# 10.524
# Self-assembly and Nanotechnology


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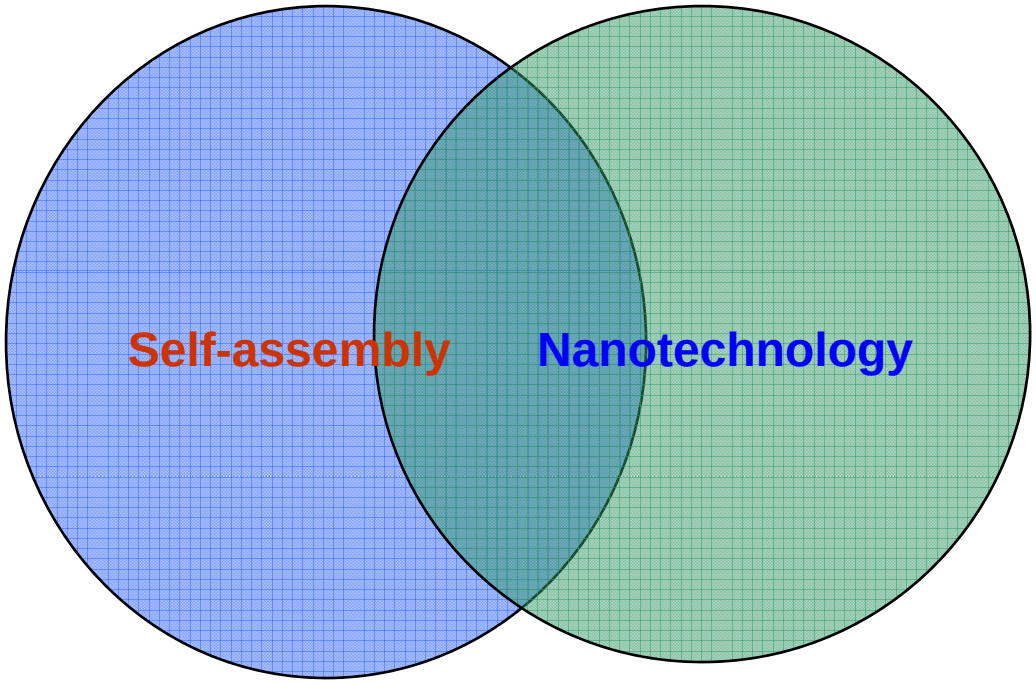
Office hours: Mon 11:00am-12:30pm;
Wed 11:00am-12:30pm, and by appointment

# Why Together?



# What's Nanotechnology??????

- Nanomaterials
- Nanoscience
- Nanoengineering
- Nanotechnology
- Nanomanufacturing
- Nano-xxxxxxx

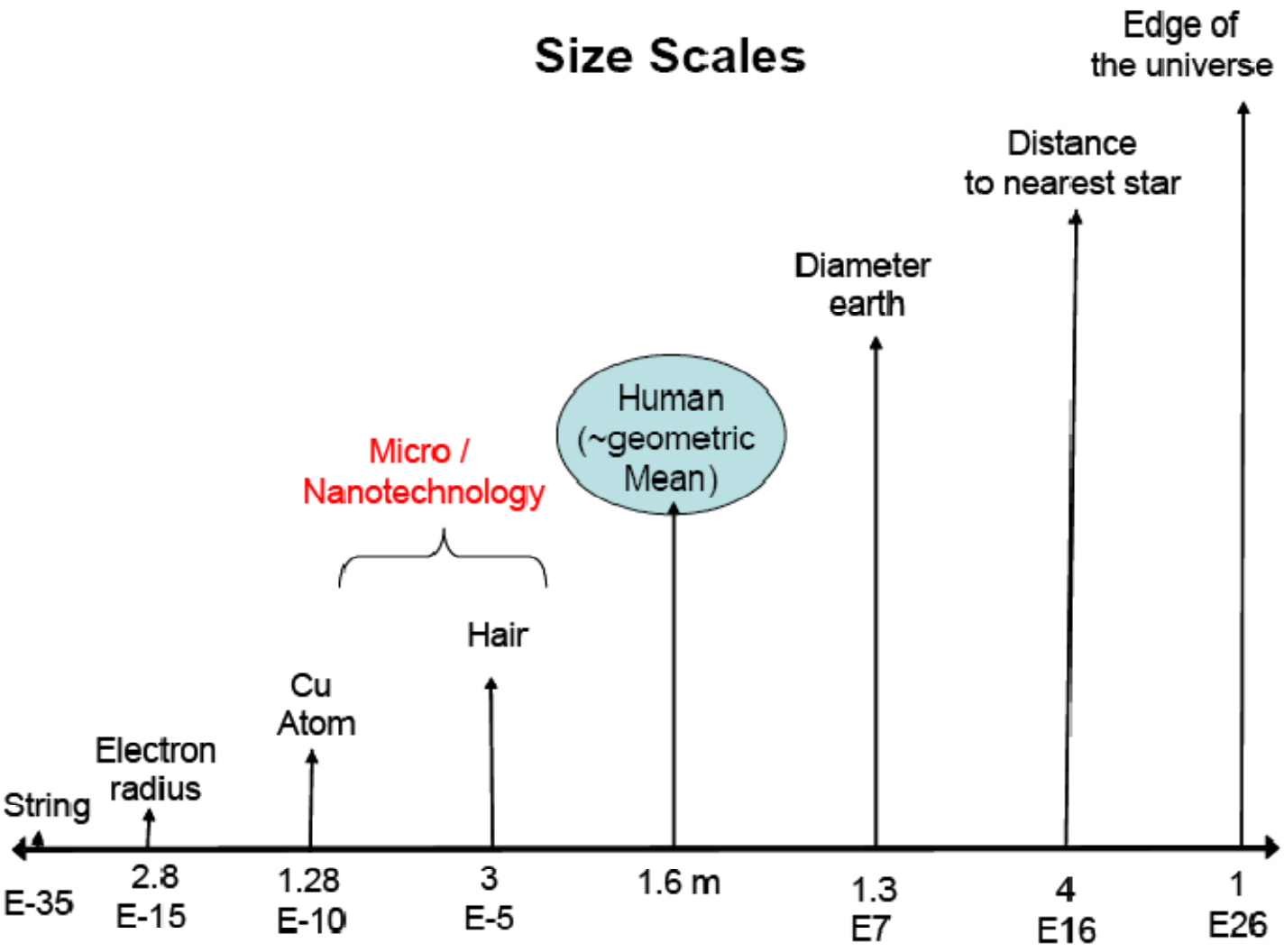
- Your answers●●●●●

"Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."

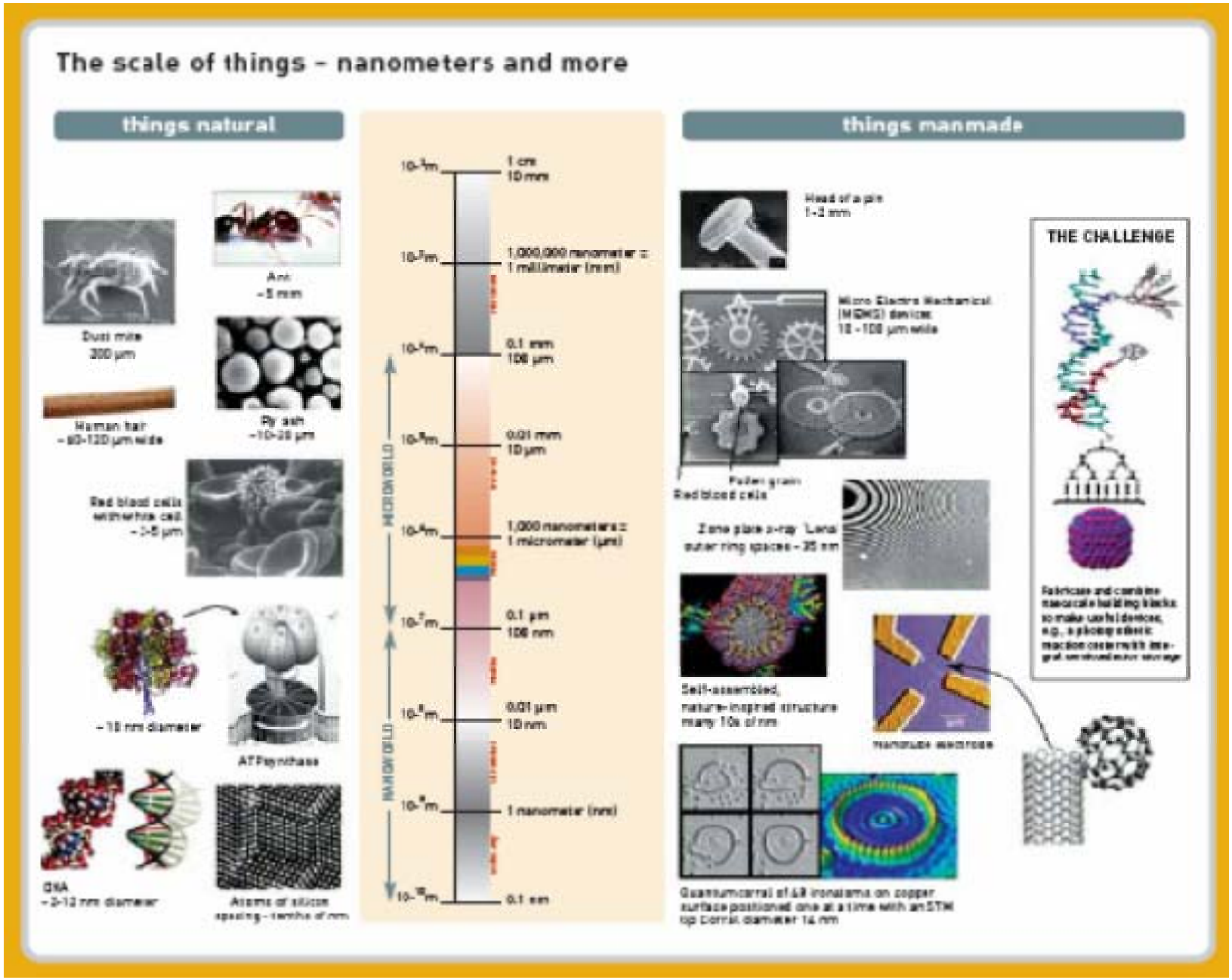
National Nanotechnology Initiative (NNI): http://www.nano.gov/index.html

(One nanometer (nm) is one billionth, or 10-9 of a meter)

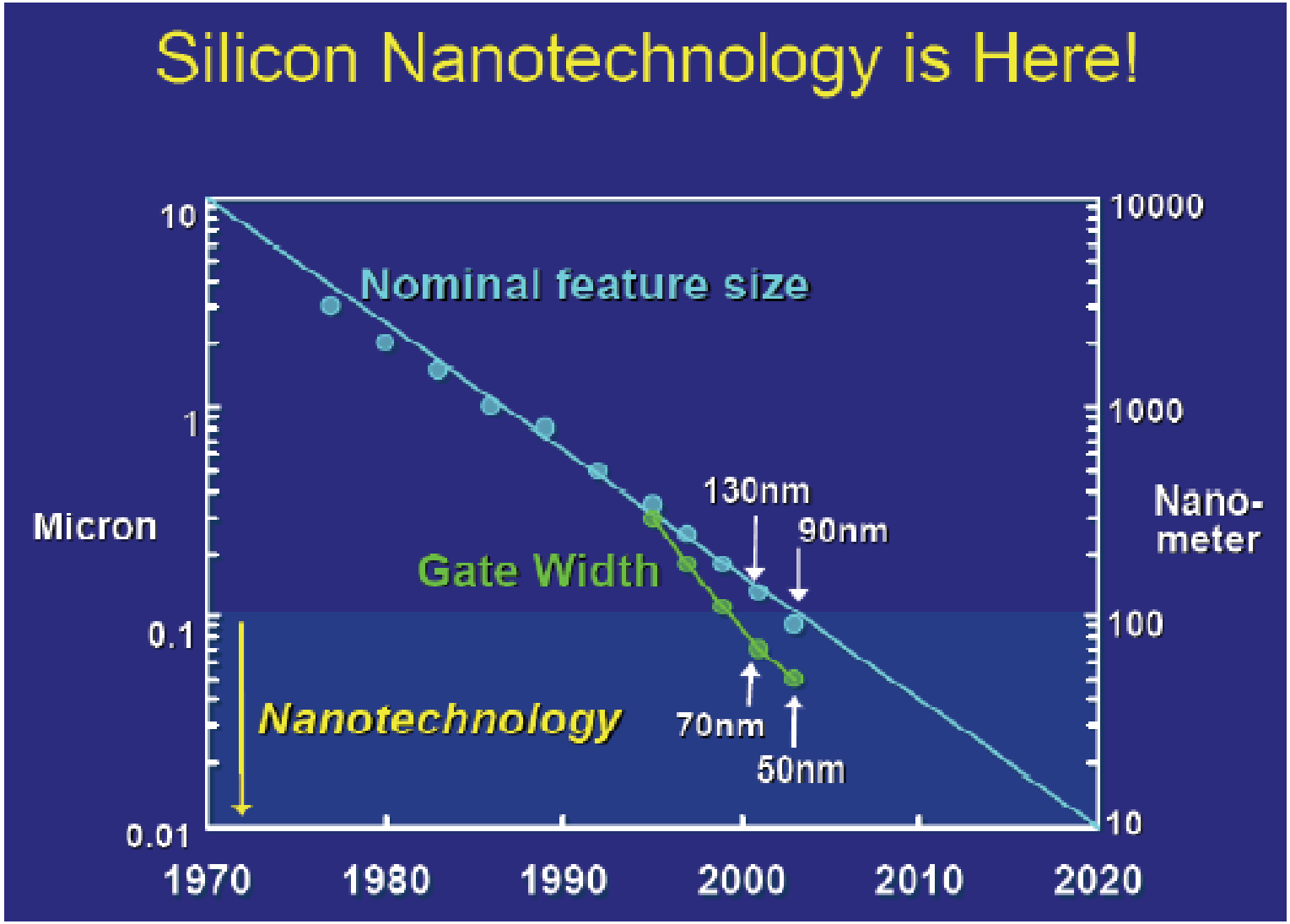
# Size Scales




From Gracias, *Micro- and Nanotechnology*

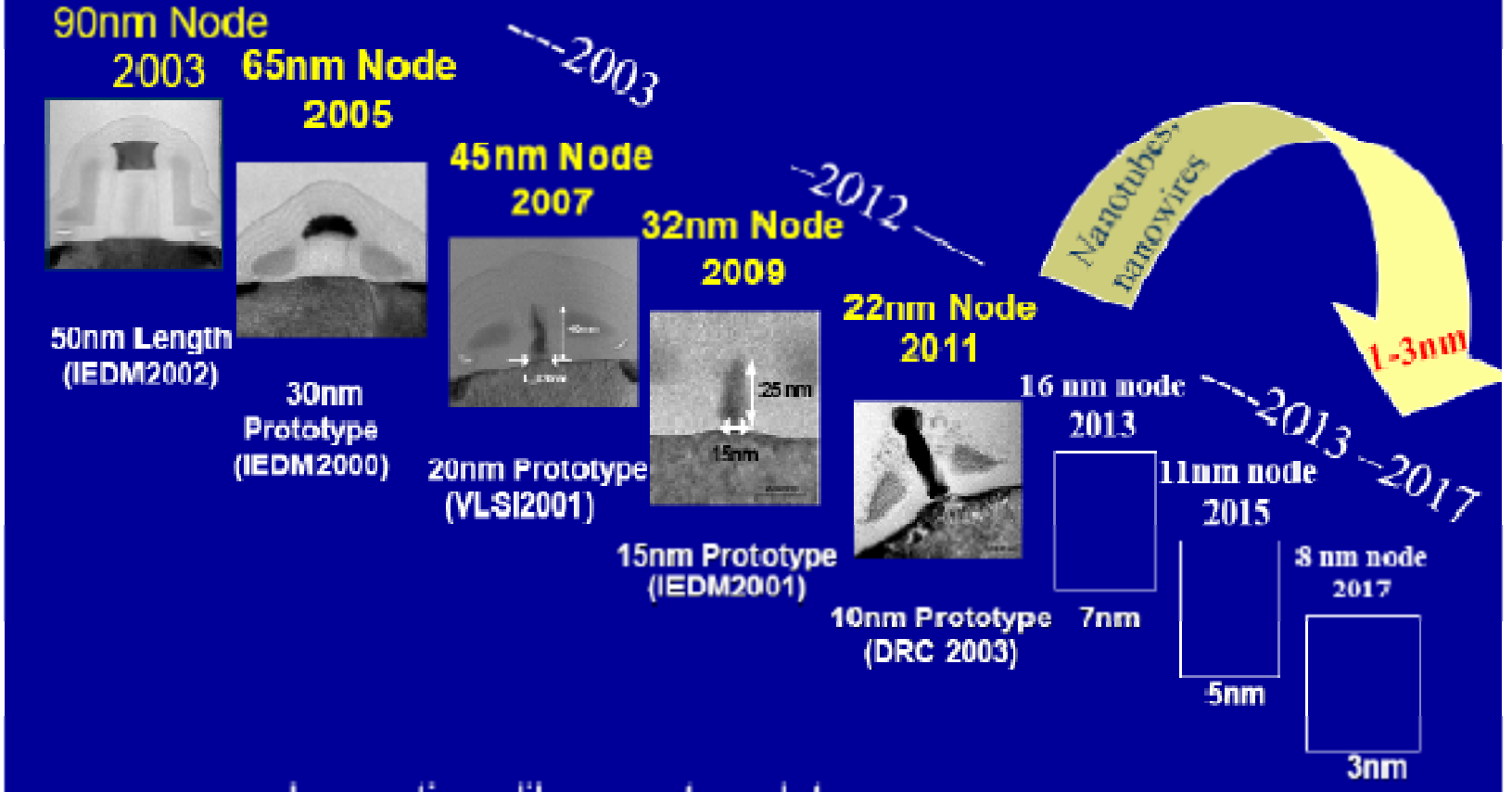



John Carruthers, Portland State University




John Carruthers, Portland State University

# Nanotechnology will extend CMOS scaling




Innovations like quantum dots,
Nanowires, Naotubes, etc.



