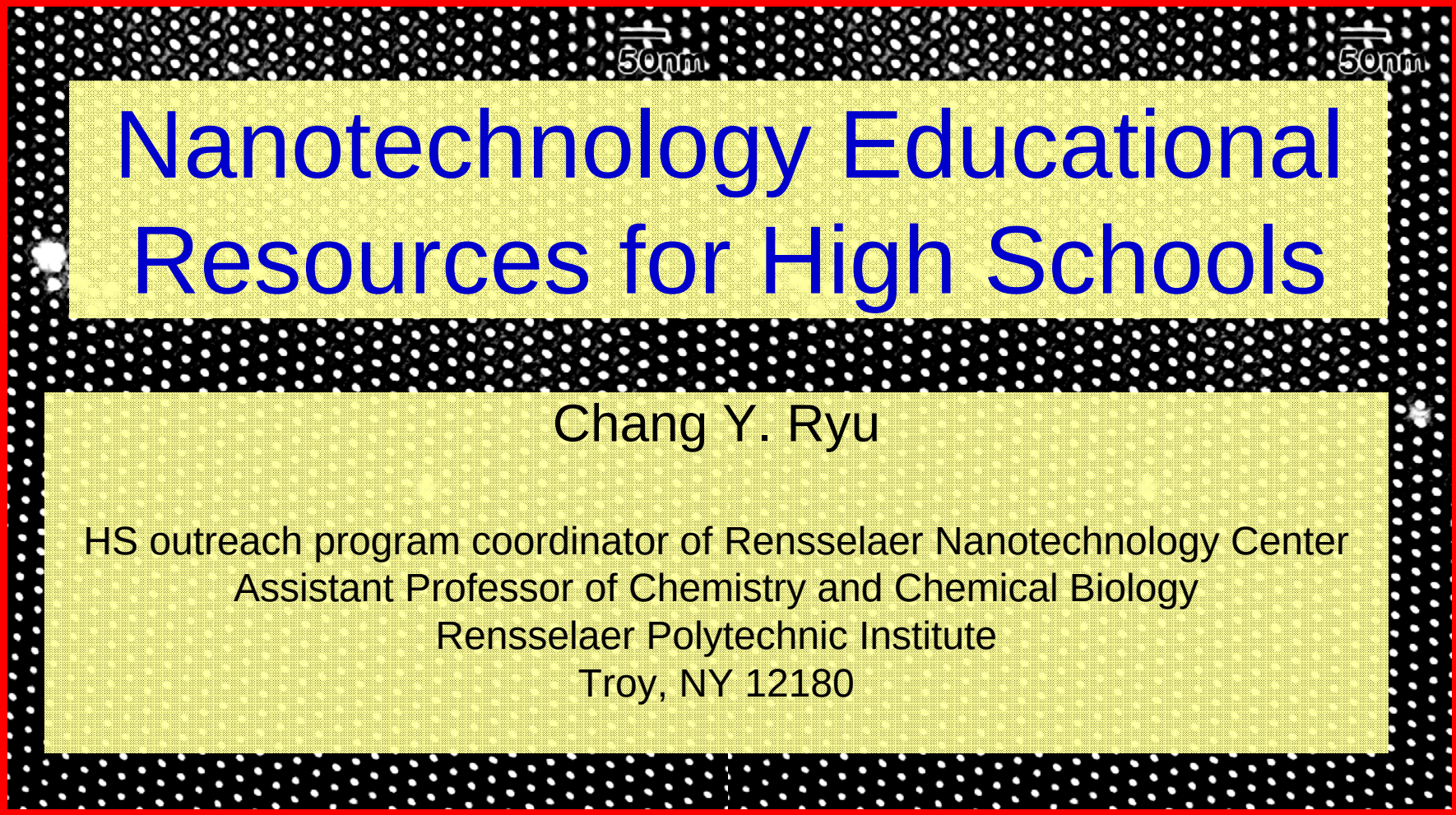


Nanotechnology Educational Resources for High Schools

Chang Y. Ryu

HS outreach program coordinator of Rensselaer Nanotechnology Center
Assistant Professor of Chemistry and Chemical Biology
Rensselaer Polytechnic Institute
Troy, NY 12180

May 23, 2006
Albany Academy for Girls (http://www.albanyacademyforgirls.org/)
Albany, NY (Host: Dr. Terrell Neuage)

Rensselaer
why not else

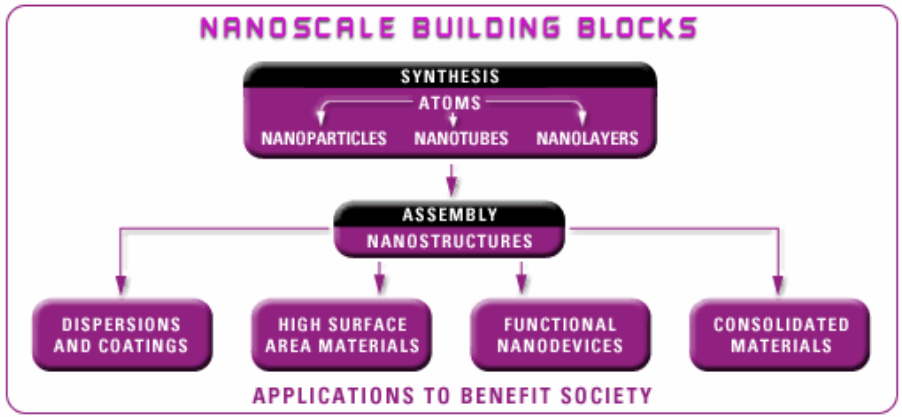
NATIONAL SCIENCE FOUNDATION – NANOSCALE SCIENCE AND ENGINEERING CENTER FOR

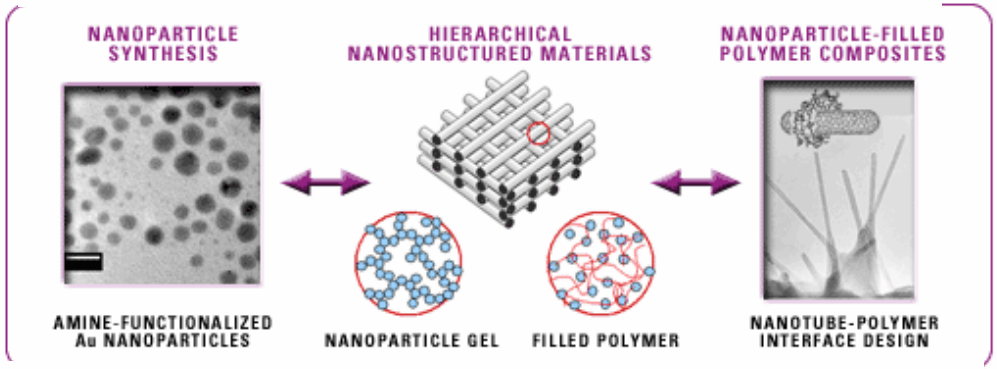
DIRECTED ASSEMBLY OF NANOSTRUCTURES

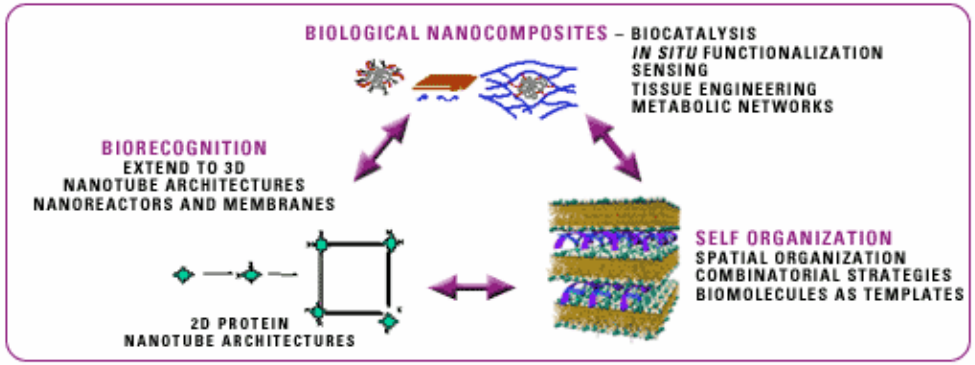
Rensselaer ILLINOIS Los Alamos

RPI (est. 1824)

www.nano.rpi.edu





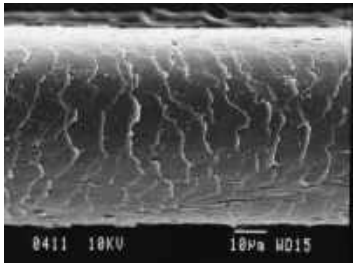


Outline

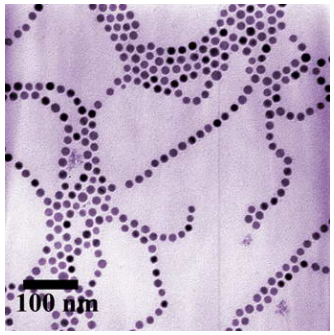
- Brief Introduction on Nanotechnology
- Educational Resources on nanotechnology
  - www.nano.gov
- RPI Nanoscale Science and Engineering Center: High school outreach program
  - Bringing nanotechnology to the classroom (Program coordinator: Chang Y. Ryu (ryuc@rpi.edu)
    - Hands on module: Carbon nanotube synthesizer
    - Multimedia module: Virtual Scanning Electron Microscopy (SEM)
    - Lecture module: Atomic Force Microscopy (AFM)
    - Class supplementary information using nanoscale microscopy tools

nano-meter

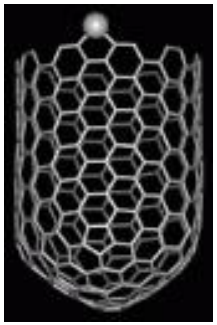
- 1 mm = 1,000 μm = 1,000,000 nm
- nm = 10^{-9} m
  - Thickness of human hair = 100 μm
  - Typical size of cells = 30 – 1 μm
  - Wave length of visible lights ~ 0.5 μm
  - Nanoparticles, nanotubes, nanowires, …
  - Length of C-C bond: 0.15 nm (1.5 Å)



