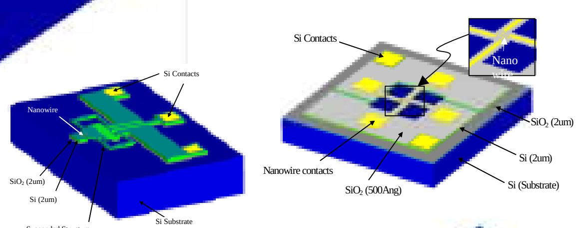


MEMs Nanoscale Characterization and Reliability Testbed



Conceptual layout of a MEMs test structure capable of applyings maximum strain at the nanowire location.

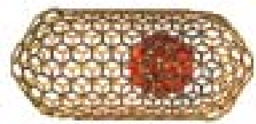
Innovative MEMS-based test beds are designed and fabricated to characterize nanowires (also nanotubes, nanorods & nanofibers) and conduct accelerated lifetime testing allowing rapid mechanical, electrical, and thermal cycling.

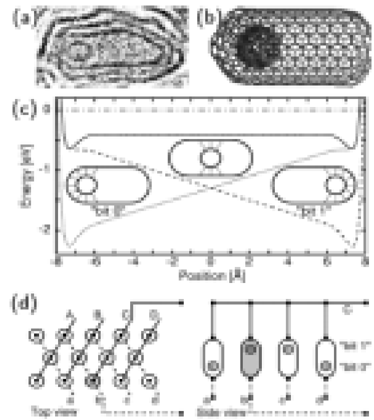


Synthesis Processes

Single Walled Nanotubes On Demand

- ► Bottom-up synthesis of soluble, functional SWNTs
- ► Controlled molecular dimensions and properties
- ► Solubility and selectivity built into each structure
- ► Water soluble SWNTs or Oil soluble SWNTs
- ► Sites that selectively bind/recognize various chemical or biological agents?





Another option in considered for SWNT memory device.

- ➢ A non-volatile memory device based on the One Pea in a Pod
- ➢ Provides fast writing speed that's higher than 1 THz and high Packing density greater than 5 TB/cm2

1. Young-Kyun Kwon, David Tománek, and Sumio Iijima, Phys. Rev. Lett. 82, 1470 (1999)
2. U.S. Patent 6,473,351

Collaboration and Interaction

23 COMPANIES

BAE SYSTEMS, Polytec PI, tsi, Bentley, Zyvex, MOTOROLA intelligence everywhere, Konarka, MRI Institute, CeraMem, Applied Epidemiology Inc., nexia, AST Products Inc, Boston Scientific, Micro Biochip, Coventor, Millennium, Foster-Miller, Massachusetts Technology Collaborative, SCFluids, altran, tyco Electronics, M/A-COM

Students
Faculty

Facilities
Researchers

Faculty
Researchers
Students

Faculty
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Summary

The NENCET center is developing the science and technology needed to enable:

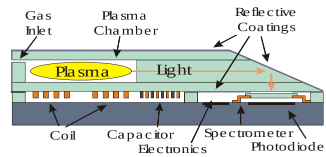
- **Massive parallel assembly of nanoelements such carbon nanotubes, inorganic nanotubes, proteins, etc.**
- **Assembly and sorting of nanoelements in two or three dimensions and their transfer to a new surface.**
- **Delivery of nanoelements in a pattern that reflects the feature sizes and densities of the nano pattern on the Nanotemplate.**
- **Test the reliability of nanoelements and their connections and characterize their nanoscale electrical and material properties.**
- **Bottom-up synthesis of SWNTs (On Demand) where SWNT to produce set of uniform SWNTs with desired functionality (such as transistor, magnetic SWNT, Higher adhesion, etc.)**

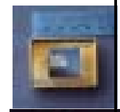
Workshop Summary

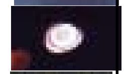
- **What is the current state of the art?**
  - Very few commercial products entering marketplace some on the way
- **Where are we headed?**
  - Need Development of new manufacturing processes
- **What are the barriers?**
  - Many fundamental questions still remain
  - Infrastructure and education required
- **How to accelerate nanomanufacturing success?**
  - More industry-academe collaboration
  - More support $$$$

NSF Center for Micro and Nanoscale Contamination; Goals and Objectives

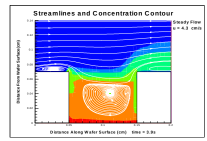
Our goal is to provide solutions and state of the art techniques for micro and nanoscale contaminants characterization, control and removal In manufacturing and fabrication processes.

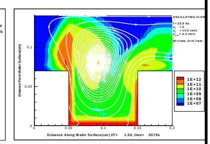


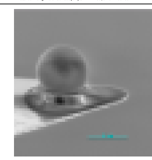




- ➢ **Fundamentals of surface cleaning and preparation.**
  - ➢ Cleaning of nanoscale particles, trenches and vias.
  - ➢ New Nanoparticle removal Technologies:
    - ➢ Laser Shock Removal
    - ➢ High frequency streaming removal
    - ➢ Super critical CO2 removal
- ➢ **Nano Particle adhesion and removal mechanisms.**
  - ➢ Consider particle adhesion on Cu and low-K dielectrics
- ➢ **Development and fabrication of contamination micro sensors technology.**
- ➢ **Nano Particle generation, transport and deposition.**







- ➢ **Collaboration with Hanyang University funded by NSF and KOSF**

Hanyang University