John Carruthers, Portland State University

# Feynman's Talk of "Nanotechnology" in 1959

I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, ``What are the strange particles?") but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications.

What I want to talk about is the problem of manipulating and controlling things on a small scale.

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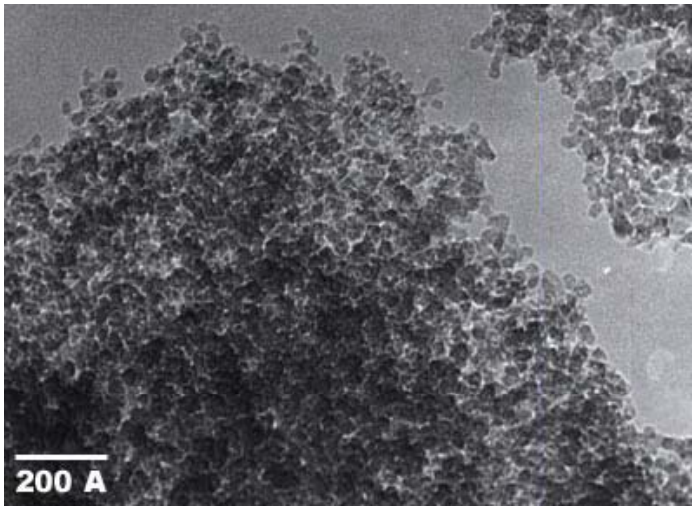
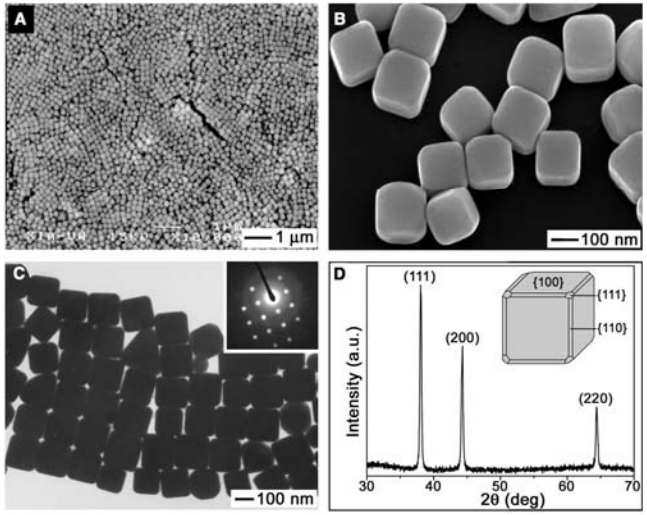
*There's plenty of room at the bottom; by Richard P. Feynman*
1965 Nobel Prize in Physics, for quantum electrodynamics

# Spherical and Shaped Nanoparticles

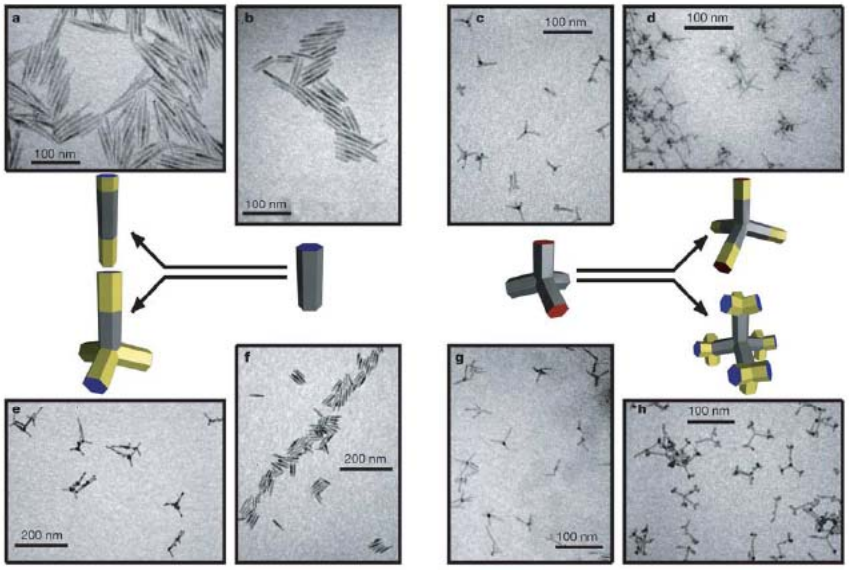



Nanodiamonds




Nanocubes

Sun & Xia, Science, 2002




Nature, 430, 2004, 190

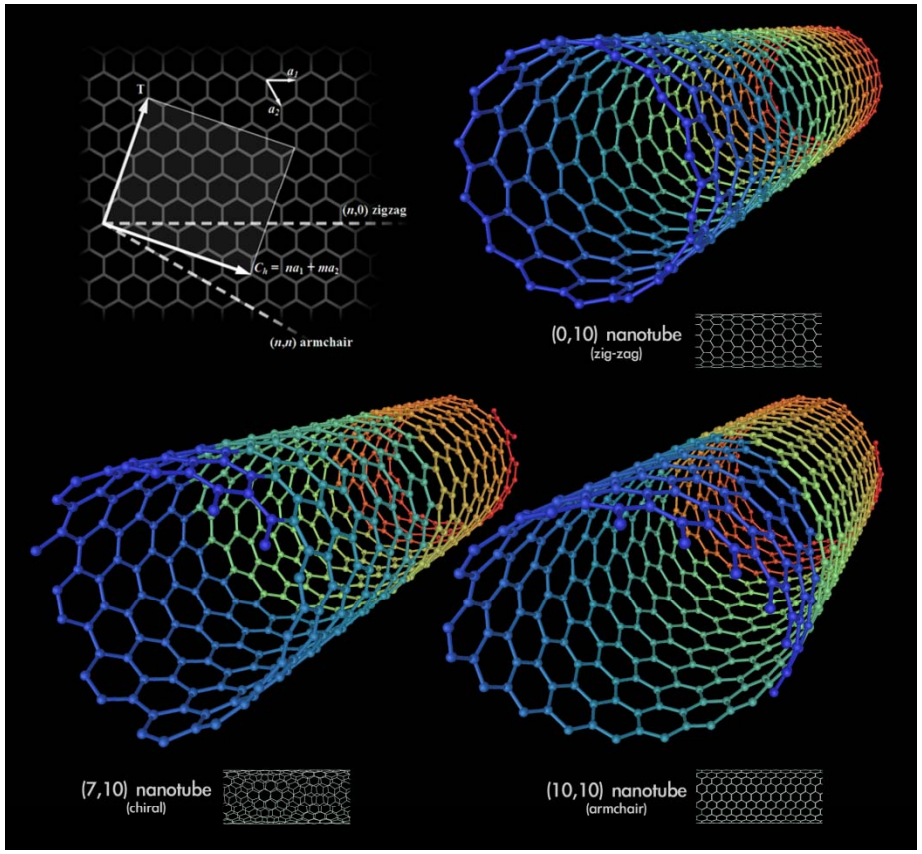
# Quantum Dots

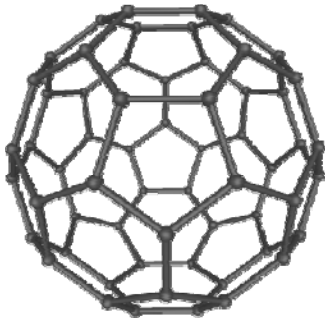

A **quantum dot** is a semiconductor nanostructure that confines the motion of conduction band electrons, valence band holes, or excitons (pairs of conduction band electrons and valence band holes) in all three spatial directions.

Fluorescence induced by exposure to ultraviolet light in vials containing various sized Cadmium selenide (CdSe) quantum dots

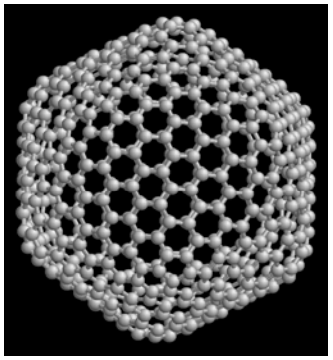
From: http://en.wikipedia.org/wiki/Quantum_dots

# Carbon Nanotubes

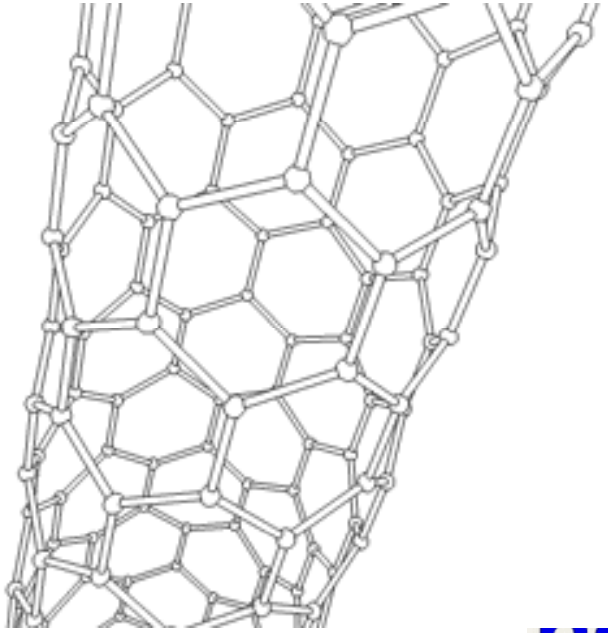


Buckyballs: C60



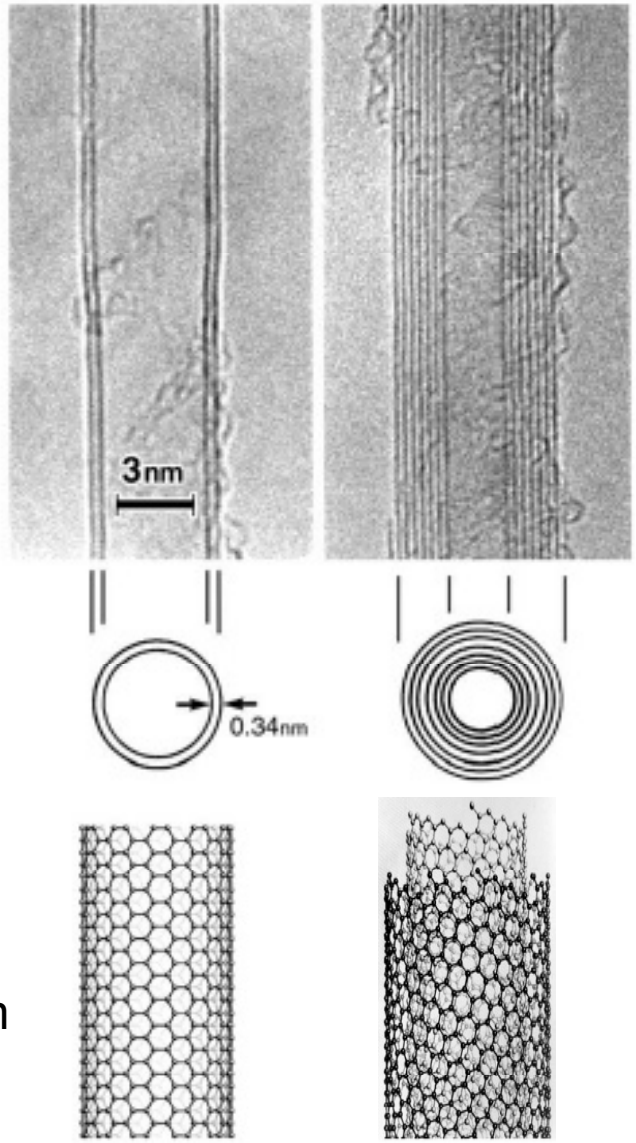
C540



**Carbon nanotubes** (CNTs) are an allotrope of carbon

(Pictures from Wikipedia)