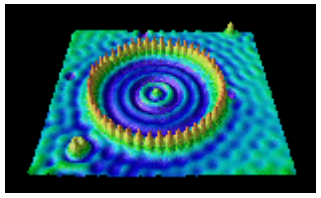
E. coli Bacterium



NIST magnetic nanoparticles

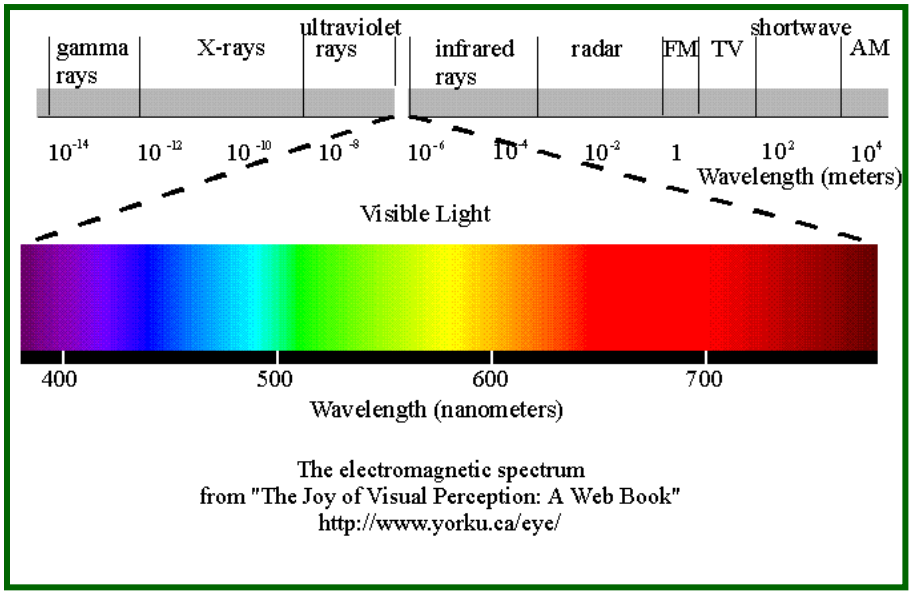


Carbon nanotubes



Iron on Copper

Xe on Nickel



The electromagnetic spectrum
from "The Joy of Visual Perception: A Web Book"
http://www.yorku.ca/eye/

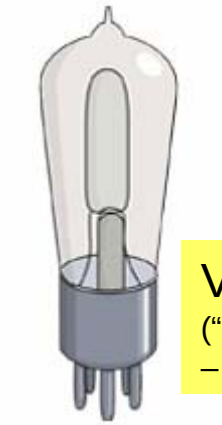
Technological advances

- In 1900,
  - Most people did not have cars, electricity, or indoor plumbing
- By 1950
  - Most people have cars, electricity, or indoor plumbing
  - Development of antibiotics, radio, TV, plastics, nuclear weapons and power, and the computer
- By 2000
  - Jet airliners are common
  - TV, computers, cell phones, global communications network, internet, biotechnology
- Future?
  - Nanotechnology, biotechnology, information technology, energy technology, ???

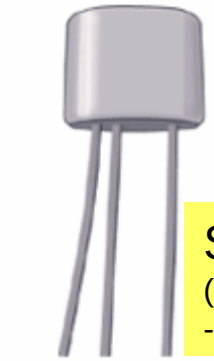
Transistor & Information Technology

http://nobelprize.org/physics/educational/transistor/history/index.html

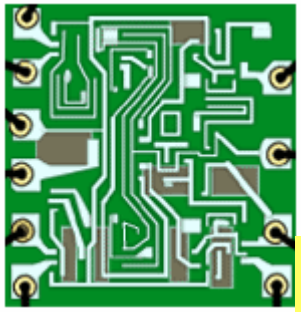
time →



Vacuum tube
("Triodes", Thomson – Nobel,1906)

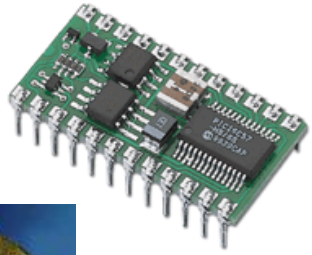


Solid state
(Bardeen and Brattain -Nobel, 1956)

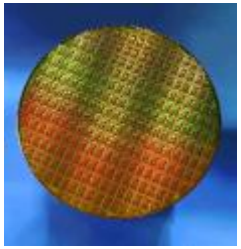


Integrated Circuit
(Jack Kilby - Nobel, 2000)

Portable radio from Motorola (1959)



Computer
(late 1940's)



Nanotechnology: Definition
(National Science Foundation)

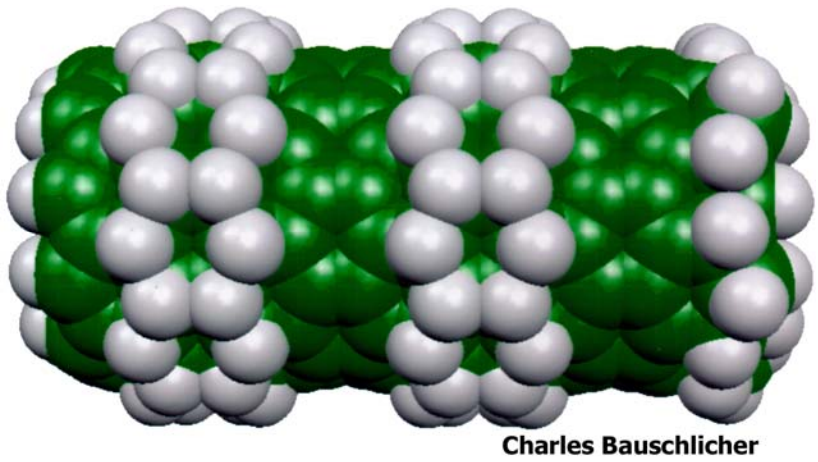
http://www.nsf.gov/crssprgm/nano/reports/omb_nifty50.jsp

- Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm.
- Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~0.1 nm) or be larger than 100 nm (e.g., nanoparticle reinforced polymers have the unique feature at ~ 200-300 nm as a function of the local bridges or bonds between the nano particles and the polymer).

Ames Research Center

What is Nanotechnology?

Nanotechnology is the creation of **USEFUL/FUNCTIONAL** materials, devices and systems through control of matter on the nanometer length scale and exploitation of novel phenomena and properties (physical, chemical, biological) at that length scale



Charles Bauschlicher

"If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering."