# Single Wall and Multi Wall Carbon Nanotubes



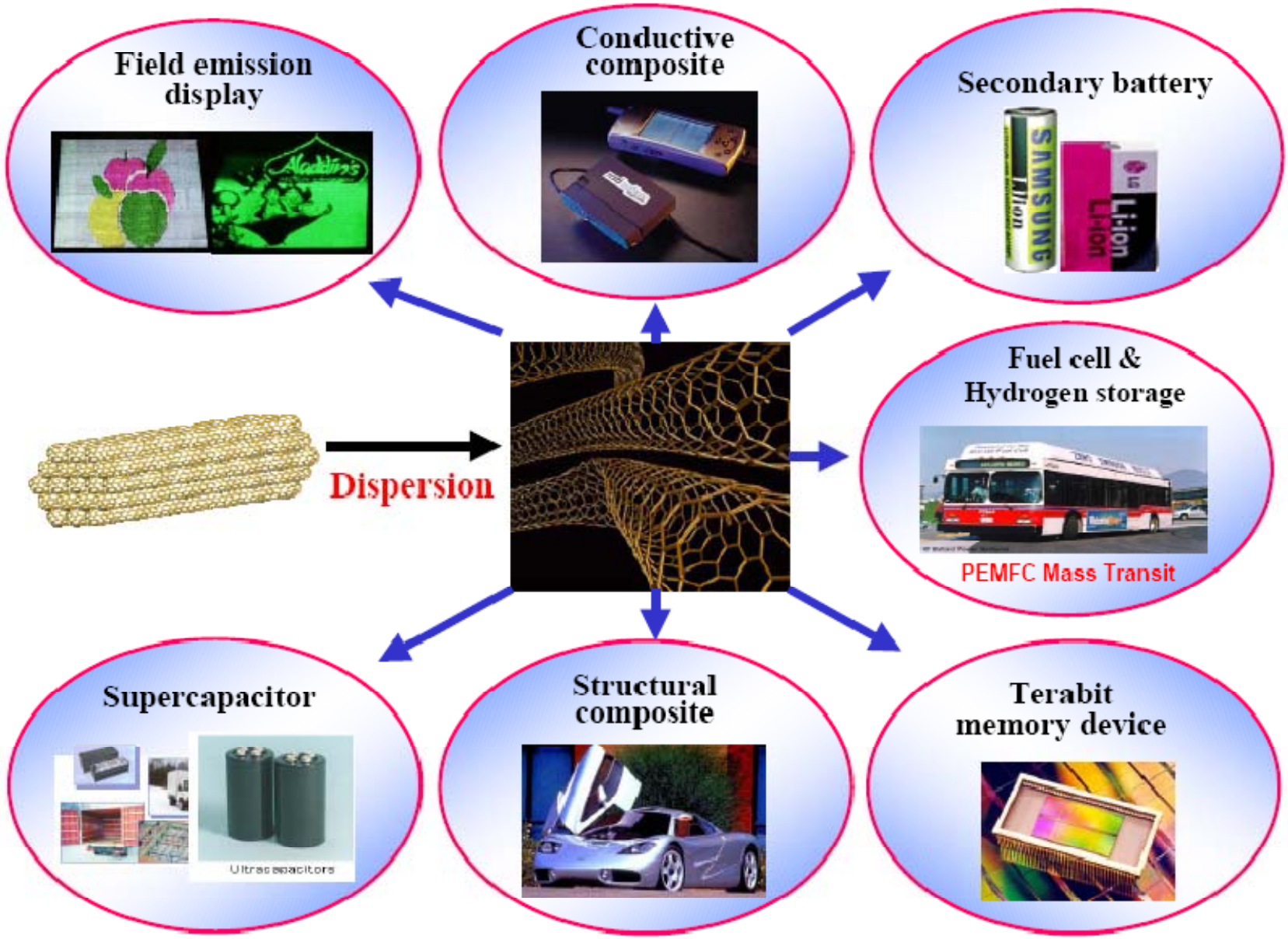

Up to cm long

SWNT
(single
Wall nanotube)
Diameter ~ 1.4 nm

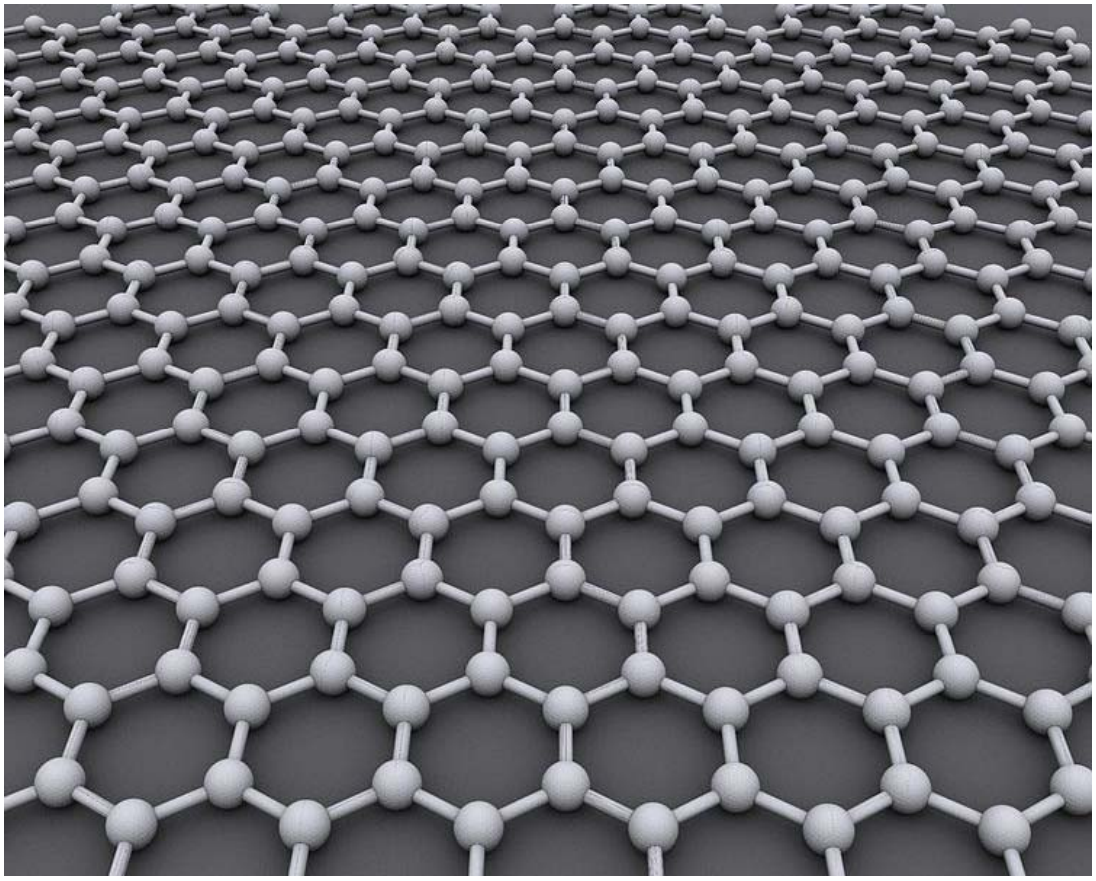
MWNT
(multiwall)
Diameter 10-20 nm

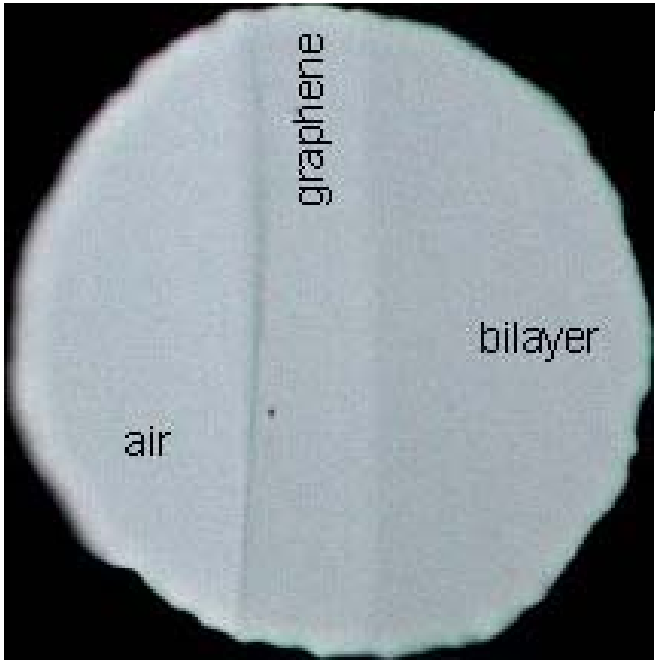
Iijima, S. Carbon nanotubes: past, present, and future. Physica B: Condensed Matter (2002), 323, 1-5

# Potential applications of CNs



# Graphenes



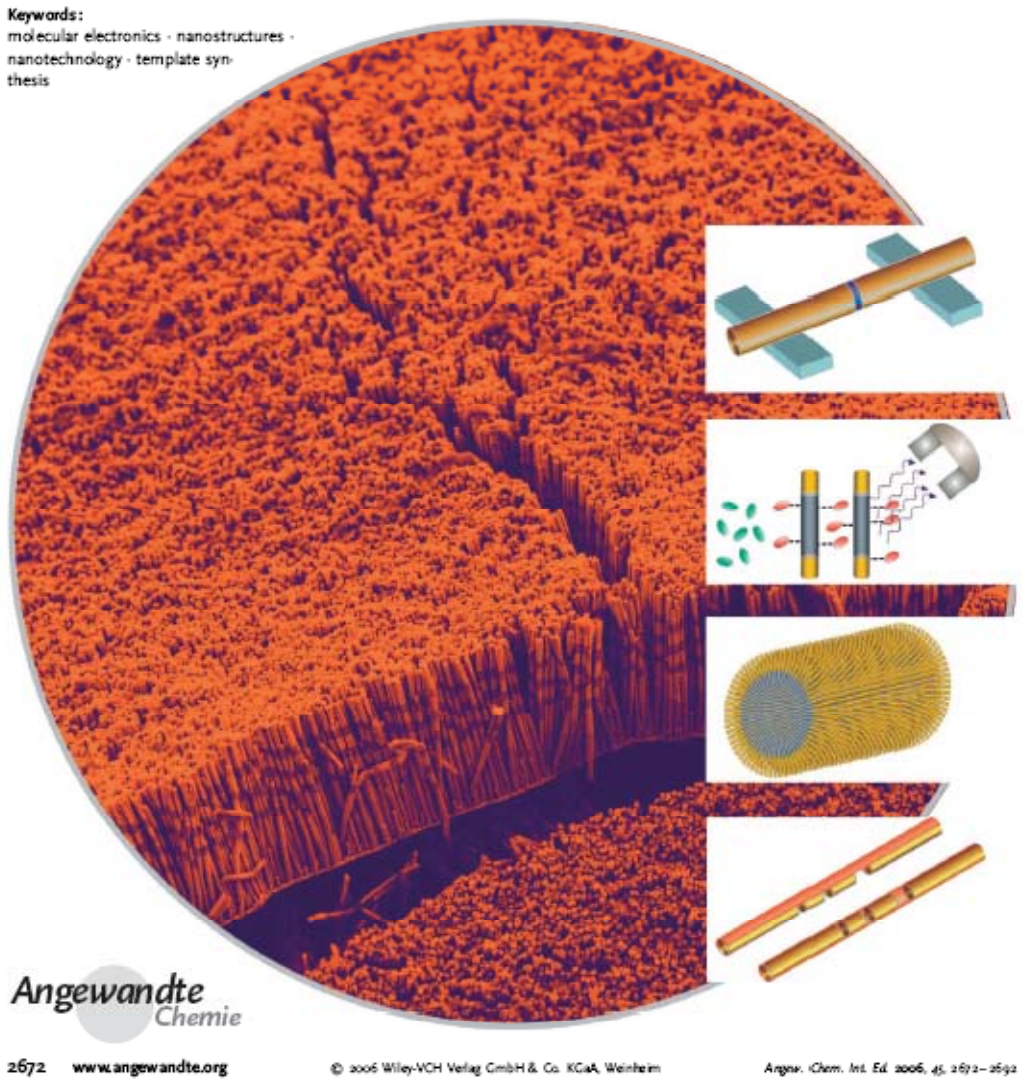


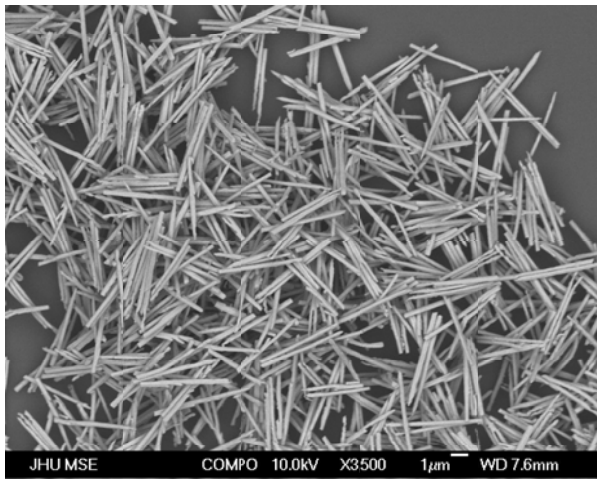

**Optical property**

**Graphene is an atomic-scale honeycomb lattice made of carbon atoms.**

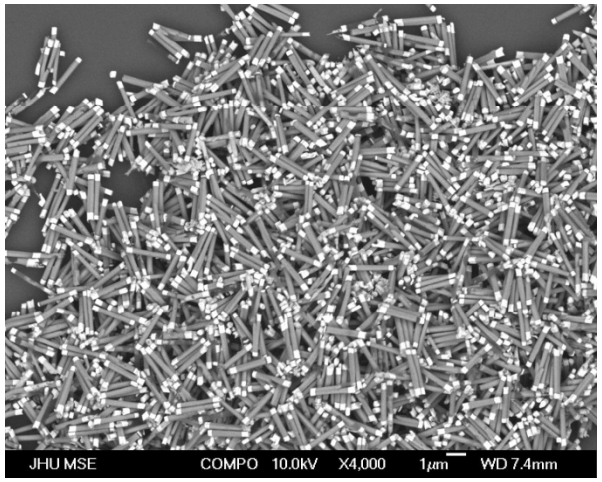
The Nobel Prize in Physics 2010 Andre Geim, Konstantin Novoselov

# Nanowires/Nanorods




One component nanowires




Multicomponent nanowires



nano manufacturing center at UML

# Optical Properties of Nanoparticles and Nanowires

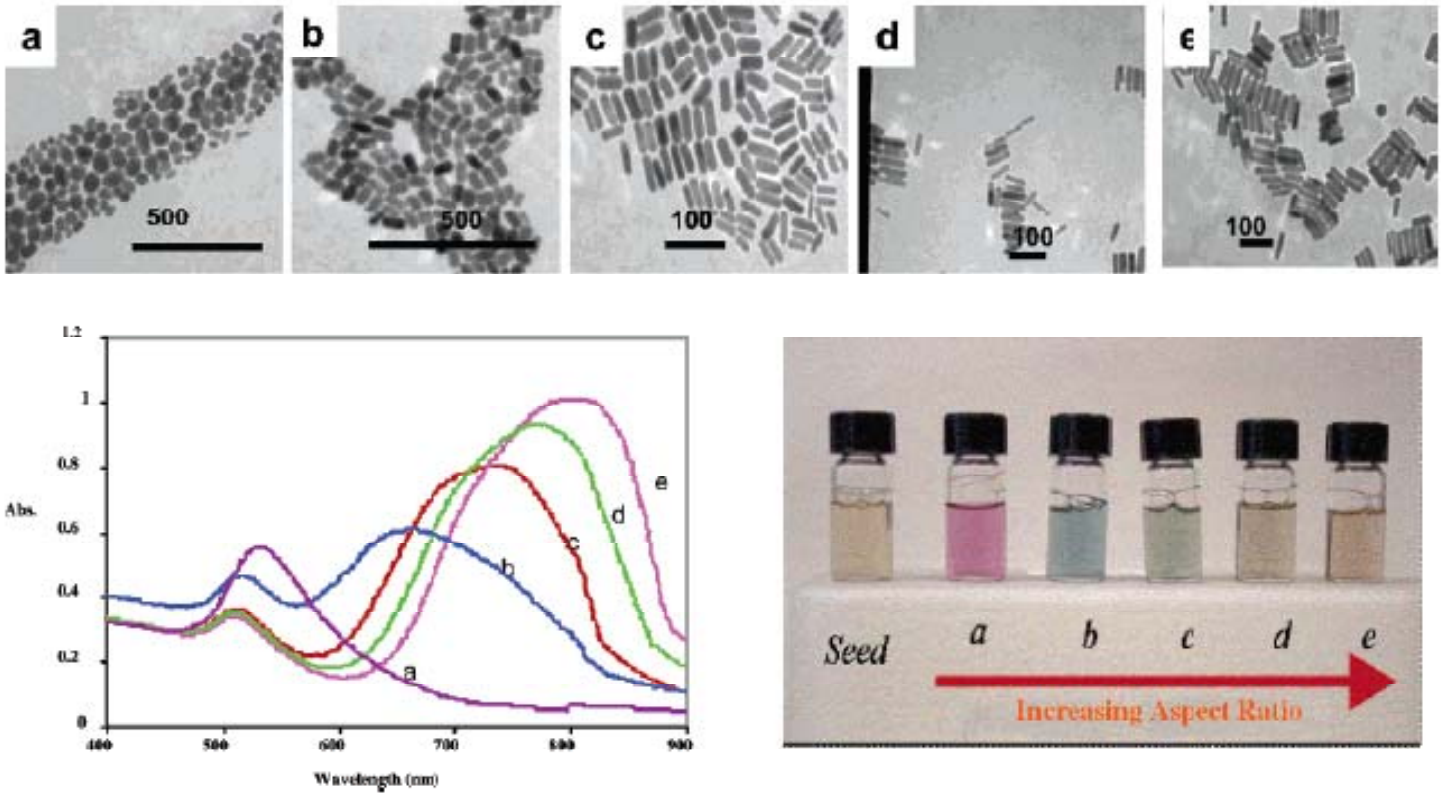
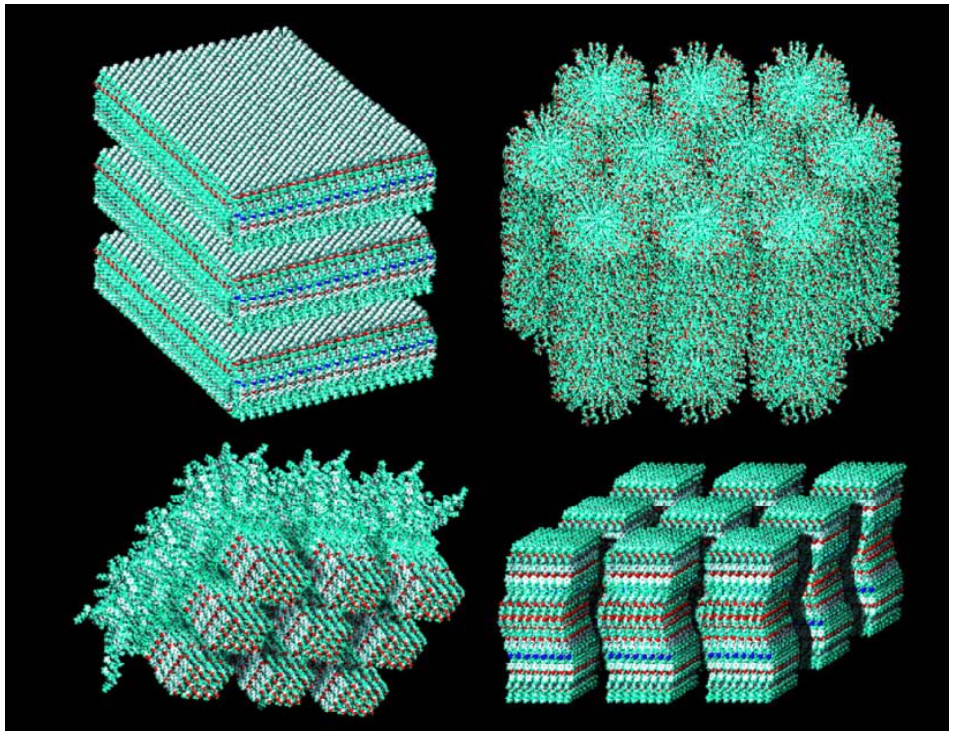