-Neal Lane
Former Assistant to the President for Science And Technology

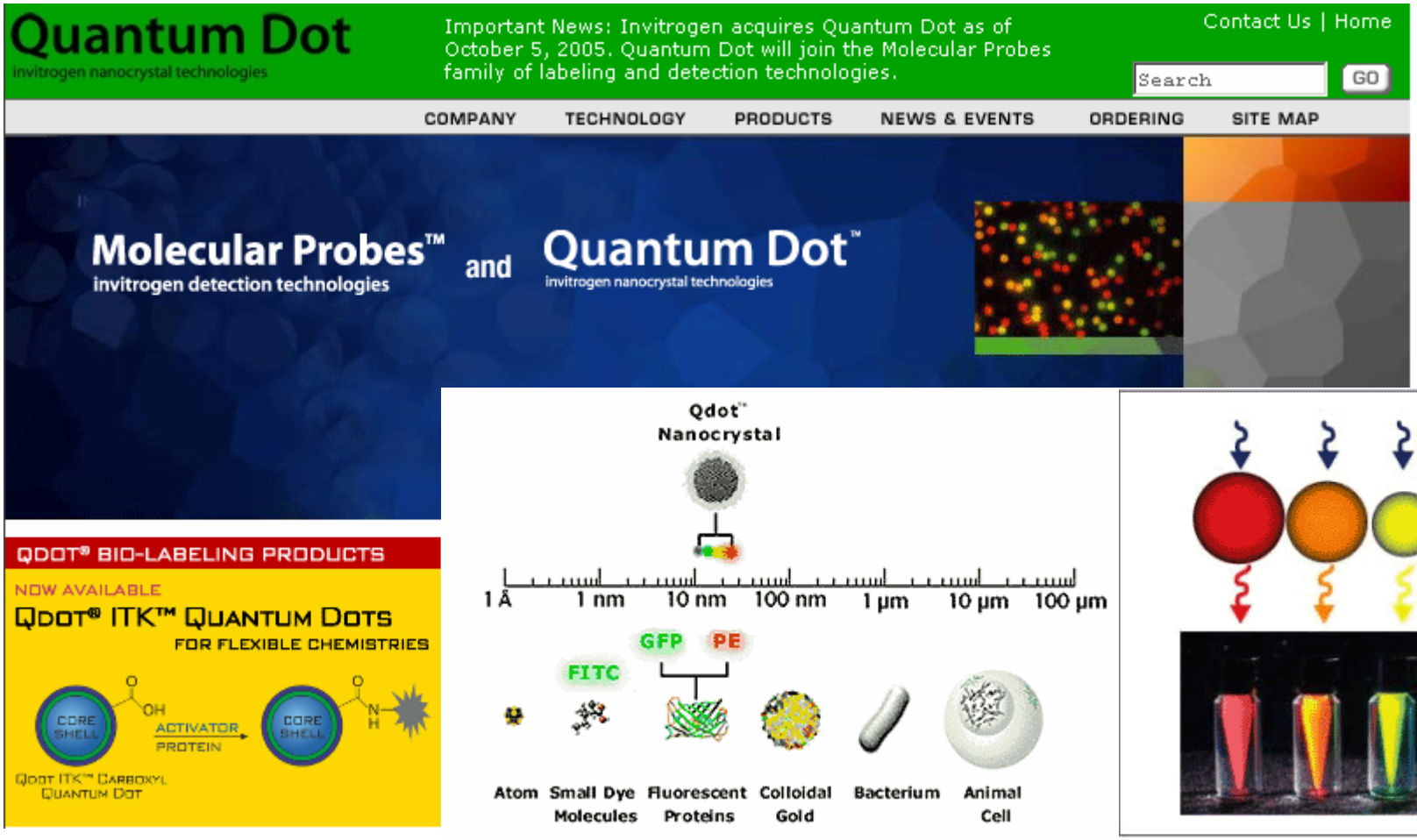
Source: http://www.ipt.arc.nasa.gov/

Current Nanotechnology examples - Size matters! -

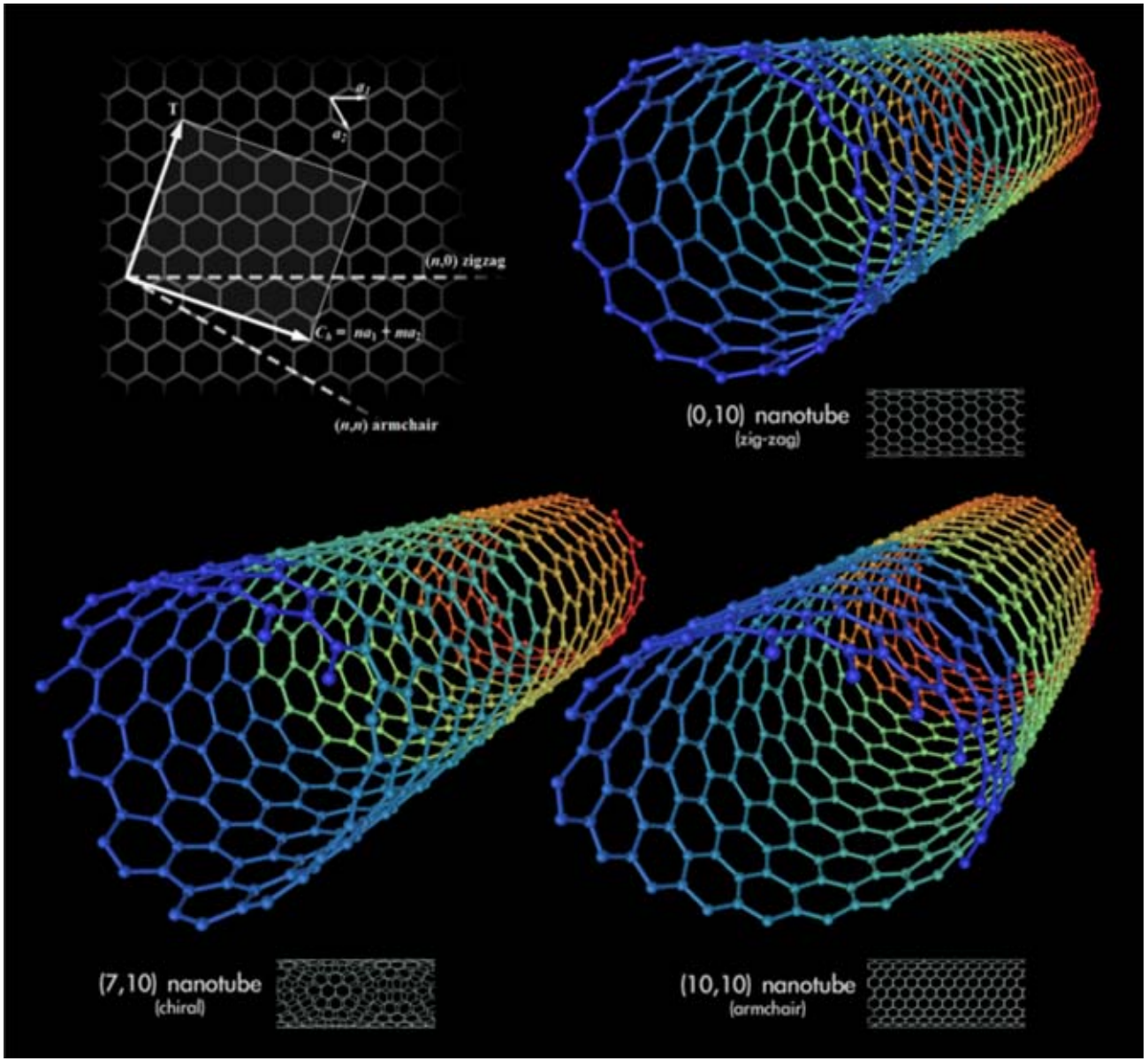
- Nanoparticles & “quantum dots”
- Carbon nanotubes
- Micro- and nano-lithography
- Nano- and molecular-electronics
- Nano-materials
- Nano-batteries

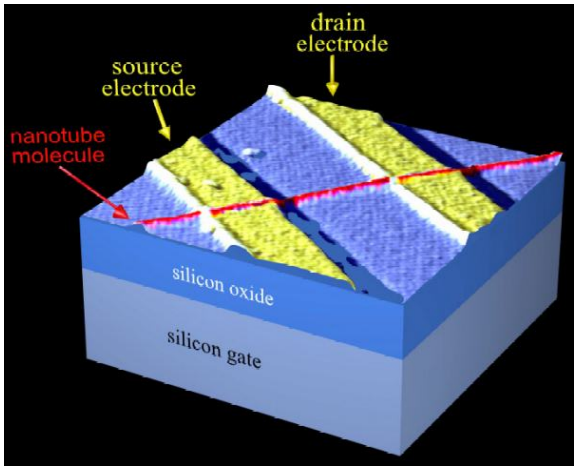
Quantum dot – Biological tags

(www.qdots.com)



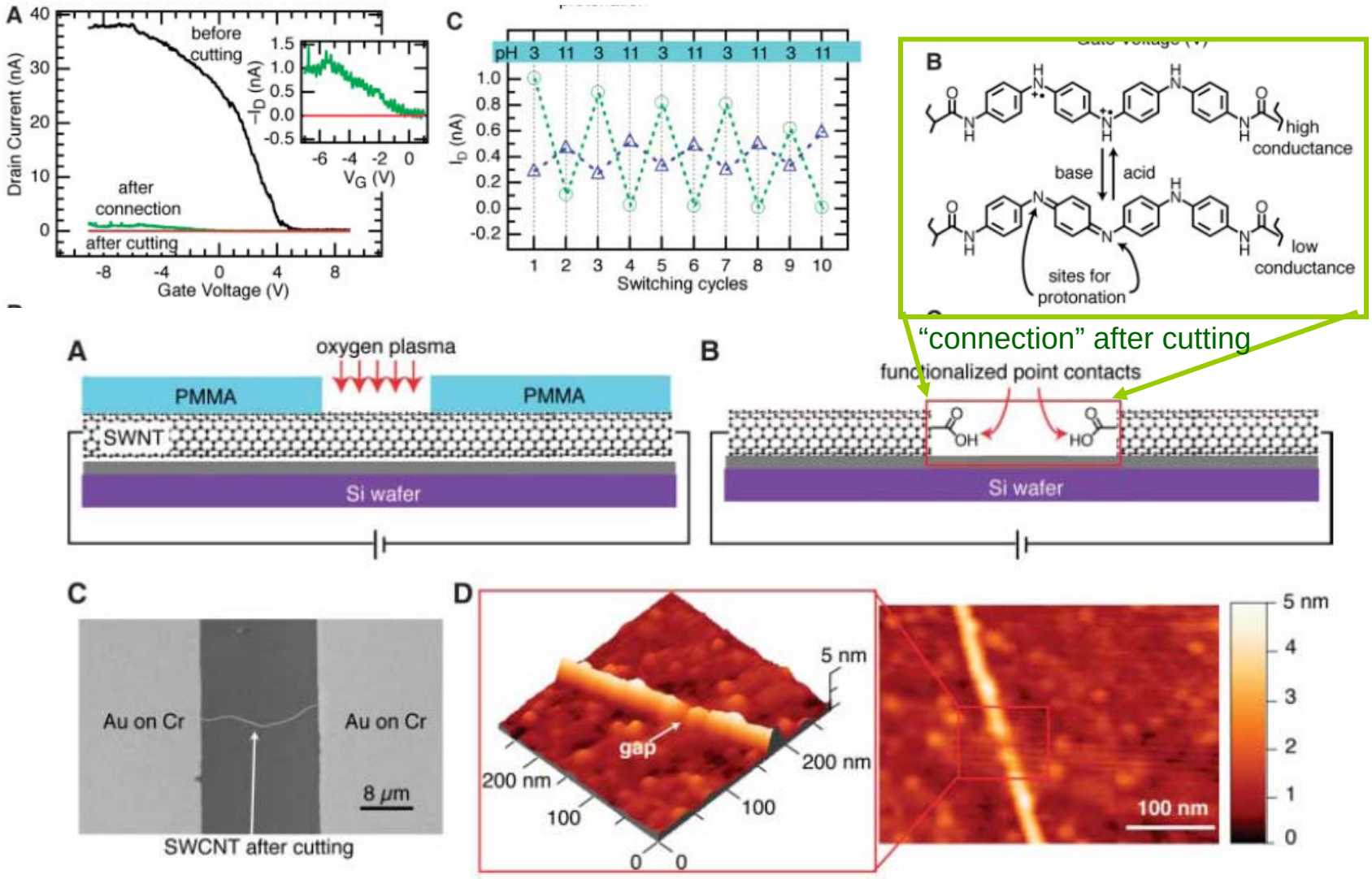
Carbon nanotubes





e.g. Nanotube chemical sensors

Kim and Nuckolls *et al.* (Columbia Univ.), *Science* (Jan, 2006) 311, 356



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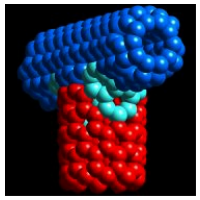
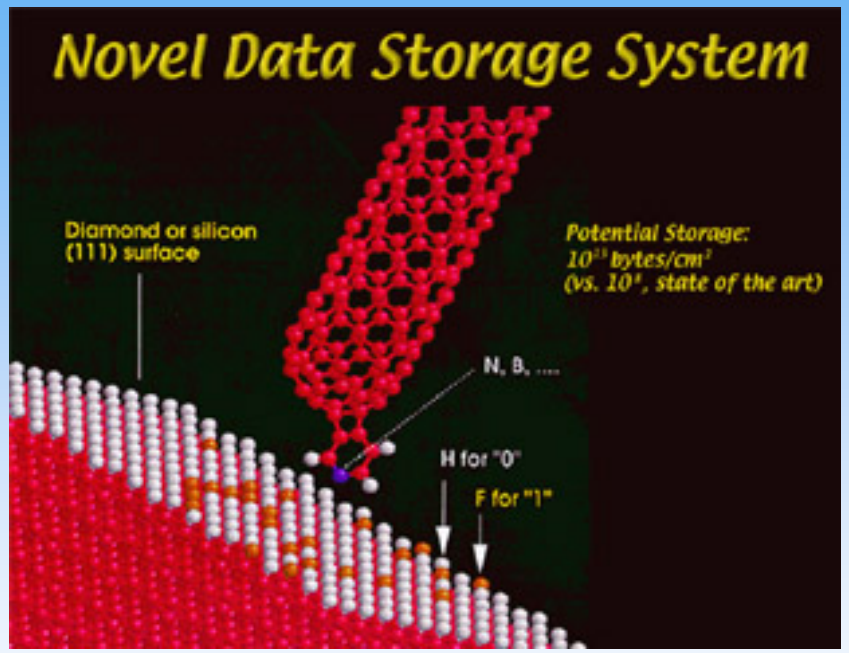
Impact of Nanotechnology





Nanotechnology is an enabling technology

- Computing and Data Storage
- Materials and Manufacturing
- Health and Medicine
- Energy and Environment
- Transportation
- National Security
- Space exploration
-

Source: http://www.ipt.arc.nasa.gov/

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    - Lecture module: Atomic Force Microscopy (AFM)
    - Class supplementary information using nanoscale microscopy tools