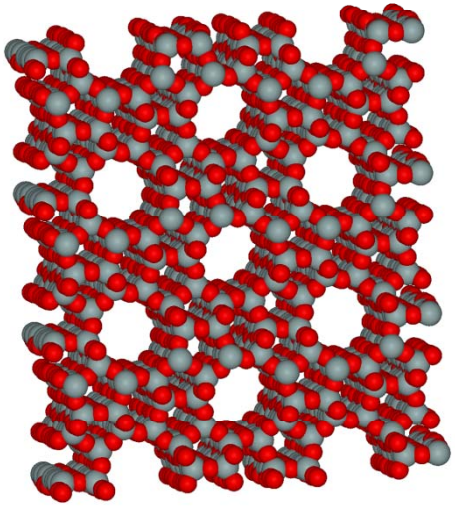

**Figure 1.** Transmission electron micrographs (top), optical spectra (left), and photographs of (right) aqueous solutions of gold nanorods of various aspect ratios. Seed sample: aspect ratio 1; sample a, aspect ratio 1.35 ± 0.32; sample b, aspect ratio 1.95 ± 0.34; sample c, aspect ratio 3.06 ±0.28; sample d, aspect ratio 3.50 ± 0.29; sample e, aspect ratio 4.42 ± 0.23. Scale bars: 500 nm for a and b, 100 nm for c, d, e.

*J. Phys. Chem. B, Vol. 109, 2005,* 13857

# Molecular Nanostructures



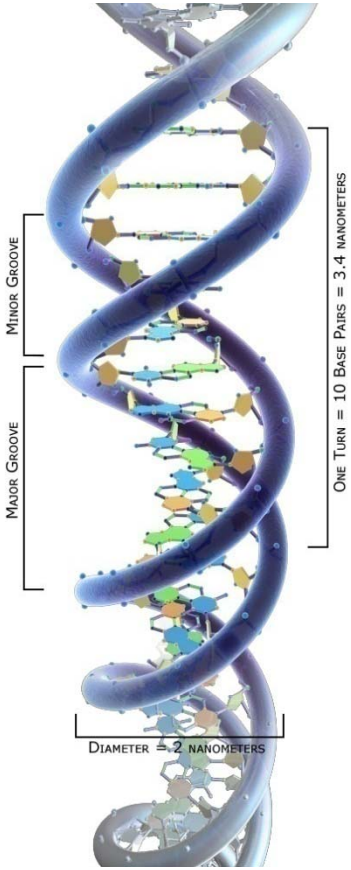
Supramolecular nanostructures

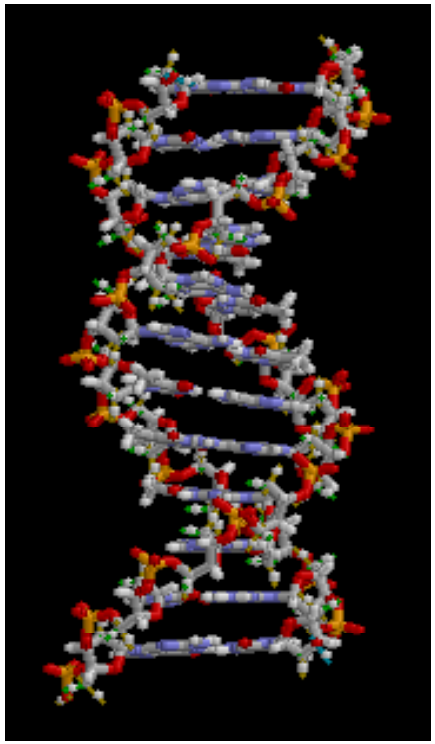


Zeolites

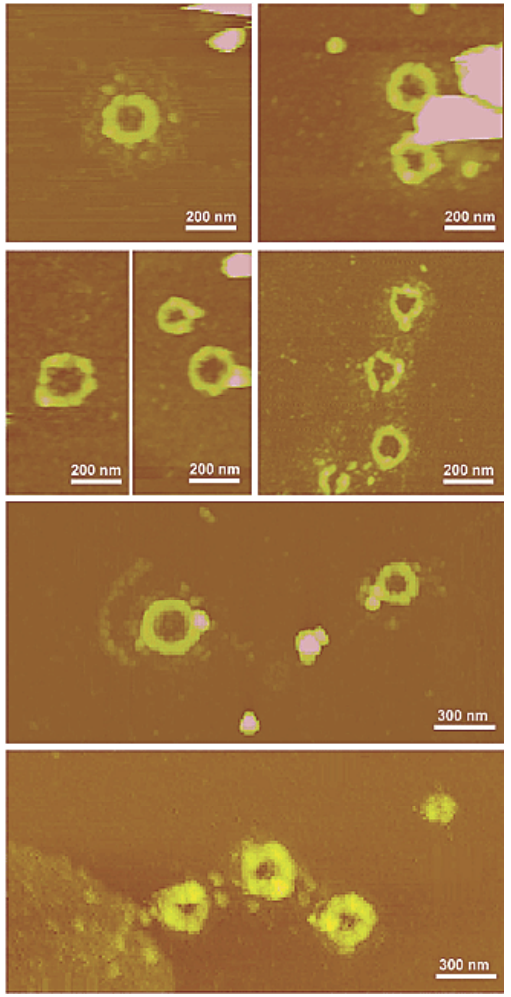
(Pictures from Wikipedia)

# Biomolecules: Natural Nanostrucutres



DNA (22 to 24 angstroms wide)

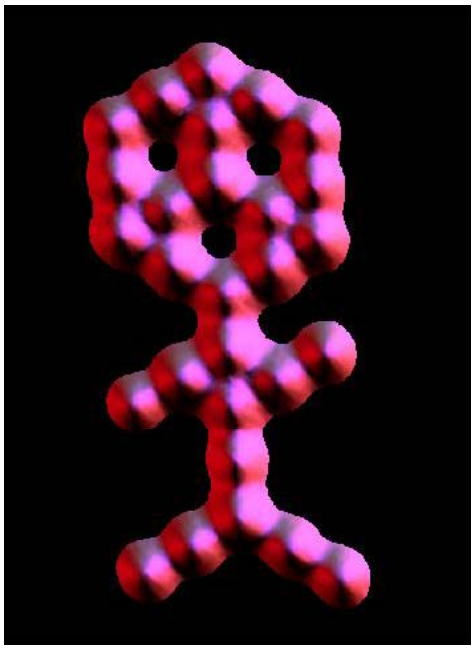



M13 virus-based ring structures observed by AFM on mica surface

*Nano Letters,* **4 (**1), 23 -27, 2004

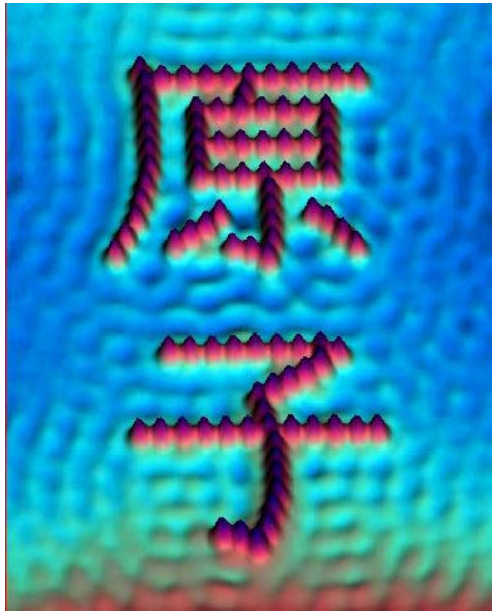
# Scanning Tunneling Microscopy (STM)

**STM**: a new method for confining electrons to artificial structures at the nanometer lengthscale



Carbon Monoxide Man

Carbon Monoxide on Platinum (111)

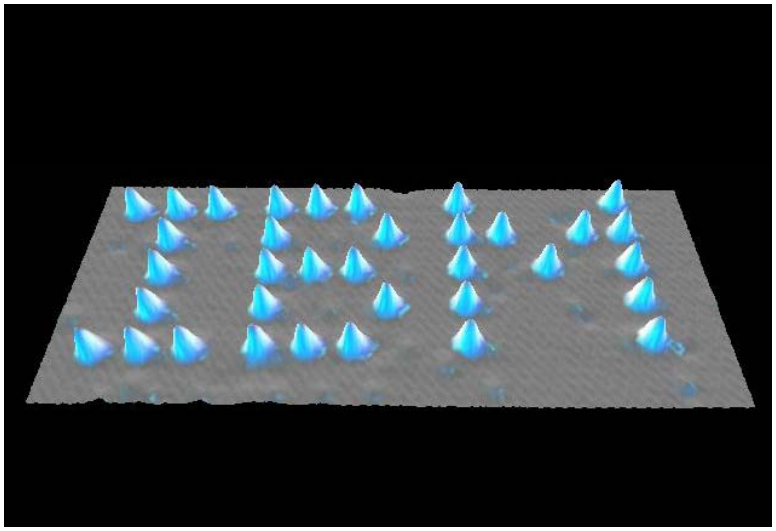


Atom (in Chinese)

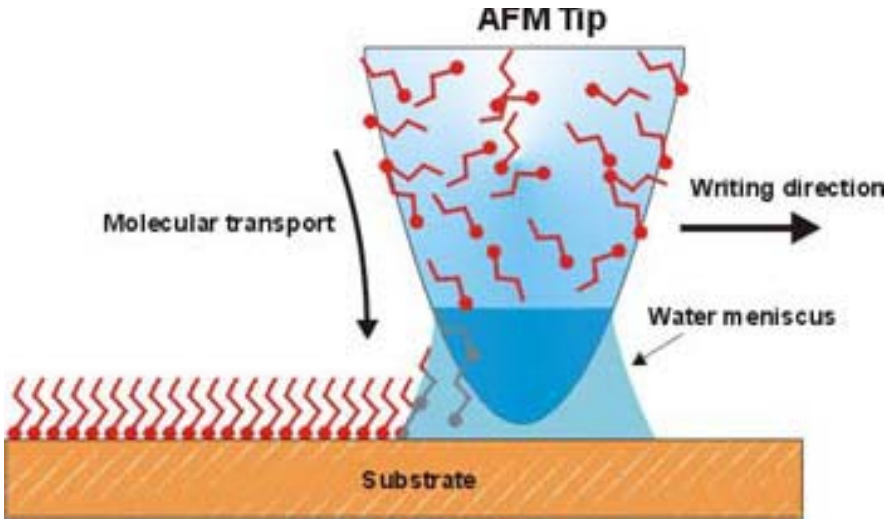
Iron on Copper (111)

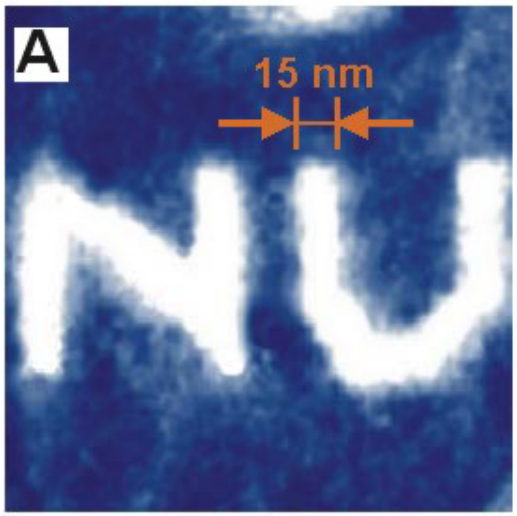
The biginning

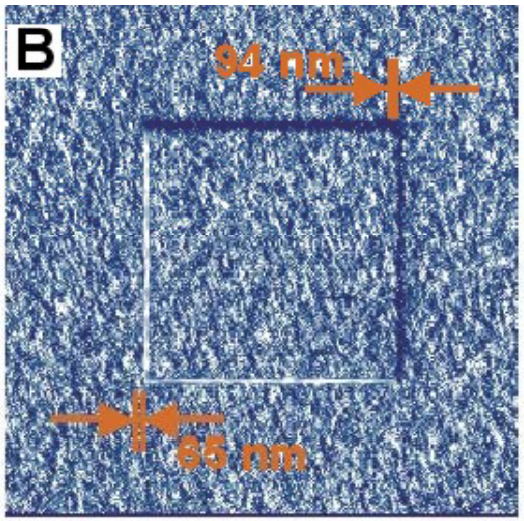
Xenon on Nickel (110)

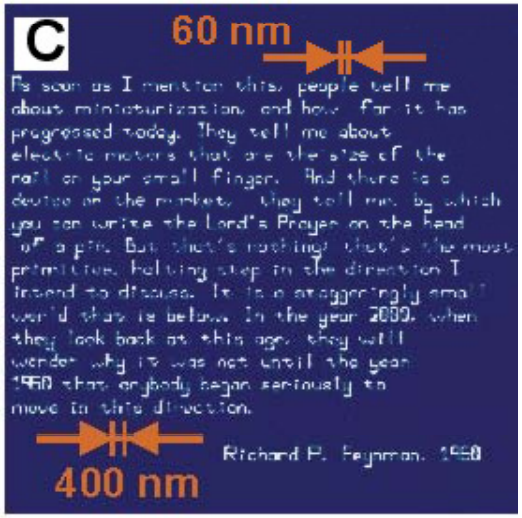


# Dip Pen Nanolithography (DNP)



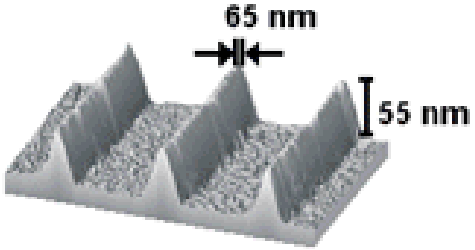



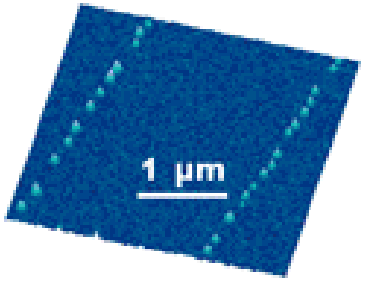



# Applications of DPN

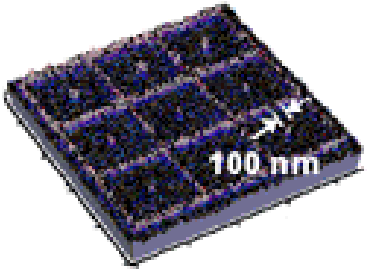

Conducting Polymers




Silicon Nanostructures

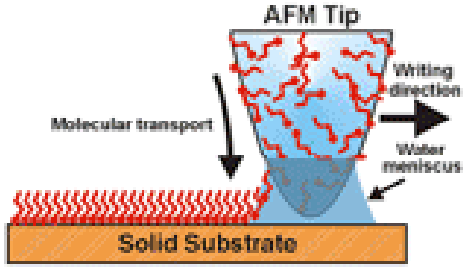


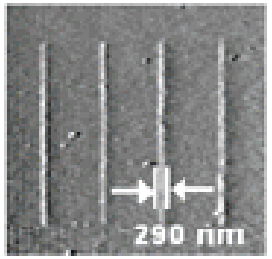

Single Nanoparticle Lines



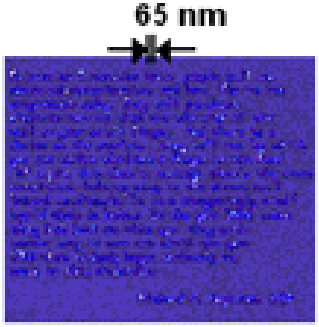

Protein Nanoarrays

## Dip-Pen Nanolithograpy

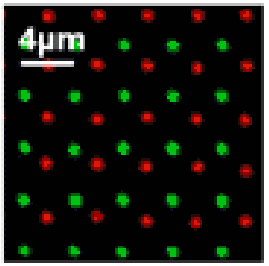


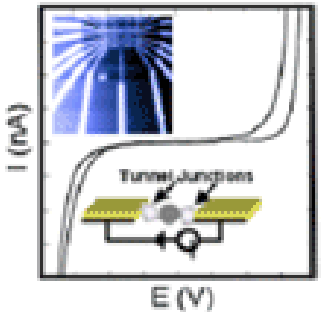

Sol Gel Templates




Small Organic Molecules



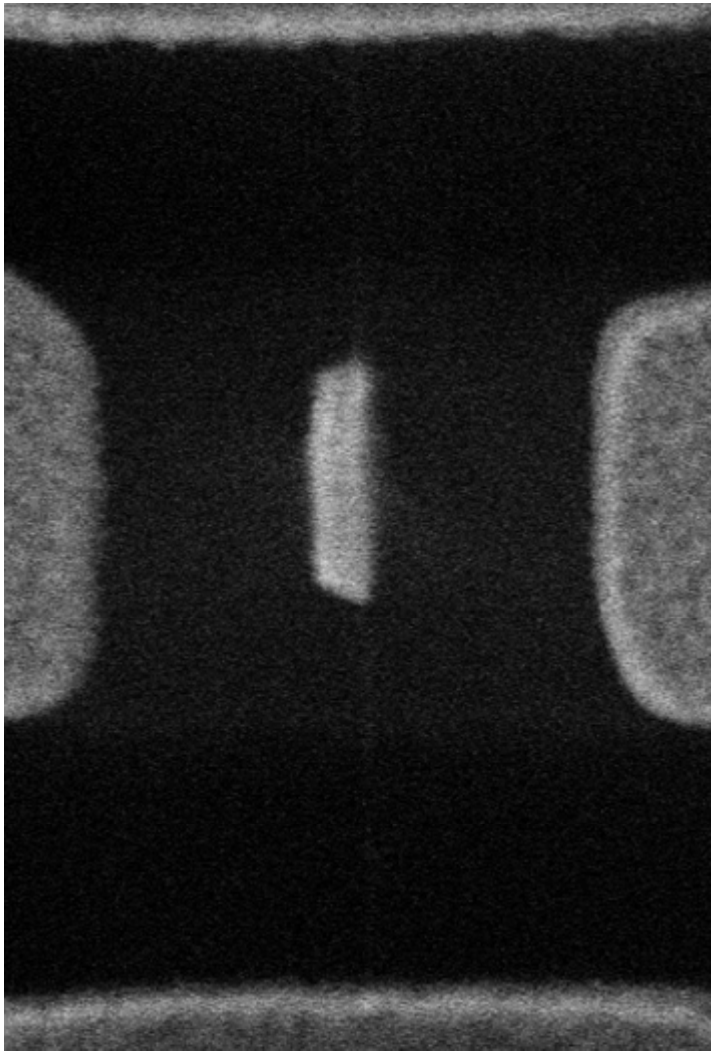

Ultrahigh Density DNA Arrays




Single Particle Devices

http://www.chem.northwestern.edu/~mkngrp/dpn.htm

# Nanomotors



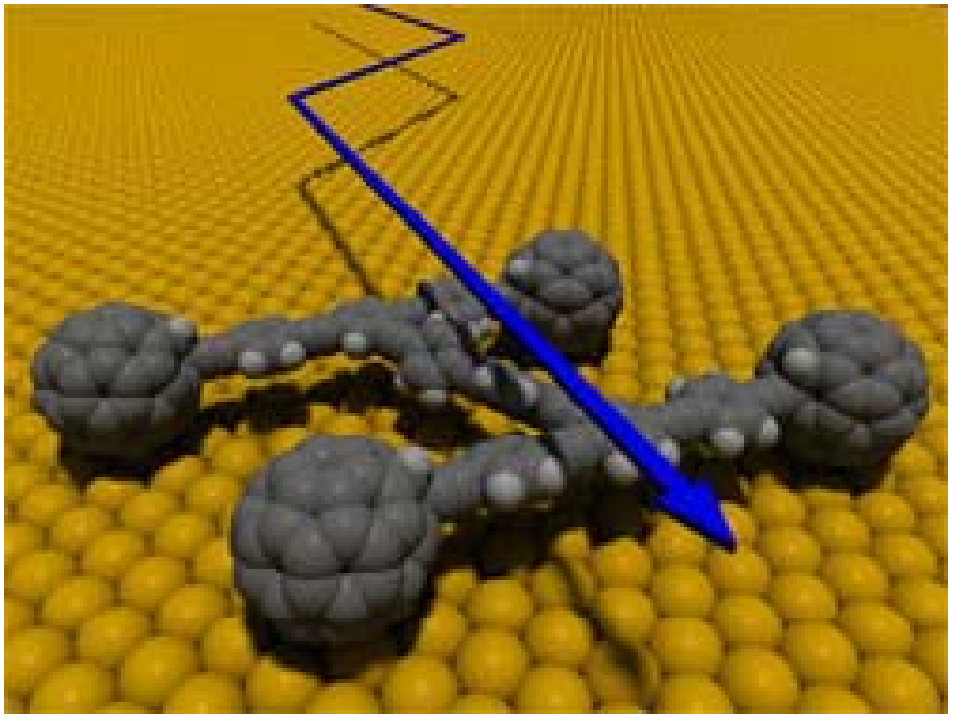
A **nanomotor** is a molecular device capable of converting energy into movement and forces on the order of the piconewtons.

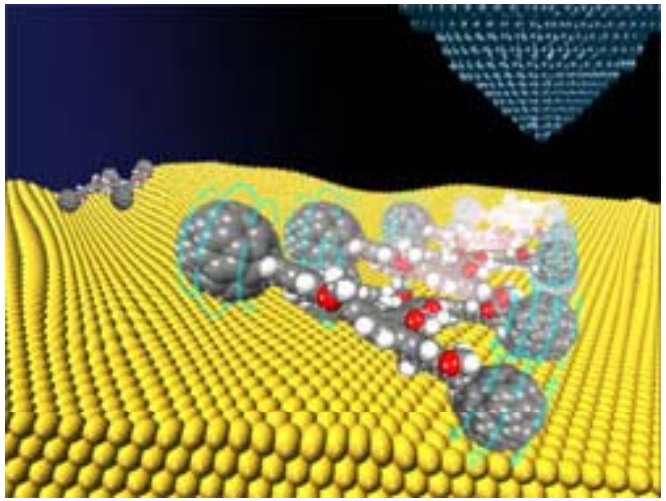
By attaching a gold plate (with dimensions of order 100nm) to the outer shell of a suspended multiwall carbon nanotube (like nested carbon cylinders), they are able to electrostatically rotate the outer shell relative to the inner core. These bearings are very robust; Devices have been oscillated thousands of times with no indication of wear. The work was done in situ in an SEM.

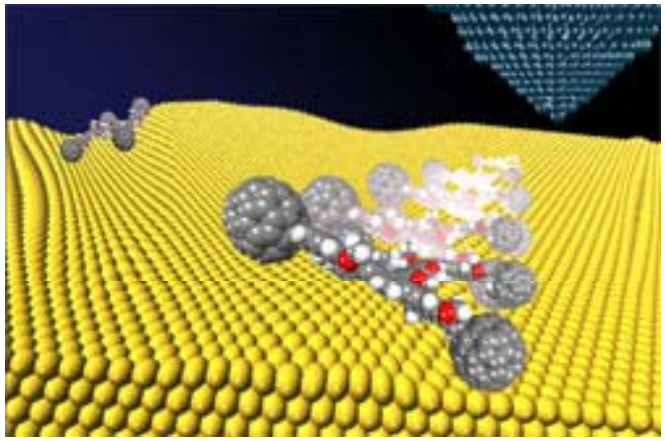
http://en.wikipedia.org/wiki/Nanomotor

Nanomotor constructed at UC Berkeley. The motor is about 500nm across:
300 times smaller than the diameter of a human hair

# Nanocars







The nanocar consists of a chassis and axles made of well-defined organic groups with pivoting suspension and freely rotating axles. The wheels are buckyballs.

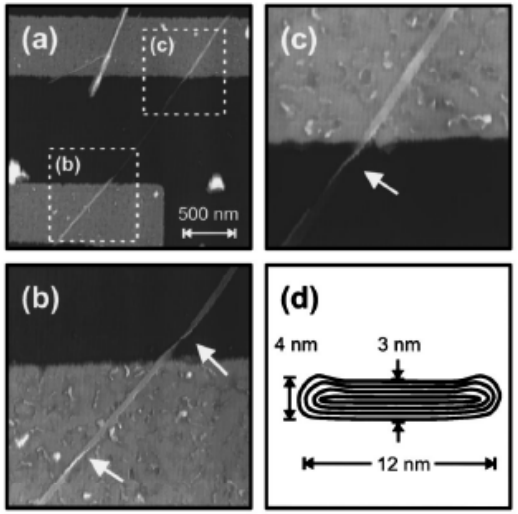
Rice's vehicle is the first that actually functions like a car, rolling on four wheels in a direction perpendicular to its axles.

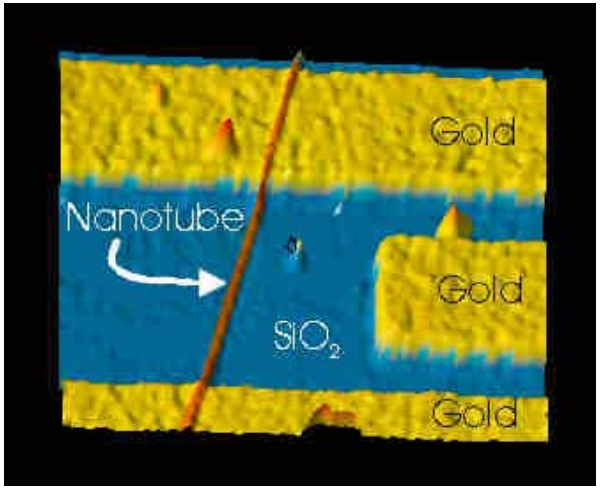
Scanning tunneling microscopy (STM), provided the measurements and experimental evidence that verified the rolling movement

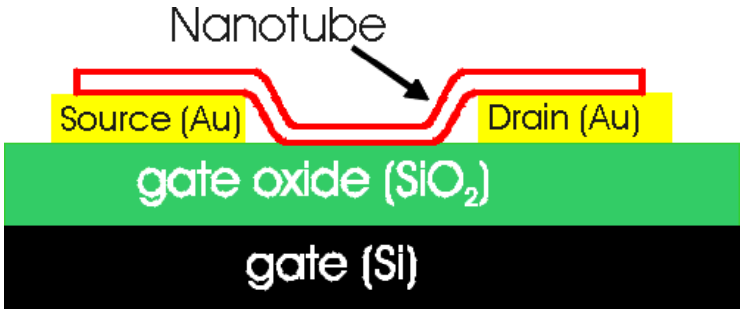
http://en.wikipedia.org/wiki/Nanocar

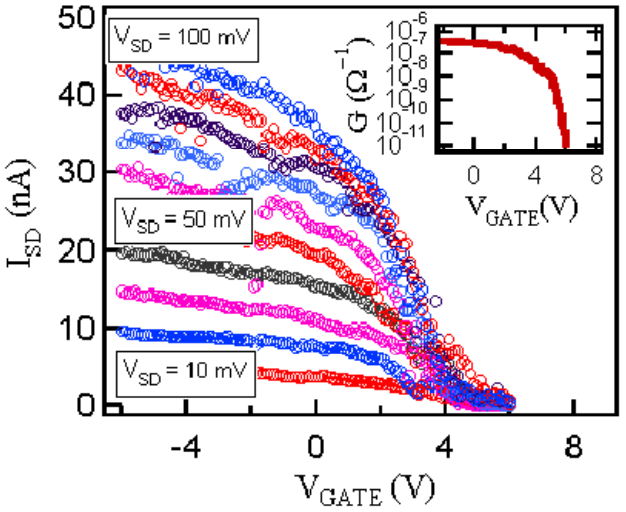
# Nanotube Field-effect transistor (FET)

Transistors are the basic building blocks of integrated circuits (ICs)



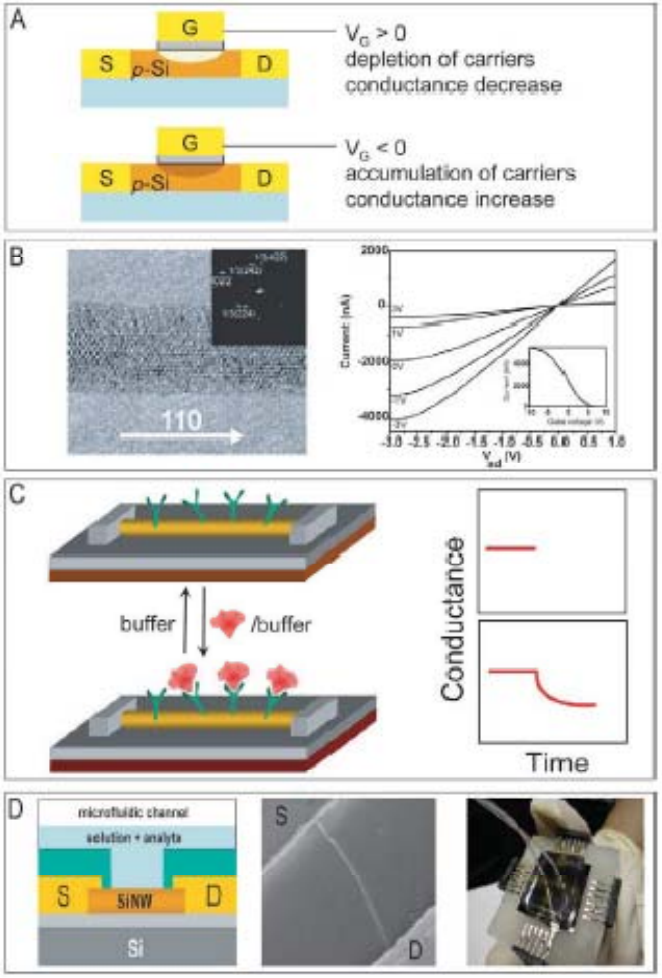



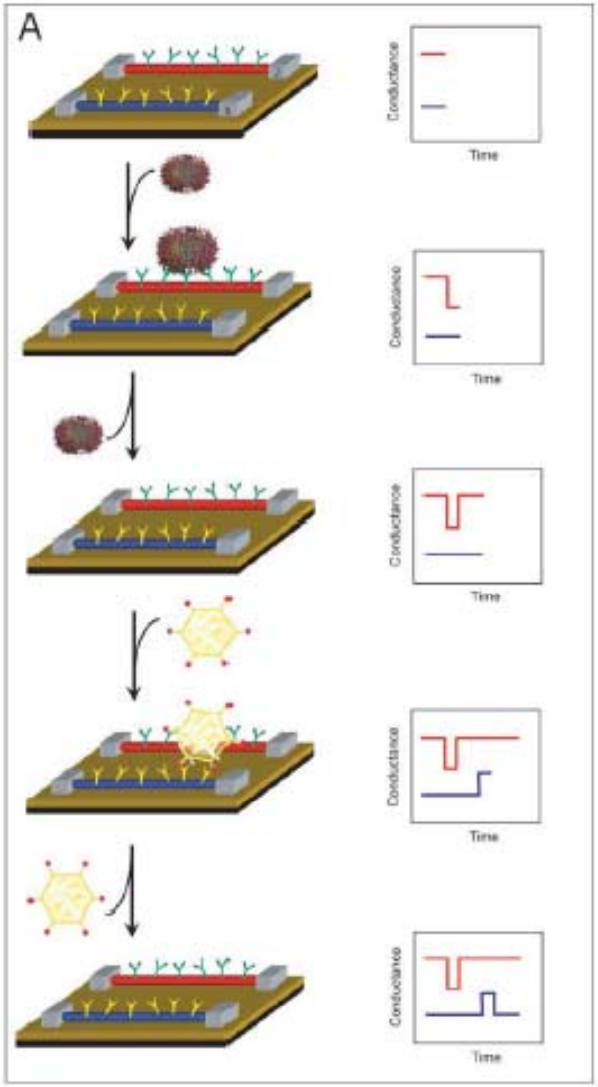




Applied Physics Letters, vol 73, p. 2447 (1998)