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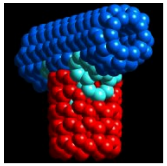
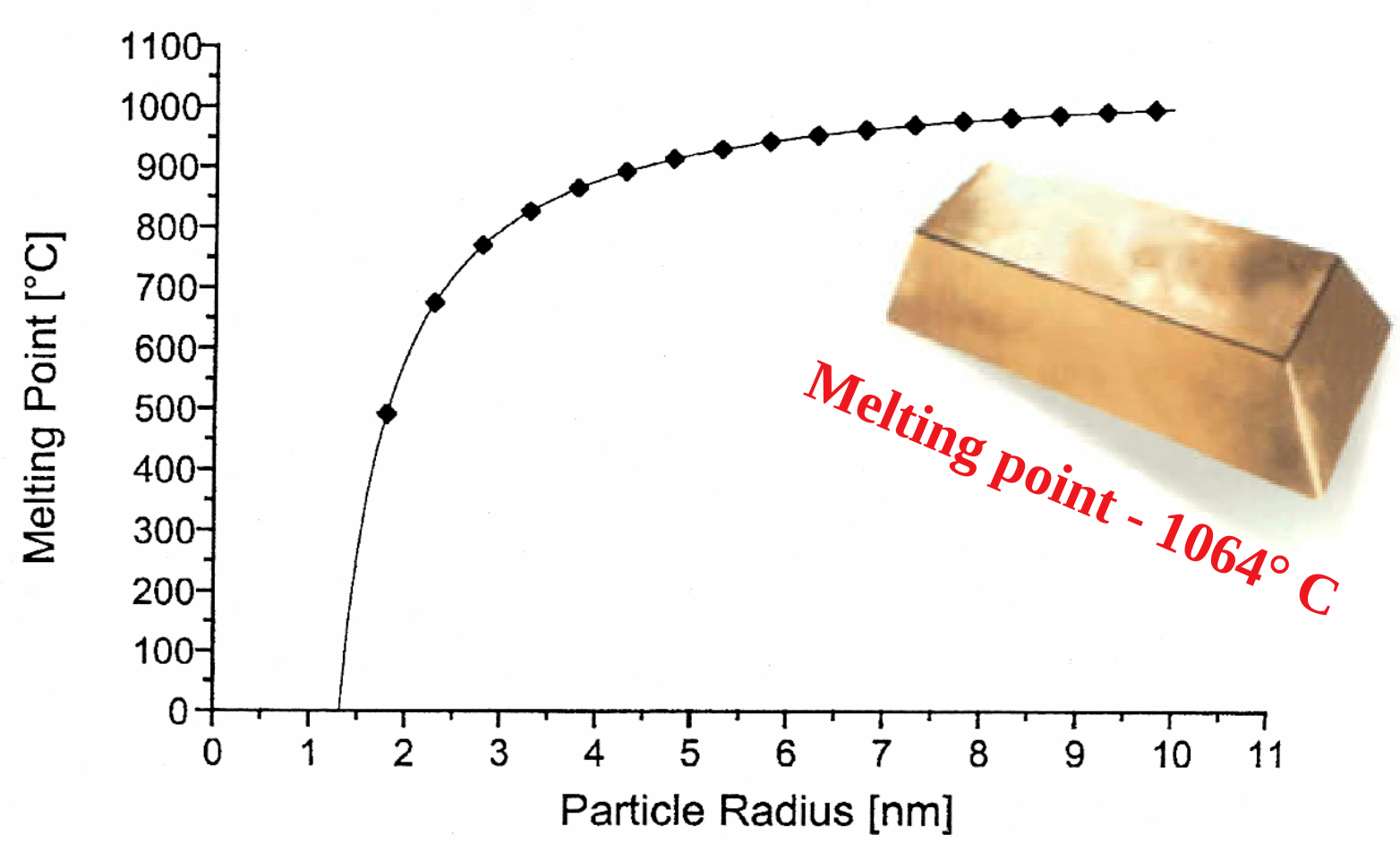
Melting Point of Gold

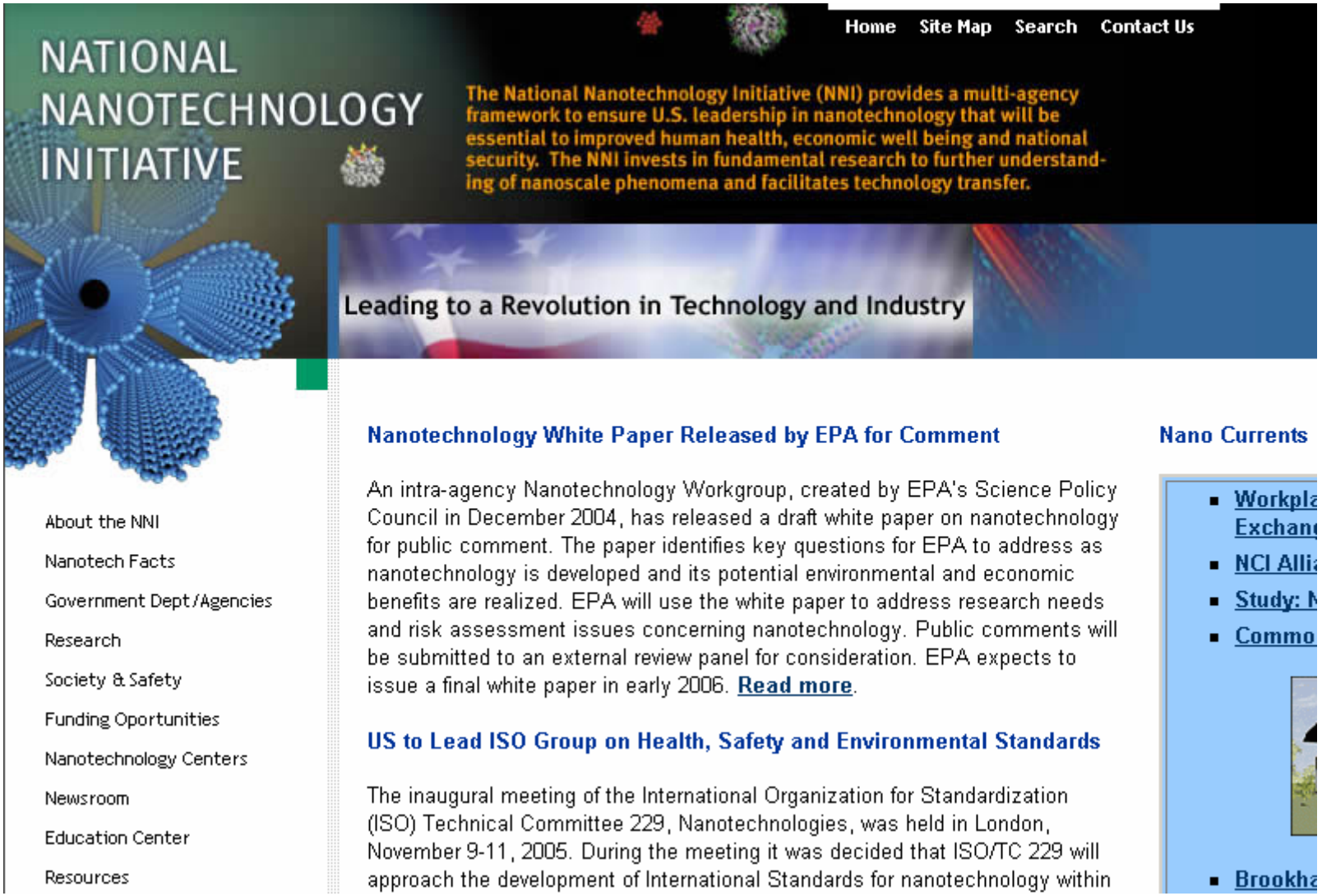




Source: http://www.ipt.arc.nasa.gov/

Source: K.J. Klabunde, 2001

www.nano.gov


NATIONAL NANOTECHNOLOGY INITIATIVE
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The National Nanotechnology Initiative (NNI) provides a multi-agency framework to ensure U.S. leadership in nanotechnology that will be essential to improved human health, economic well being and national security. The NNI invests in fundamental research to further understanding of nanoscale phenomena and facilitates technology transfer.
Leading to a Revolution in Technology and Industry
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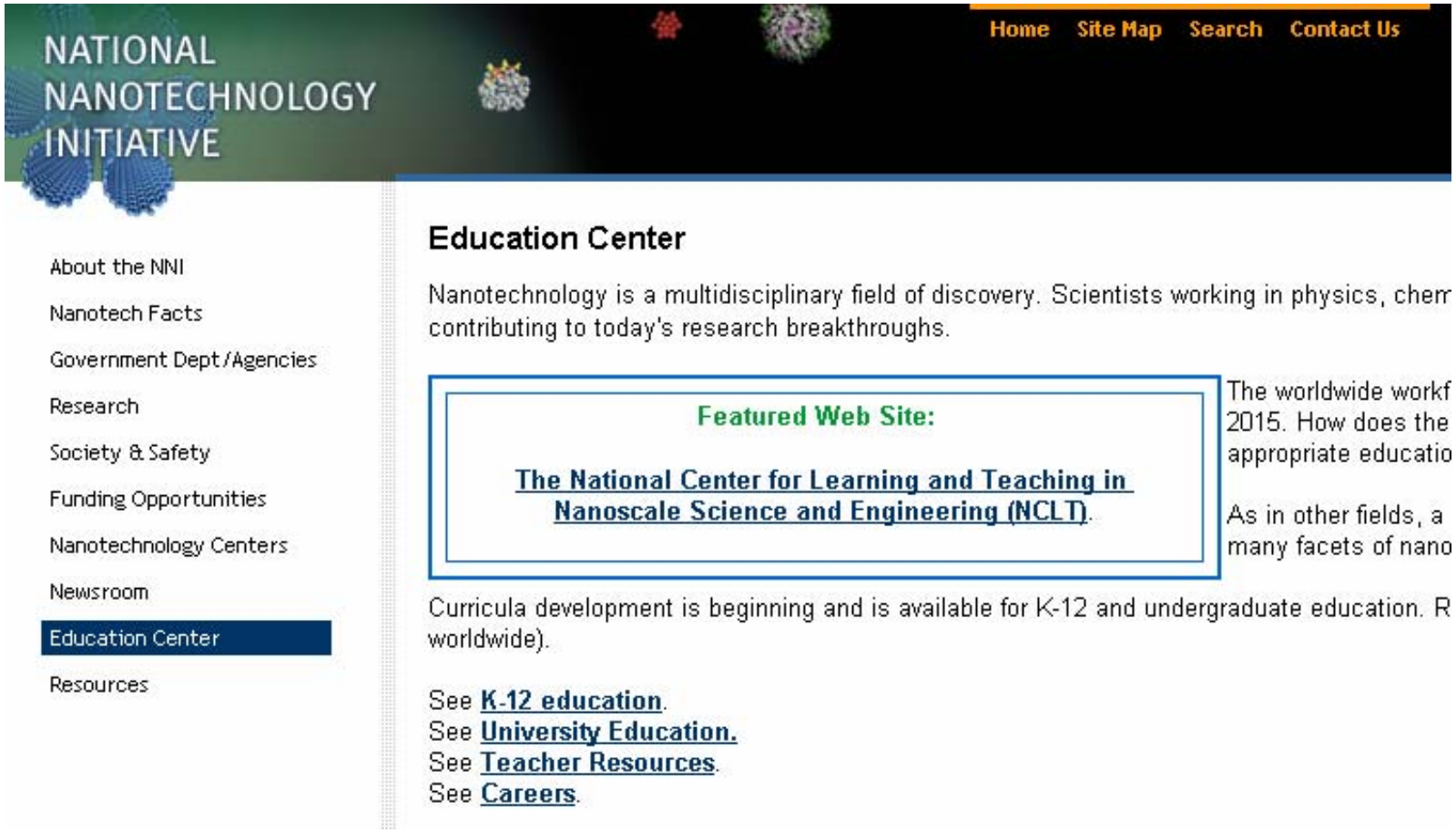
Nanotechnology White Paper Released by EPA for Comment
An intra-agency Nanotechnology Workgroup, created by EPA's Science Policy Council in December 2004, has released a draft white paper on nanotechnology for public comment. The paper identifies key questions for EPA to address as nanotechnology is developed and its potential environmental and economic benefits are realized. EPA will use the white paper to address research needs and risk assessment issues concerning nanotechnology. Public comments will be submitted to an external review panel for consideration. EPA expects to issue a final white paper in early 2006. Read more.
US to Lead ISO Group on Health, Safety and Environmental Standards
The inaugural meeting of the International Organization for Standardization (ISO) Technical Committee 229, Nanotechnologies, was held in London, November 9-11, 2005. During the meeting it was decided that ISO/TC 229 will approach the development of International Standards for nanotechnology within
Nano Currents

NNI

- The National Nanotechnology Initiative (NNI) is a federal R&D program established to coordinate the multiagency efforts in nanoscale science, engineering, and technology.
- The goals of the NNI are to:
  - Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology;
  - Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit;
  - Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and,
  - Support responsible development of nanotechnology

NNI – Educational Resources



http://www.nclt.us/

NSF NISE network (2005)

Informal Education on Nanotechnology

National Science Foundation
WHERE DISCOVERIES BEGIN

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NSF Web Site

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Earth & Environment

Press Release 05-179

New Grants Are Awarded to Inform the Public and Explore the Implications of Nanotechnology

A hands-on introduction to science at the San Francisco Exploratorium.
Credit and Larger Version

October 6, 2005

The National Science Foundation (NSF) has announced a series of initiatives that will greatly expand efforts to inform the general public about nanotechnology, and to explore the implications of that fast-moving field for society as a whole.