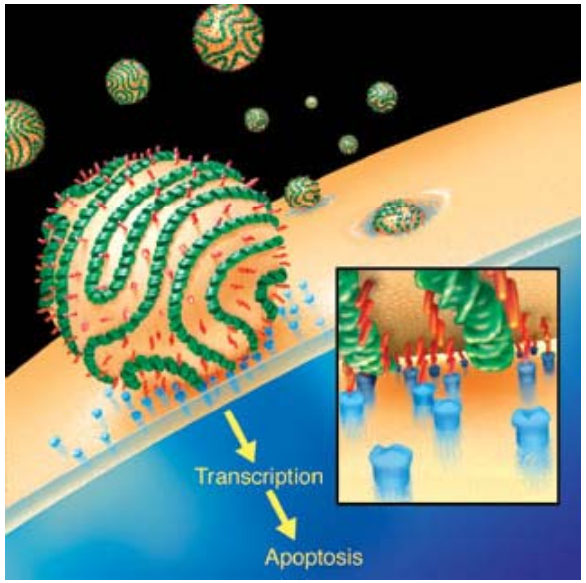
# Nanowire-Based Biosensors



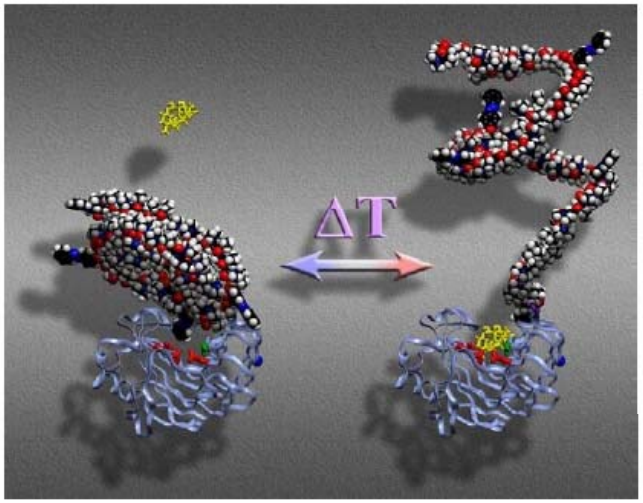

Materials Today, 2005, 20



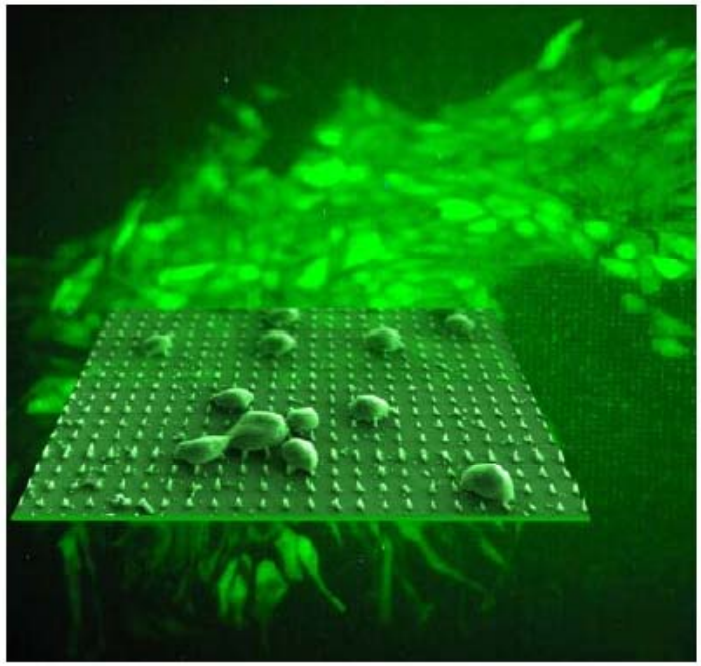
# Nanobiotechnology and Nanomedicine




Nanoparticles packed with targeting molecules (red) anchor to integrins (blue) on the outside of a tumor blood vessel cell before shuttling mutant DNA (green) inside

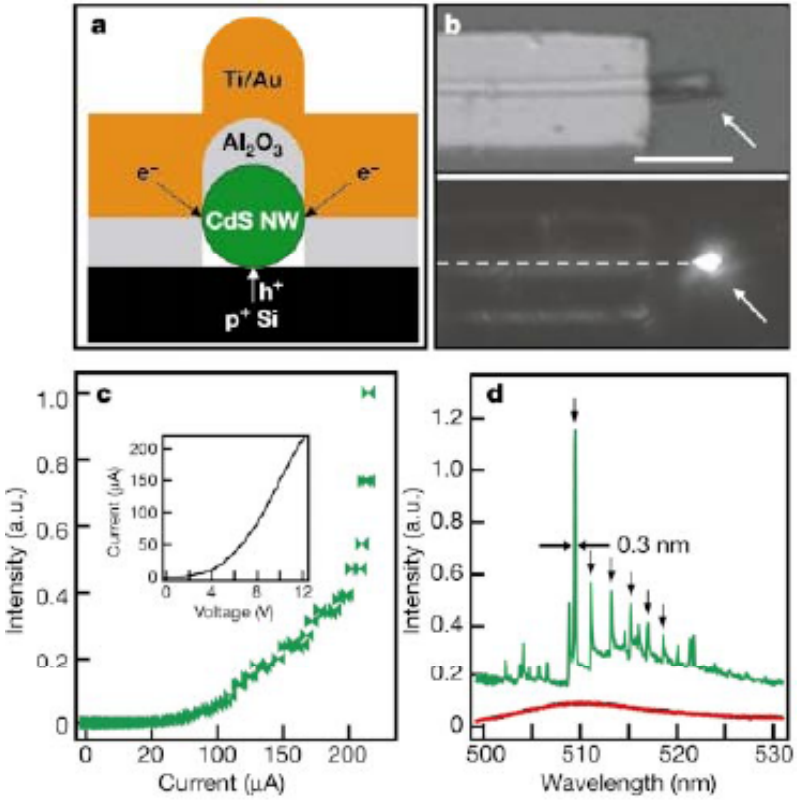



Molecular switchs that can turn on and off enzyme



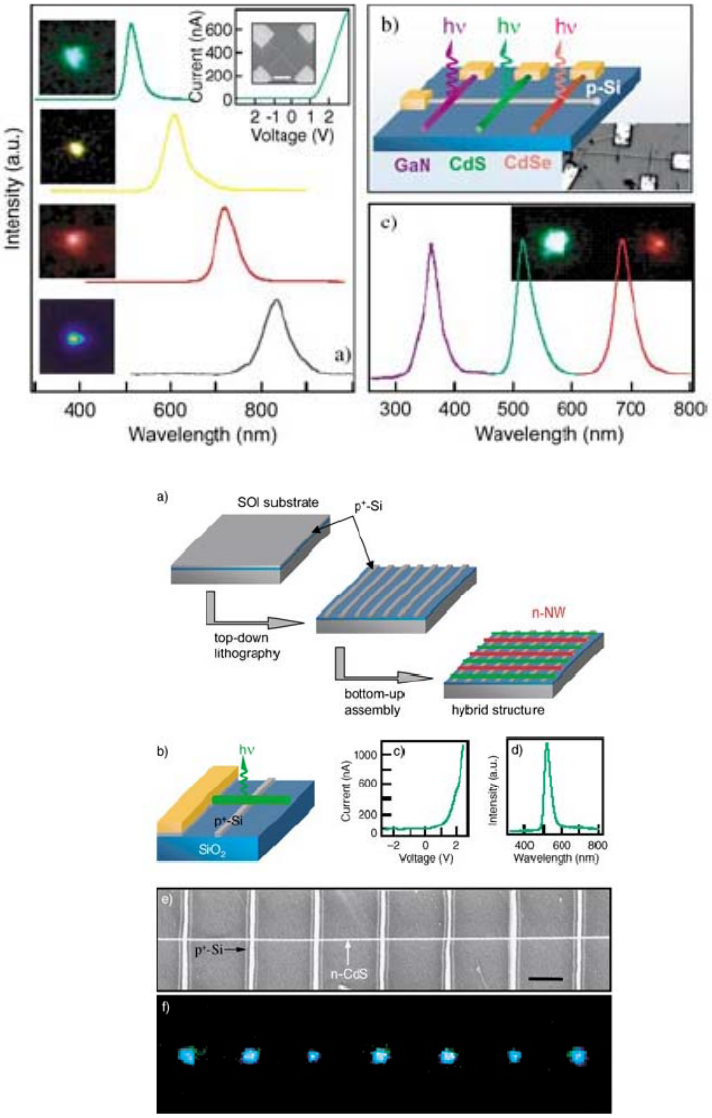
Patterned carbon nanofibers control chemical release to cells

# Nanowire Lasers and Photonics




Nanowire lasers

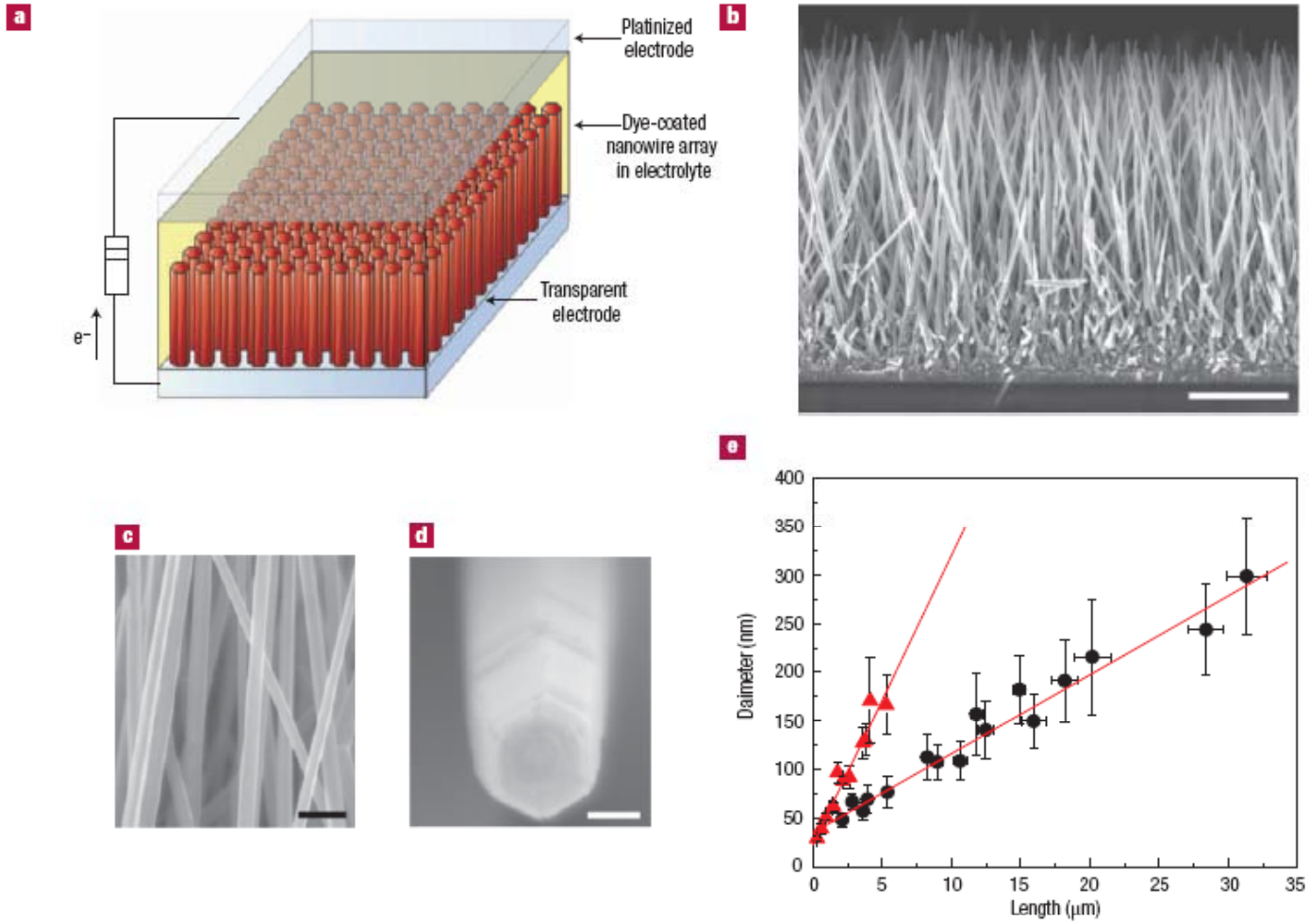
(Nature, Vol 421, 2003, 241)




Nanowires for Integrated Multicolor Nanophotonics

(Small, 2005, 1, 142)

# Nanowire Dye-Sensitized Solar Cells




The nanowire dye-sensitized cell, based on a ZnO wire array

Nature Materials vol 4, 2005, 455

*More and more applications in Nano-xxxxxx*

●●●●●●

●●●●●●

# Break!

***Nano-Break!!!***

# Section II: Self-assembly

# What's self-assembly???

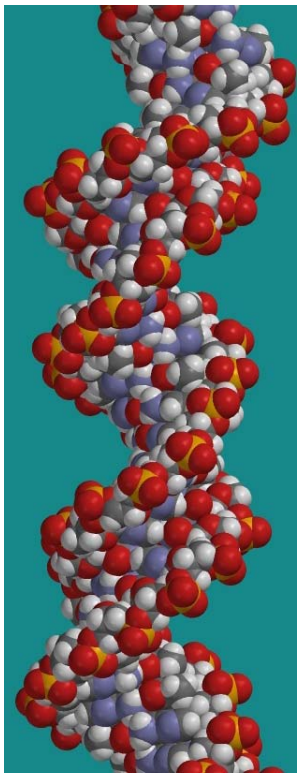
"**Self-assembly** is the fundamental principle which generates structural organization on all scales from molecules to galaxies.

It is defined as reversible processes in which pre-existing parts or disordered components of a preexisting system form structures of patterns.

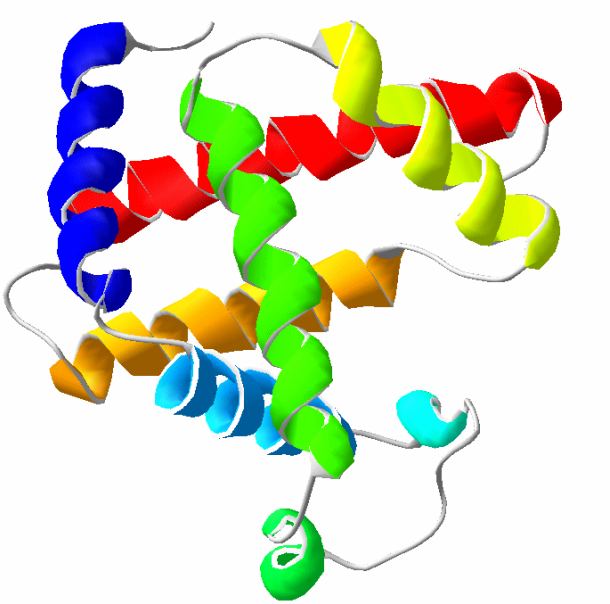
Examples of self-assembling system include weather patterns, solar systems, histogenesis (formation of different tissues from undifferentiated cells ) and self-assembled monolayers. The most well-studied subfield of self-assembly is molecular self-assembly "

From Wikipedia: http://en.wikipedia.org/wiki/Self-assembly

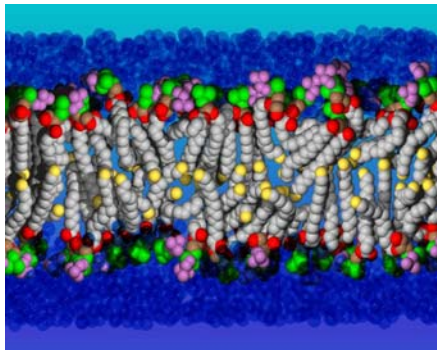
# Self-Assembly in Living Systems



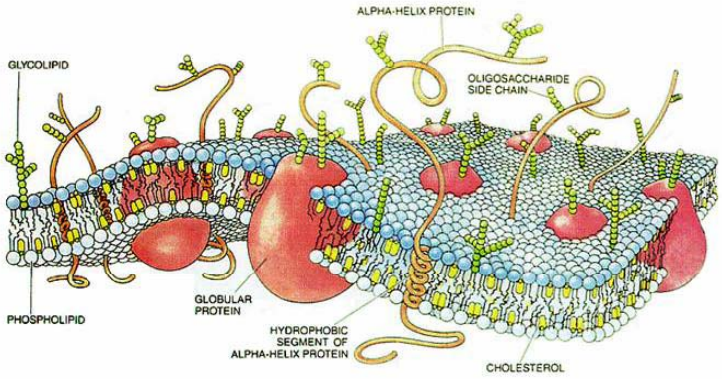
DNA double-helix



Protein: A representation of the 3D structure of myoglobin
“Protein folding”

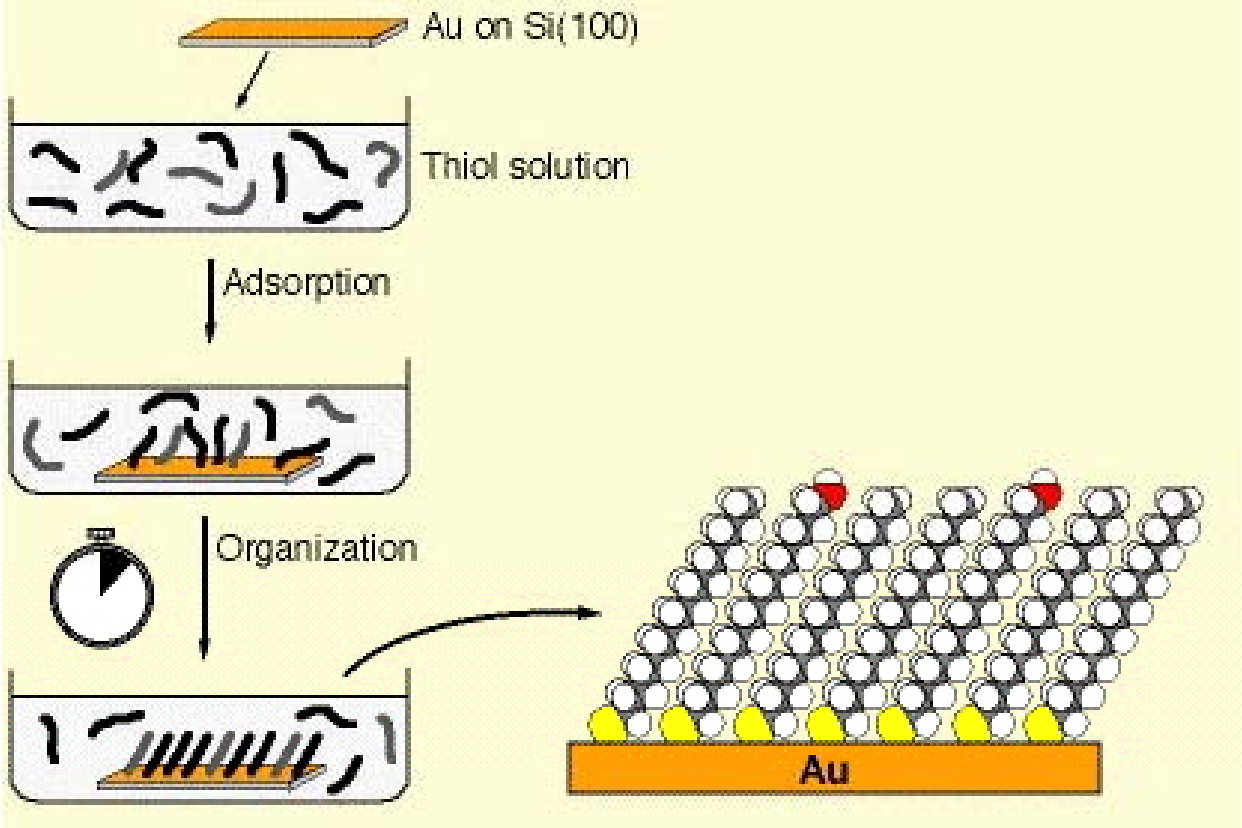


Lipid bilayer



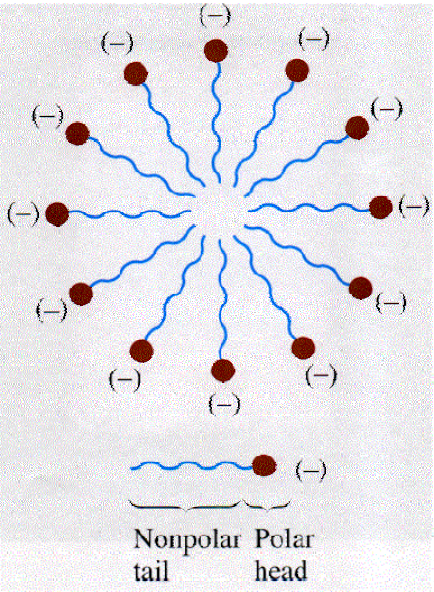

Cell Membrane

# Self-assembled Monolayers (SAMs)

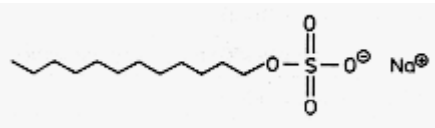



- Surface modification
- Corrosion inhibition
- Biocompatibility

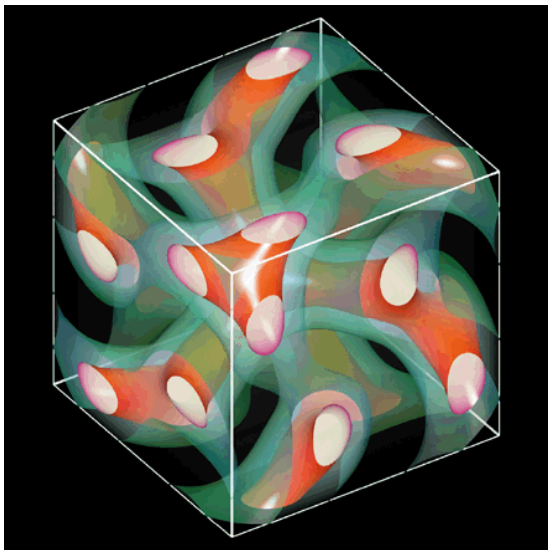
# Self-Assembly of Molecules



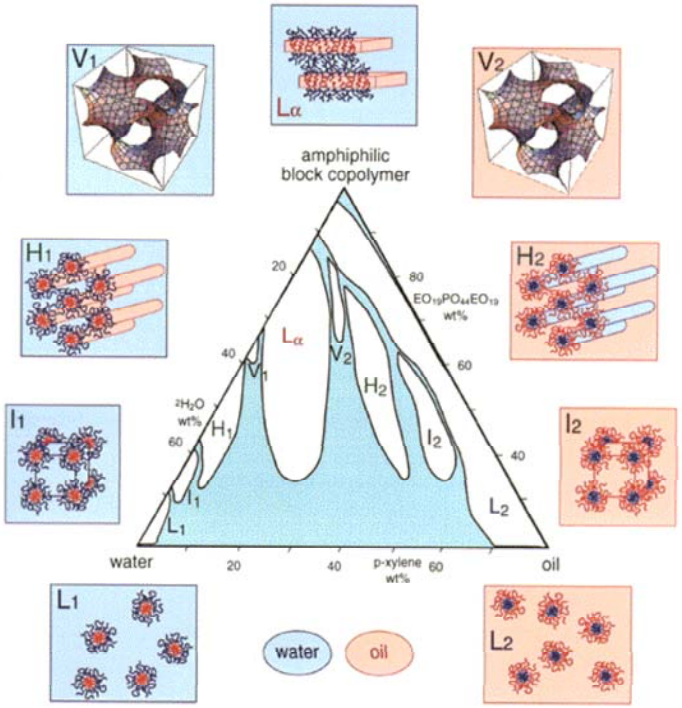

Surfactant micelles




Sodium dodecylsulfate (SDS)

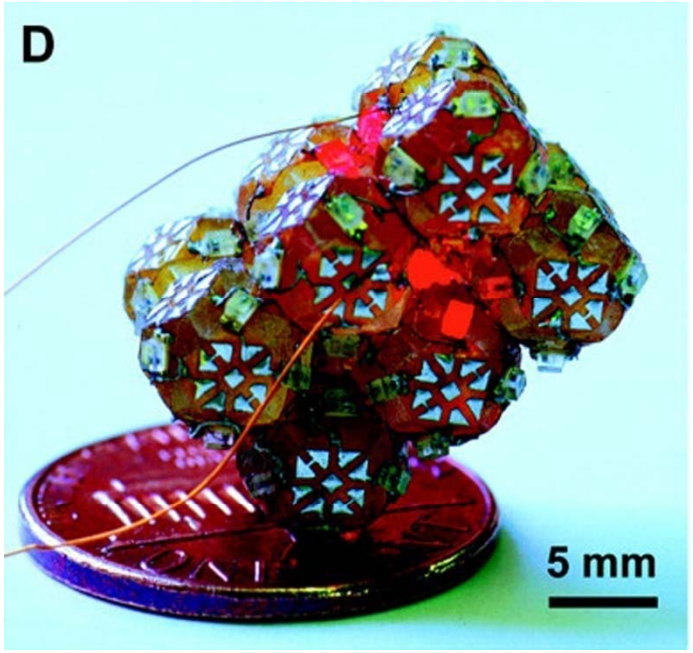


Complex block copolymer structures



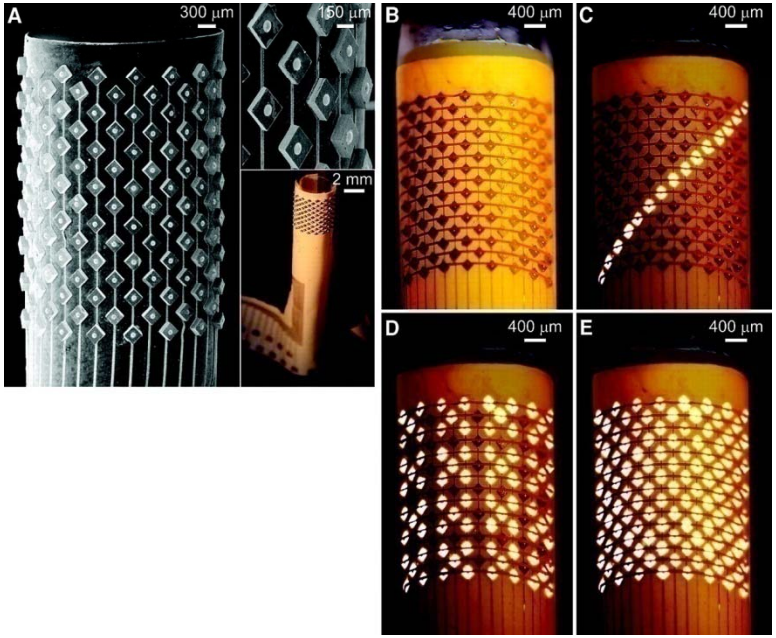

Amphiphilic block copolymers

# Self-Assembly of Electronic Systems




Millimeter scale

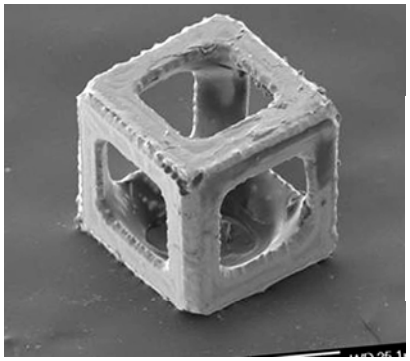
Gracias, Tien, Breen, Hsu, Whitesides.
*Science* **2000**, *289*, 1170.

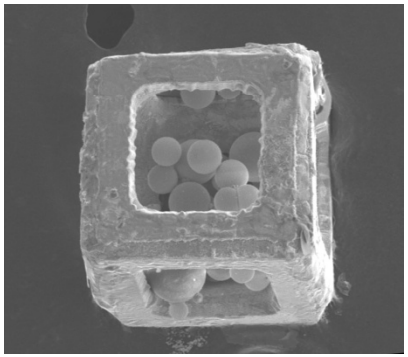


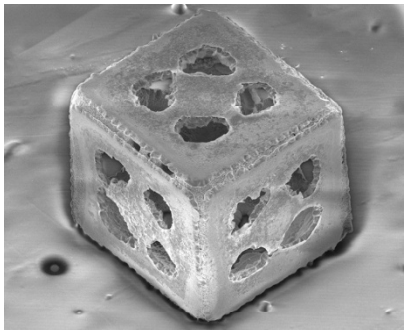

200 μm scale

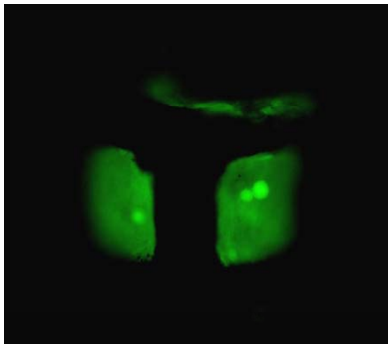
Jacobs, Tao, Schwartz, Gracias, Whitesides.
*Science* **2002**, *296*, 323.