The Nanoscale Informal Science Education Network. NSF has selected the Museum of Science, Boston, along with the Science Museum of Minnesota and the Exploratorium in San Francisco, to create and lead this network, which will also include many other science museums and research institutions (partial list below). The $20 million, five-year effort represents the largest single award NSF has given to the science-museum community, and will be a cornerstone of the foundation's multidisciplinary Nanoscale Science and Engineering Education program. The award was made by NSF's Informal Science Education program, with additional funding provided by 12 research programs from across the foundation.

The NISE Network Core Leadership Team

- The Museum of Science, Boston
- The Science Museum of Minnesota
- The Exploratorium in San Francisco

For Students K-12 @ www.nano.gov

NATIONAL NANOTECHNOLOGY INITIATIVE

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- Government Dept/Agencies
- Research
- Society & Safety
- Funding Opportunities
- Nanotechnology Centers
- Newsroom
- Education Center
- Resources

For Students K-12

What's Your Nano IQ? Find out HERE!

Take a fun quiz on the National Institute of Standards and Technology web site!

Main Street Science has created a new science web magazine called Nanooze, a project of the National Nanotechnology Infrastructure Network (NNIN) -- a great place to hear about the latest exciting stuff in science and technology that is too small to see.

Let a click of your computer mouse transport you to London, England to their Science Museum's fantastic exhibit on Nanotechnology: Small Science, Big Deal -- and, as long as you are visiting that side of the Atlantic Ocean, be sure to go exploring with Duckboy in Nanoland!

Check out The Wonderful World of Carbon Nanotubes Presentation at the Museam of Science, Boston along with other articles and features related to Nanotech!

"Discover the secrets of everyday stuff" on this SUPERCOOL web site Strange Matter. The Strange Matter exhibit will soon be in Durham, North Carolina (October 1 to January 8). See the Strange Matter web site for details on upcoming exhibits near you.

Nanotechnology has become FUN! through these and other programs, such as the adventures of NanoKids™, who materialize after a computer crashes in chemist Jim Tour's lab! (See the cool dancing Kids in the graphic below and the brains behind the Kids, chemist Jim Tour.) Video game lovers, this is for you!!

There are other great programs too. See also the Science News for Kids article about "The Incredible Shrunken Kids."

Atoms and molecules are the building blocks of nature, and a lot of kids worldwide are having fun using familar blocks, such as Legos®, and computer generated figures made of these ultra-basic materials.

See Exploring the Nanoworld with Lego® Bricks, an offering of the University of Wisconsin - Madison Materials Research Science and Engineering Center (MRSEC) Interdisciplinary Education Group (EG).

NanoKids™ The Nanobiotechnology Center is located at Cornell University and is sponsored in collaboration with Princeton University, Oregon Health & Science University, Wadsworth Center, Clark Atlanta University, and Howard University.

Nano IQ from NIST

http://www.nist.gov/public_affairs/nanotechquiz.htm

What's Your Nano IQ?

NIST National Institute of Standards and Technology

A-Z subject index | Search NIST webspace | Contact NIST | Home

What's your Nano IQ?

(get quiz answers)

1. The prefix "nano" comes from a Greek word meaning _____.

a. billion
b. dwarf
c. invisible
d. infinite

2. If a nanometer were as big as the width of a pin head, about how long would a meter be?

a. as long as the pin shaft
b. as long as a ladder
c. as long as a blue whale
d. as long as a trip between Washington, D.C. and Atlanta, Ga.

3. How many hydrogen atoms lined up "shoulder to shoulder" would fit in a one nanometer space?

a. less than one
b. ten
c. 1 thousand
d. 1 billion

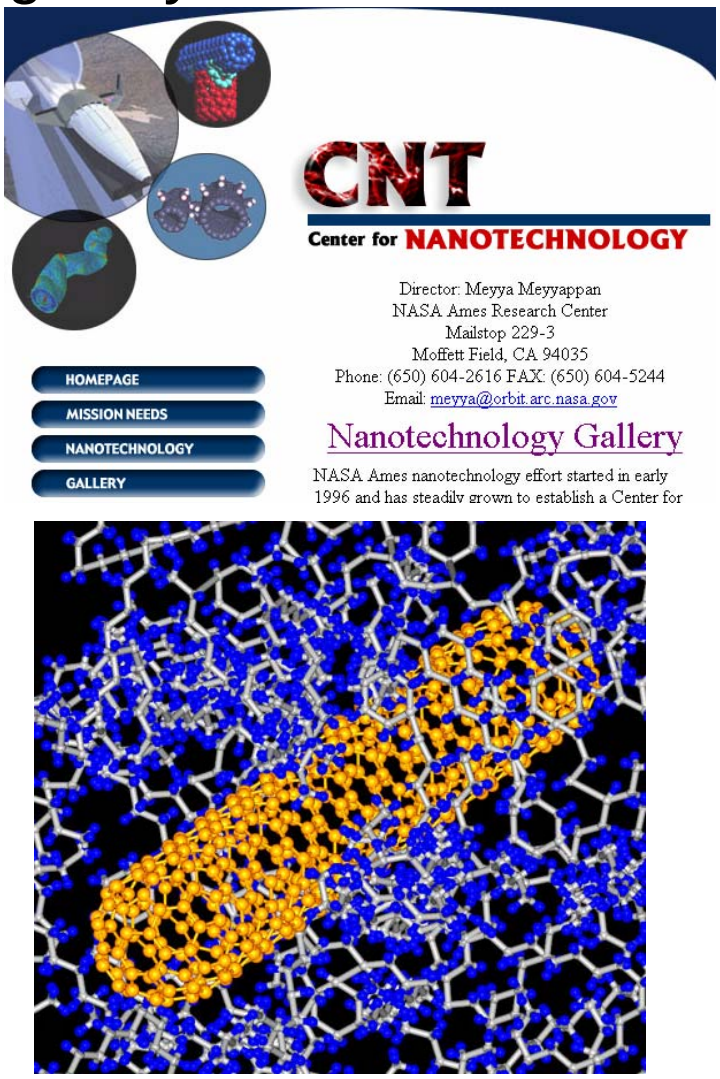
4. Which of the following products contain nanoscale manufactured parts or materials?

a. sunscreen
b. khaki pants
c. tennis balls

d. devices that read computer hard drives
e. all of the above

Nanotech Gallery from NASA

http://www.ipt.arc.nasa.gov/gallery.html

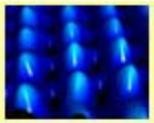


NASA - continued

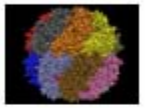
MOVIE CLIPS

Brief Video Descriptions of All Movies Listed Below

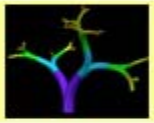
- Molecular Electronics: Self Assembly and Transport by Tunneling Microscopy - MOV
  Contributed by: Geetha R Dholakia



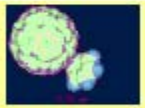
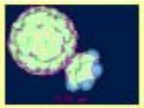
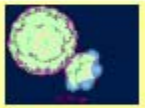
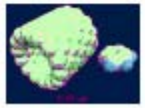
- Protein Nanotubes - Quicktime
  Contributors: Jonathan Trent, Andrew McMillan, Chad Paavola, Hiromi Kagawa, Suzanne Chan, Jeanie Howard, Yi-Fen Lee, Linda Molnar, Kira Foygel, Amy Ouellette, Amber Sanford, and Alessandro Airo
  http://bionanex.arc.nasa.gov



- Biomimetic Computing and Logic Architecture Based on "Y-Branched" Carbon Nanotubes - MPEG



- **Carbon Nanotube Gears - MPEG Movies**
  Contibutors: Jie Han, Al Globus, Richard Jaffe, and Glenn Deardorff

Benzyne Reacting with C60 (Buckyball)	 [377 KB] Slow (non-reactive)	 [327 KB] Medium (reactive)	 [669 KB] Fast (dissociative)
Benzyne Reacting with Carbon Nanotube	 [184 KB] Slow (non-reactive)	 [290 KB] Medium (reactive)	

Nano screen saver from NSF

http://www.nsf.gov/news/overviews/nano/screensaver.jsp#pc

National Science Foundation
WHERE DISCOVERIES BEGIN

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NANOSCIENCE

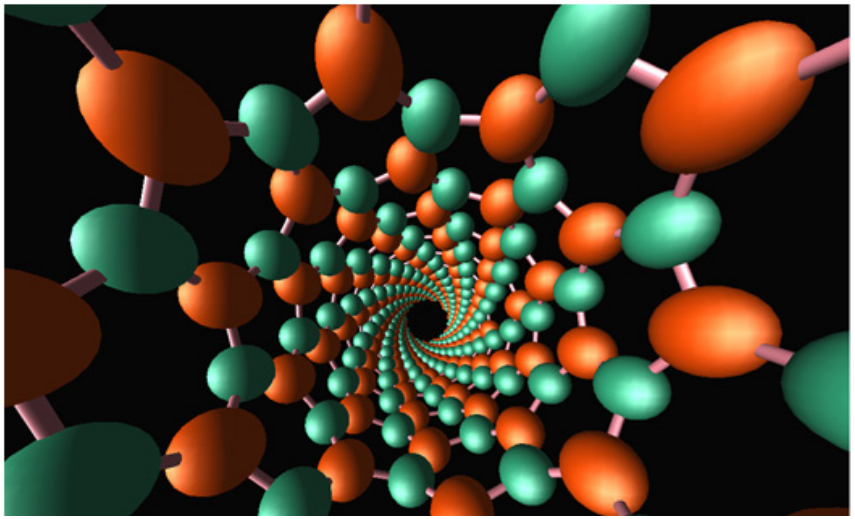
Nanoscience Home | More Research Overviews

NANOSCIENCE SCREEN SAVER

The images below represent just a tiny sampling of the marvels that scientists are discovering at the nanoscale. Many of them are from the online gallery of Harvard physicist Eric J. Heller, who generates them in the course of studying wave behavior and chaos in the quantum realm. But they also include one example apiece from the work of Vincent H. Crespi at Pennsylvania State University; Chad Mirkin at Northwestern University; and Ghim Wei Ho and Mark Welland at the University of Cambridge.

Download the screen saver for Windows (2.59MB)
Download the screen saver for Mac OS X (2.53MB)
Installation instructions

Boron Nitride Nanotube



Nano*High

Schedule of Talks

Online Registration

Maps and Directions

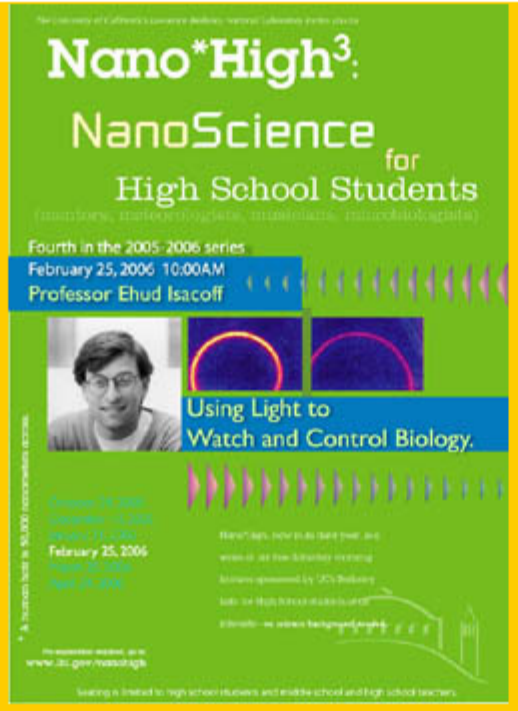
Nanoscience Links

Nano*High Home

About the Berkeley Lab

Nano*High Archive

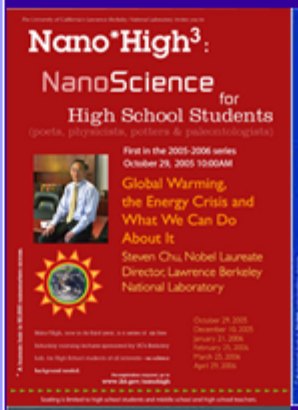
Information for Teachers

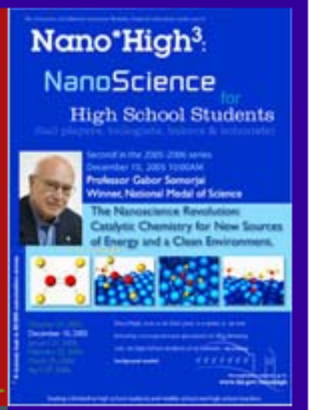


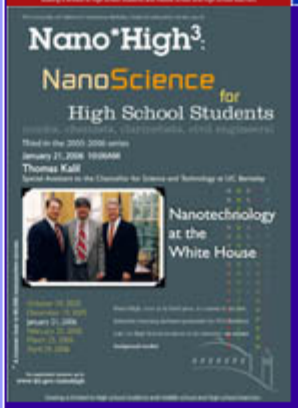
Meet and talk with world-renowned UC Professors and Berkeley Lab scientists and graduate students. Learn about their research into the world of the ultra small and how it will affect our future. Nano*High is sponsored by UC's Berkeley Lab for High School students of all interests and teachers of all subjects—no science background needed.

REGISTER ONLINE

Archive







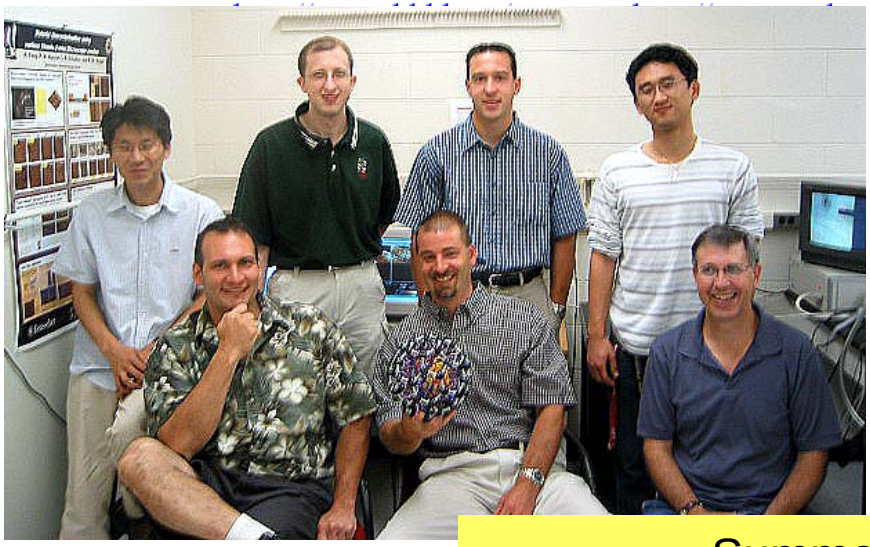
Outline

- Brief Introduction on Nanotechnology
- Educational Resources on nanotechnology
  - www.nano.gov
- RPI Nanoscale Science and Engineering Center: High school outreach program
  - Bringing nanotechnology to the classroom (Program coordinator: Prof. Chang Y. Ryu (ryuc@rpi.edu)
    - Hands on module: Carbon nanotube synthesizer
    - Multimedia module: Virtual Scanning Electron Microscopy (SEM)
    - Lecture module: Atomic Force Microscopy (AFM)
    - Class supplementary information using nanoscale microscopy tools

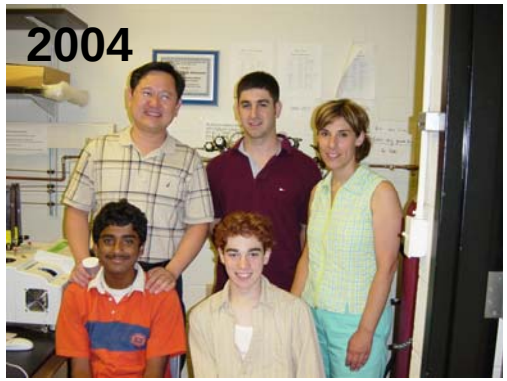
RPI NSEC High School Outreach

Welcome to the
Burnt Hills-Ballston Lake
CENTRAL SCHOOLS
Serving Ballston, Charlton, Clifton Park and Glenville, New York

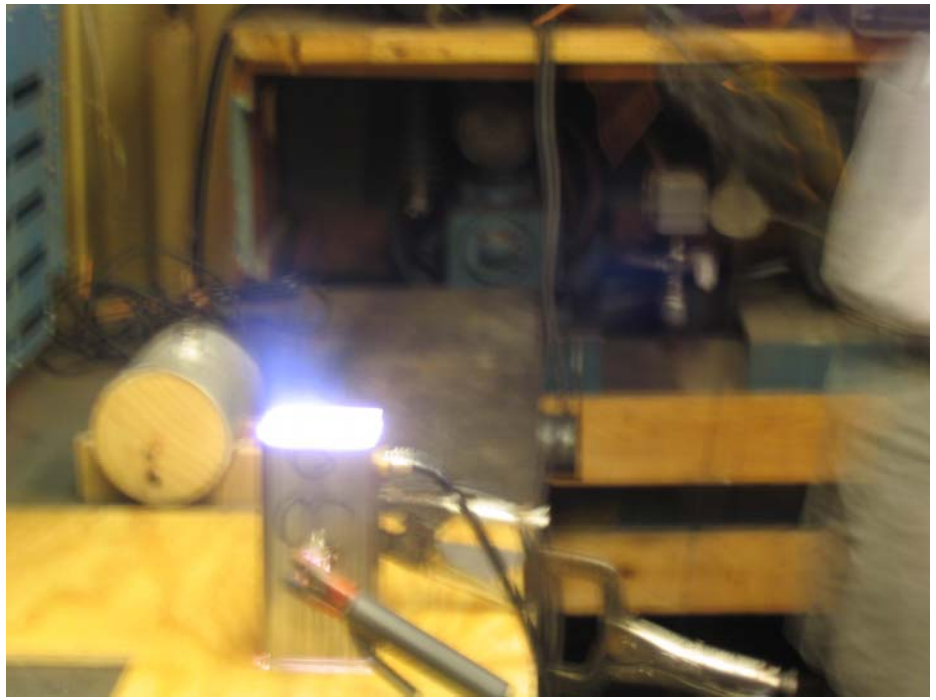
NATIONAL SCIENCE FOUNDATION – NANOSCALE SCIENCE AND ENGINEERING CENTER FOR
DIRECTED ASSEMBLY OF NANOSTRUCTURES



Summer, 2005
(will continue in the summer of 2006)



Hands on Module:
Carbon nanotube synthesizer



Tom Pittman, BHBL High School, “Metal-Tech” Teacher

Welcome to the Burnt Hills-Ballston Lake CENTRAL SCHOOLS
Serving Ballston, Charlton, Clifton Park and Glenville, New York

NATIONAL SCIENCE FOUNDATION – NANOSCALE SCIENCE AND ENGINEERING CENTER FOR
DIRECTED ASSEMBLY OF NANOSTRUCTURES

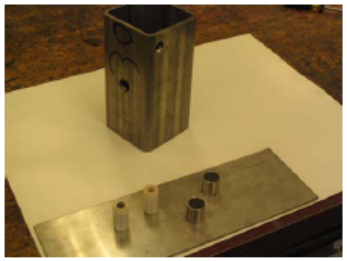
Actual module – CNT synthesizer

1.1.2 CARBON NANOTUBE SYTHESIZER PROTOTYPE #2

Tom Pittman and Paul Fedoroff

PURPOSE:
To determine if we could produce carbon soot and possibly carbon nanotubes using materials and equipment commonly found in a Technology Education classroom.

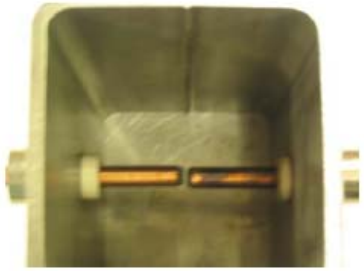
MATERIALS:
- Square stainless steel tubing 4"x 4"x 8"
- Two pieces of stainless steel plate 4"x 4"x 3/16"
- Two pieces of round stainless steel tubing 1" diameter, 1" long
- Two ceramic insulators
- Two 3/8" diameter carbon electrodes from a carbon arc torch (available at welding supply store)



POWER SUPPLY:
- AC/DC arc welder

SHIELDING GAS:
- Argon

PROCEDURE:
- Drill a hole slightly larger than insulator diameter through both sides of square tubing
- Drill a third hole near the top of the square tubing for argon hose
- Weld round tubing outside the two opposing holes
- Place square tubing on top of 4"x 4"x 3/16" plate
- Insert insulators into round tubing
- Slide carbon electrodes through holes in the insulators to visually align tips, leaving approximately a 1/16" gap between electrodes
- Set other 4"x 4" x 3/16" plate on top of square tubing
- Clamp the leads from the arc welder to the ends of the carbon electrodes
- Insert argon hose, open tank valve, set flow control valve to 15 CFH
- Set welder to 60 amps ac and turn it on. To start the arc slide one of the electrodes into the other, then immediately separate the electrodes 1/16"- 1/8".
- The arc can be viewed through a welding helmet with at least a #10 lens by sliding the top back slightly



RESULTS:
- Trial 1 – welder 60 amps AC, 15 minutes, access port closed, 1/8" electrode gap, 10 CFH Argon. No deposits.
- Trial 2 – welder 85 amps DC, 15 minutes, access port closed, 1/16" electrode gap, 15 CFH. Good results, soot deposits on bottom plate and on one carbon electrode.
- After the second trial the welder needed time to cool down.

Virtual Scanning Electron Microscopy (SEM) Laboratory

- Developed by UIUC (Our RPI NSEC partner) –

http://virtual.itg.uiuc.edu/downloads/

Go to www.java.com
And download java program first.

Also download images from
http://virtual.itg.uiuc.edu/data/

Burnt Hills-Ballston Lake Central Schools

NATIONAL SCIENCE FOUNDATION – NANOSCALE SCIENCE AND ENGINEERING CENTER FOR DIRECTED ASSEMBLY OF NANOSTRUCTURES

Actual module on Virtual SEM

- Paul Fedoroff, BHBL Physics teacher -

1.2.1 Virtual Scanning Electron Microscopy

Paul Fedoroff

Introduction

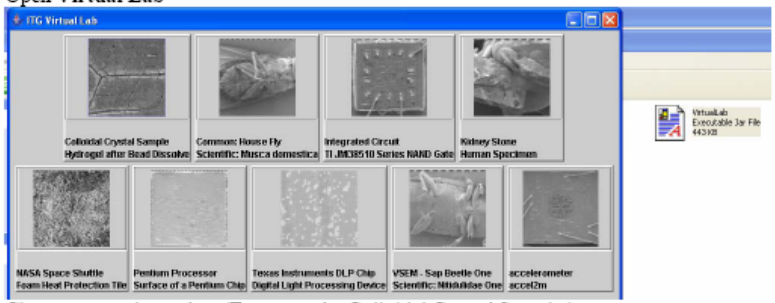
An optical microscope, the kind you might have used in biology class, uses a visible light source to reflect light off of a sample. Your eye then detects the reflected or emitted light from the sample. Lenses magnify the image. The magnification of an optical microscope cannot let you see what is happening at the nanoscale.

A Scanning Electron Microscope uses a beam of electrons that reflects off of a sample. The reflected or emitted electrons are detected and the signal is then converted into a picture, very similar to the way a television set works. The magnification is high enough to see what the surface is like at the nanoscale. Here is an animation of an SEM (http://www.mos.org/sln/sem/sem.mov).

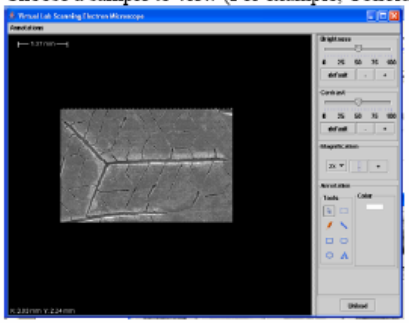
In order for the electron beam to work properly, the beam and the sample have to be in a vacuum. The sample also needs to be electrically conductive. This makes viewing a living sample impossible. Non-conducting samples can be viewed if they are first coated with a conducting film.

Activity

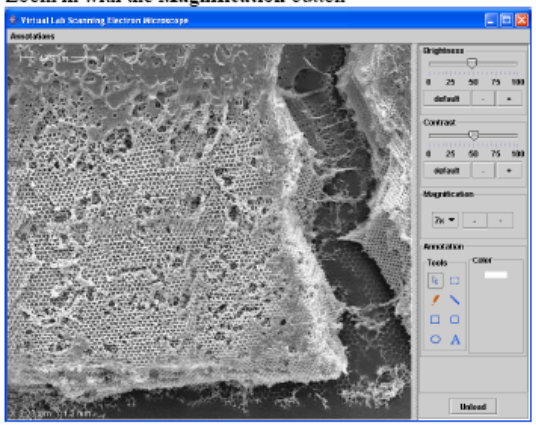
1. Open **Virtual Lab**



2. Choose a sample to view (For example, Colloidal Crystal Sample.)



3. Zoom in with the **Magnification** button



4. You might need to adjust the **Focal Plane**
5. Left click on the image to re-center the screen
6. **Scale** is in the top left corner
7. **Answer the following questions on each sample**
8. **Unload** the sample when done

Questions

1. House Fly vs. Beetle
Based on the image, why might a fly be able to "stick" to walls?
How small are these hairs?
Do you think the beetle can stick as well as the housefly? Explain.

2. Kidney Stone
Based on the structure viewed at high magnification, why might it be so painful to pass a kidney stone?

3. NASA Foam
A sweater keeps you insulated by trapping little pockets of air in the numerous wool or cotton fibers. How does NASA employ this technique of insulation?

4. Crystal Sample
Describe the material at low magnification.
Describe the material at high magnification. Any difference?

5. Pentium Processor and Integrated Circuit
How far apart are the circuit elements (wires, soldered points, etc.)?
How can one piece of dust or hair (only 1 – 100 microns wide) affect these devices?

Actual module on Virtual SEM

- Paul Fedoroff, BHBL Physics teacher -

Virtual Scanning Electron Microscopy – Teacher Copy

Paul Fedoroff

- Virtual scanning electron microscopy is educational material development project by a team of people at the University of Illinois at Urbana-Champaign. This project will seed the development of "Virtual Nanoscope" program at the RPI-UIUC-LANL NSEC (http://www.rpi.edu/dept/nsec/). In order to receive a free copy of this software, please contact either Professor Paul Braun (pbraun@uiuc.edu) or Chang Y. Ryu (ryuc@rpi.edu).
- We would like to encourage high school teachers to try it in his/her classroom. What you need is just a computer and students will experience a feeling like operating the SEM instrument.
- Java must be installed in your PC. Download java from http://www.java.com/en/index.jsp. It is free.

1. House Fly vs. Beetle

Based on the image, why might a fly be able to "stick" to walls?

Tiny hairs on legs

How small are these hairs?

A few microns

Do you think the beetle can stick as well as the housefly? Explain.

Probably not, very few hairs compared to fly.

2. Kidney Stone

Based on the structure viewed at high magnification, why might it be so painful to pass a kidney stone?

Very jagged shape

3. NASA Foam

A sweater keeps you insulated by trapping little pockets of air in the numerous wool or cotton fibers. How does NASA employ this technique of insulation?

Many very small fibers trap gas to insulate the material

4. Crystal Sample

Describe the material at low magnification.

Smooth with a crack in it

Describe the material at high magnification. Any difference?

Porous, spongy, honeycomb

5. Pentium Processor and Integrated Circuit

How far apart are the circuit elements (wires, soldered points, etc.)?

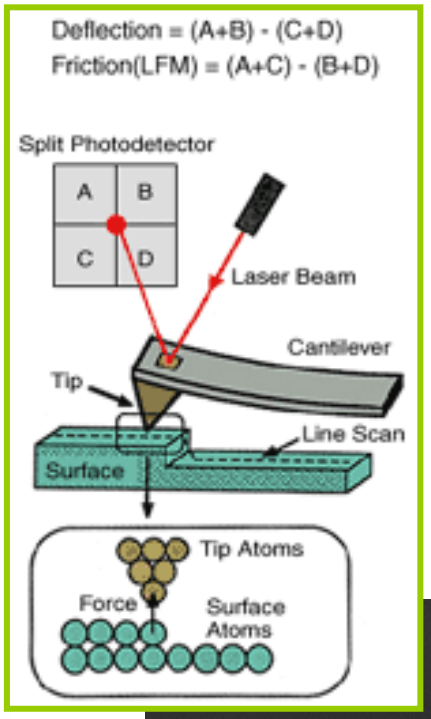
A few microns

How can one piece of dust or hair (only 1 – 100 microns wide) affect these devices?

Short Circuit and one particle can affect many elements.

Atomic Force Microscopy (AFM) & Data Storage

Paul Fedoroff & Dr. Hoichang Yang (NSEC staff)



1.3.3 Atomic Force Microscopy

Paul Fedoroff

Note to teachers:

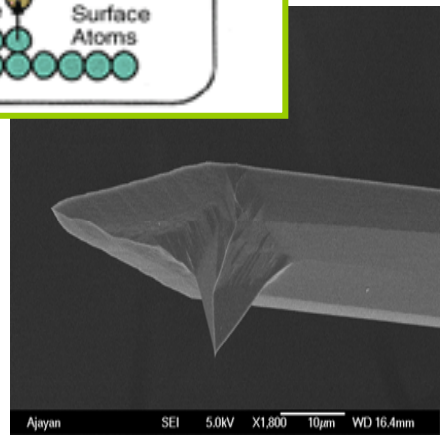
- Power point presentation file has been made for teachers' use. Specific comments are provided for each slide at the "notes" section. The following shows the carbon-copy of the slides.
- The actual PPT file can be downloaded from the web or CD.
- The following Supplementary Questions would be useful.

Atomic Force Microscopy

1. If you were to measure a force that is quite weak, would you want a large or small spring constant? Explain.

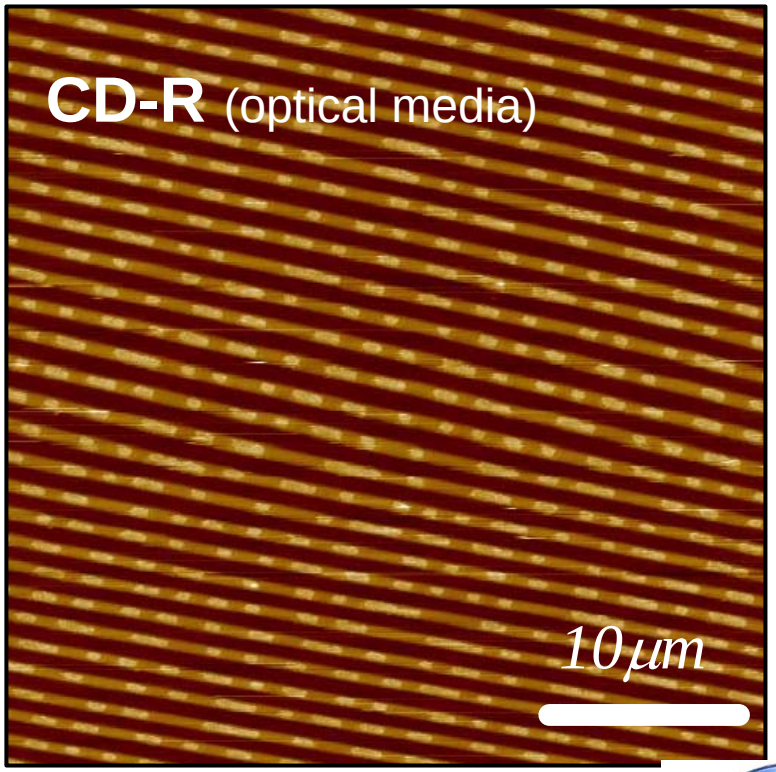
2. How would the spring constant affect the resonant frequency?

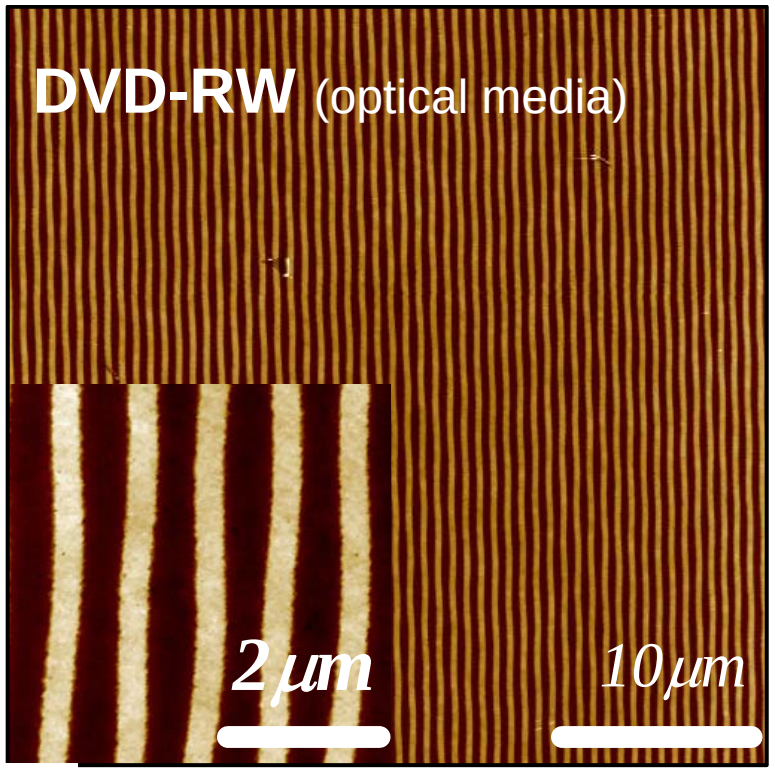
3. If you were to measure the magnetic force, would there necessarily be a difference in the topography?



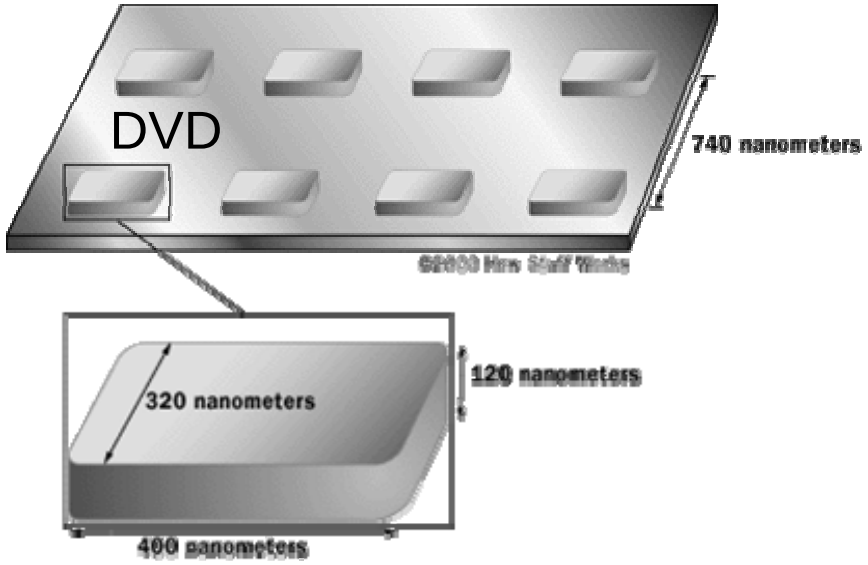
Optical Storage media – Tapping AFM


Topography TM AFM





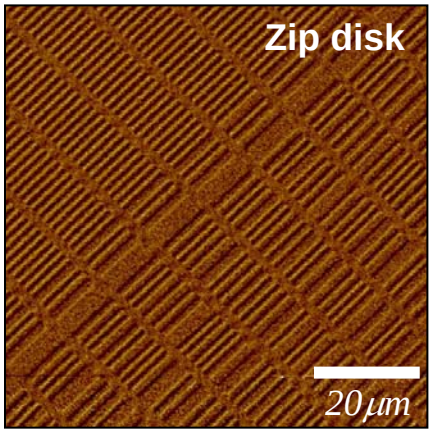
CD vs. DVD

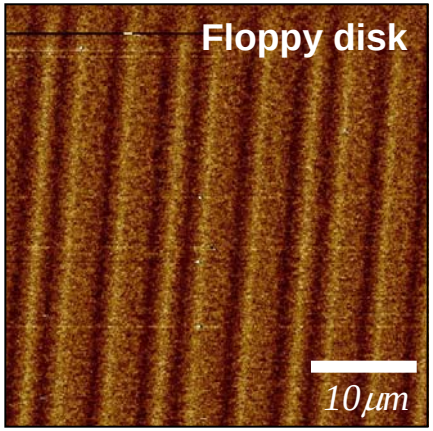


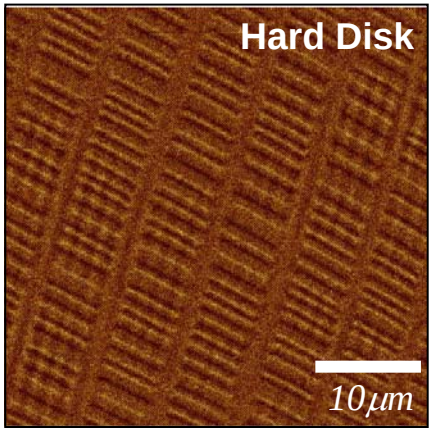
Specification	CD	DVD
Track Pitch	1600 nm	740 nm
Min. Pitch Length	860 nm	400 nm

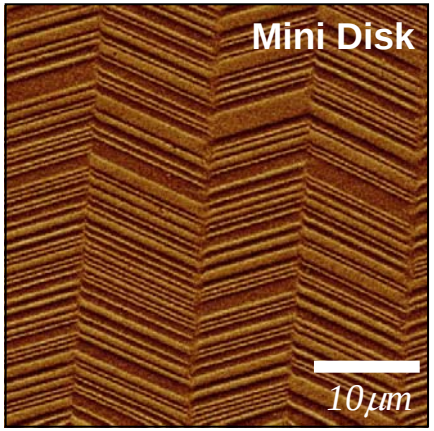
The schematic diagrams above
were obtained from http://www.howstuffworks.com/

Magnetic media - AFM

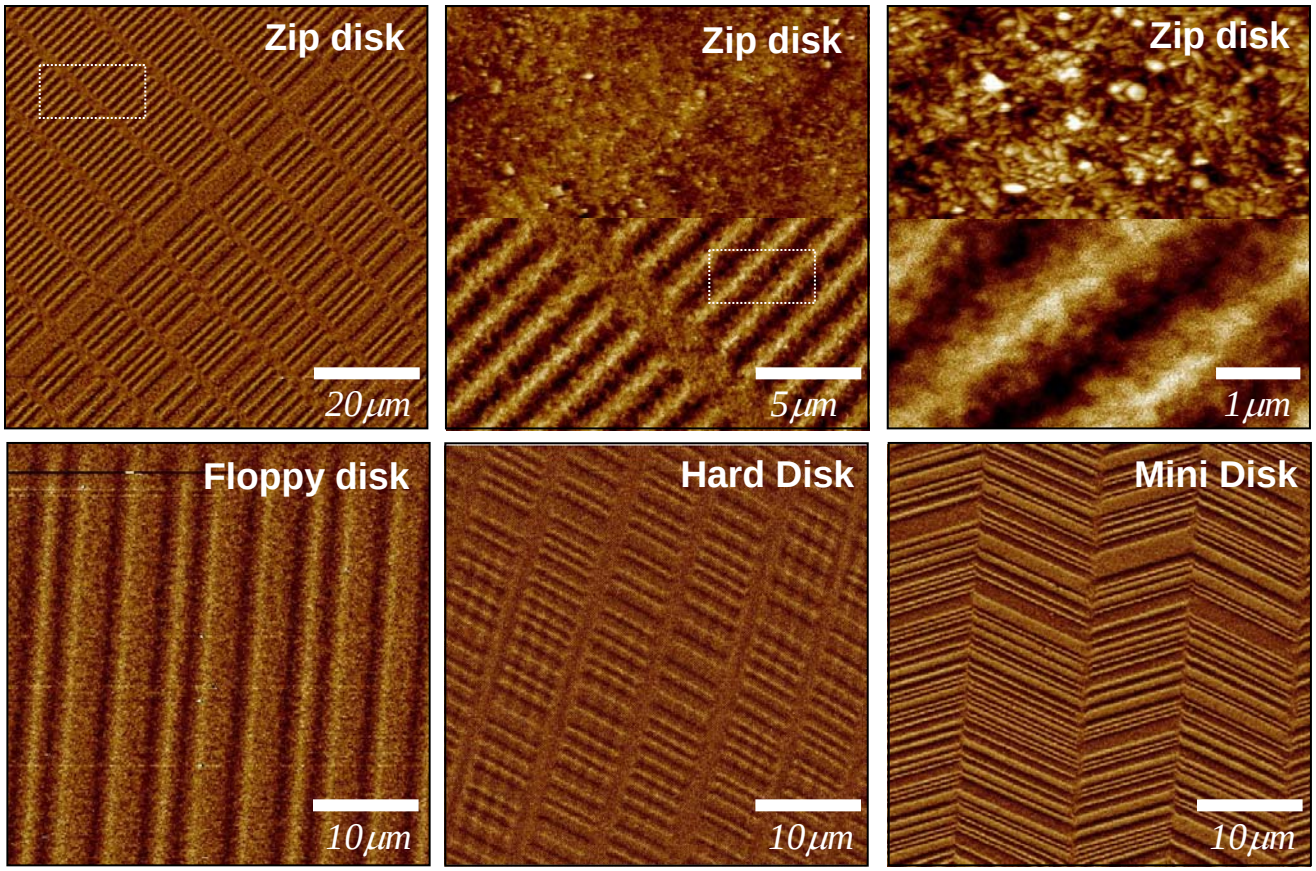








Magnetic Force AFM



TOP: Topography

BOTTOM: "magnetic" Phase

Summary

- Nanotechnology
  - K-12 educational resources are abundant
  - Many nano-research centers have HS outreach programs.
  - www.nano.gov is a good place to start.
- RPI Nanoscale Science & Engineering Center
  - "Bringing Nanotechnology to the Classroom"
    - Carbon nanotube synthesizer (Hands on activities)
    - Virtual SEM (Computer-based JAVA software)
    - AFM and other class supplementary materials using state-of-the-art nanoscale imaging tools at RPI
  - Contact me at RPI (Prof. Chang Y. Ryu (ryu@rpi.edu))

NSEC:
www.nano.rpi.edu

My research homepage
http://block.chem.rpi.edu

Acknowledgement

- NSF NSEC – Outreach Program “Bringing nanotechnology to the classroom”
- NSF-DMR CAREER Award (2005)

- BHBL High School
- GE Global Research Center