# Self-Assembled Micro-Containers





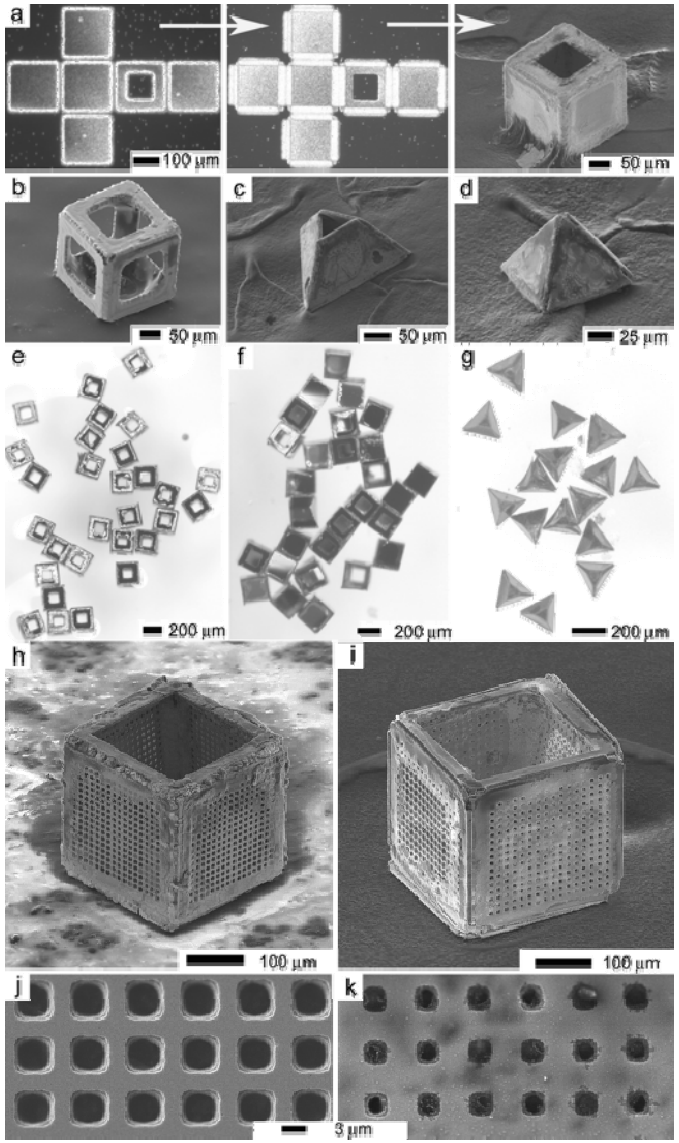


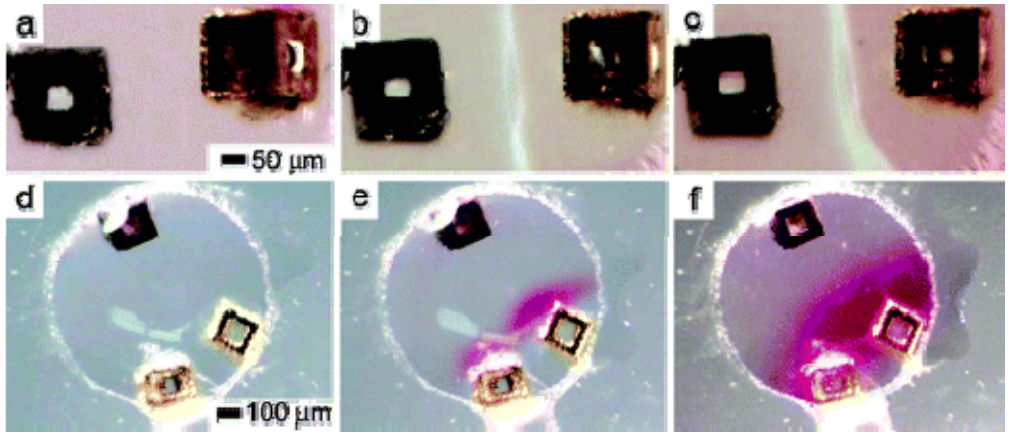


100-200 μm

Gimi, Leong, Gu, Yang, Artemov, Bhujwalla, Gracias. *Biomedical Microdevices* **2005**, *7*, 341-345.

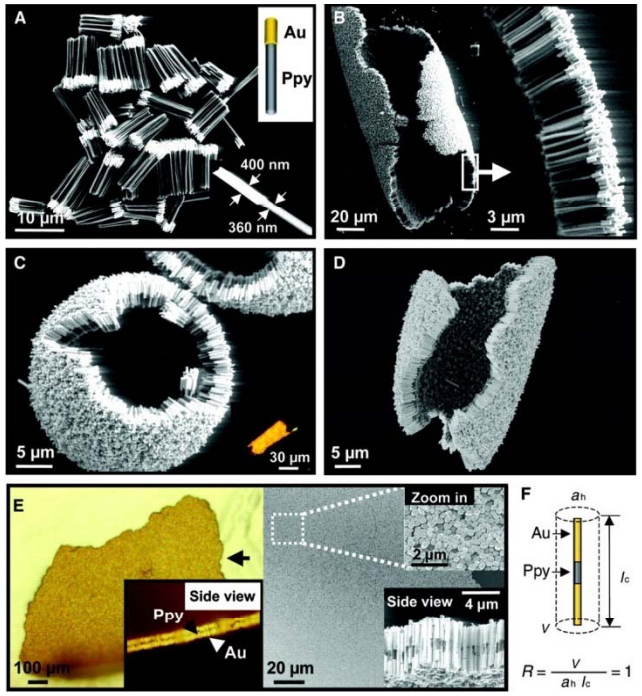
# Self-Assembled Micro-Containers

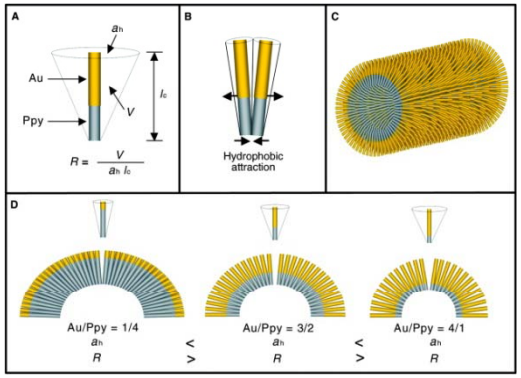


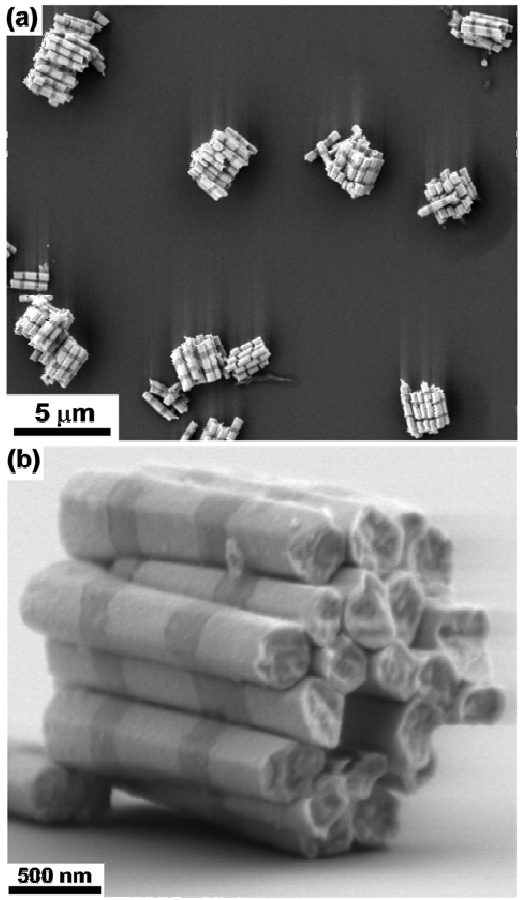

Leong, Gu, Koh, Gracias. *JACS* **2006,** *128*, 11336-11337

# Self-Assembly of Nanowires



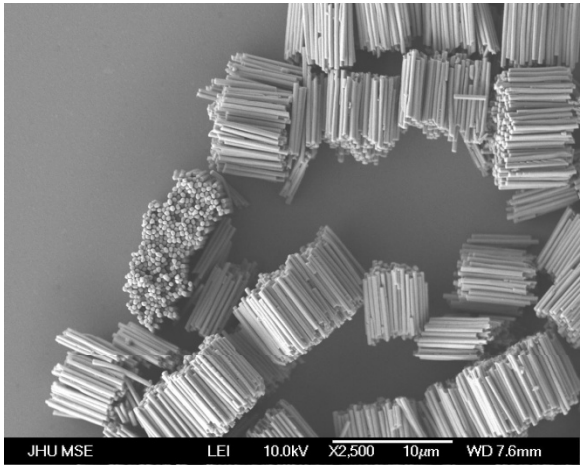

Park, Lim, Chung, Mirkin. *Science* **2004**, *303*, 348



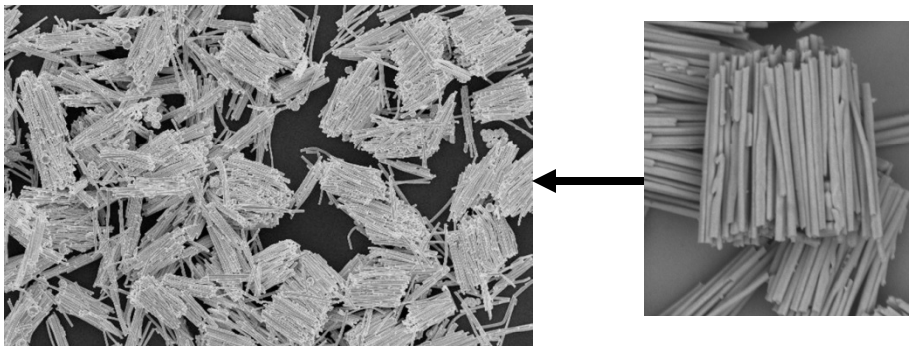

Magnetic assembly

Love, Urbach, Prentiss, Whitesides. *JACS*, **2003**, *125*, 12696.

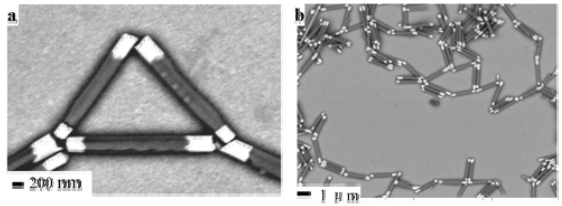
# Self-Assembly of Nanowires

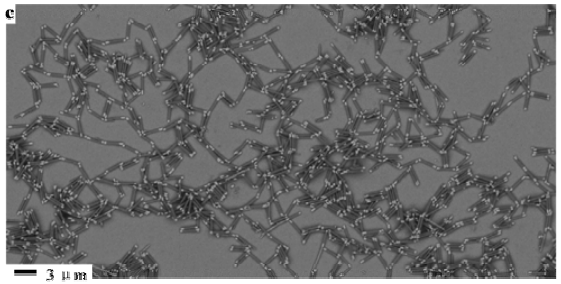



Large scale bundles during membrane dissolution



"Glued" 3D bundles



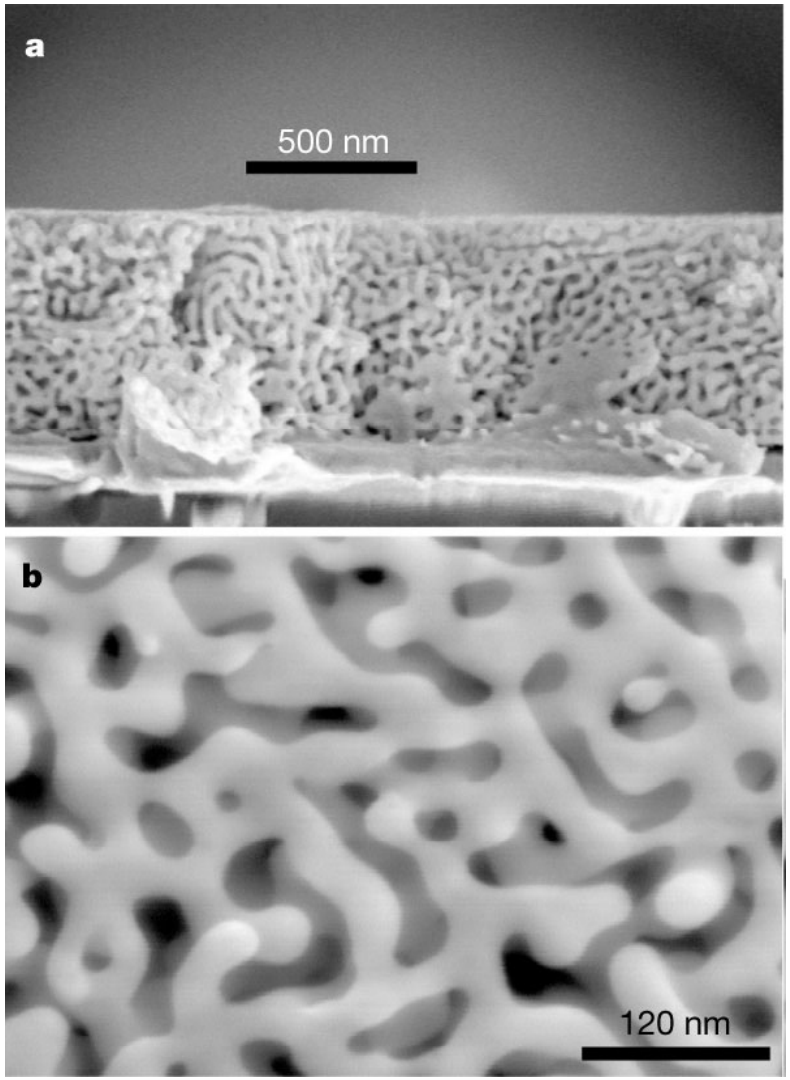




"Glued" 2D networks



Gu, Chen, Gracias. *Langmuir* **2004**, *20*,11308.

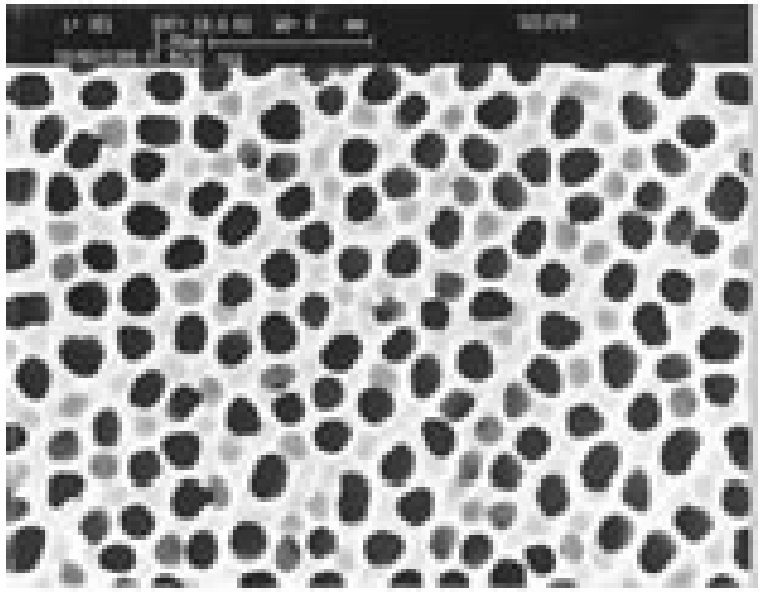
# Self-assembly: Nanoporous Gold




Erlebacher, Aziz, Karma, Dimitrov, Sieradzki. *Nature* **2001**, *410*, 450-453

# Self-assembly: Nanoporous AAO membranes


Whatman



20 -200 nm pore size

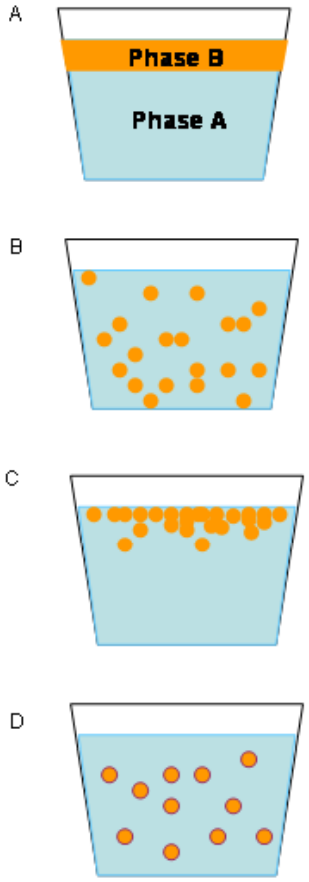
- Separation
- Nanowire, nanotube fabrication
- Biomedical engineering

# Personal and Home Products

Soap


Detergent

# Pharmaceutical and Health Products

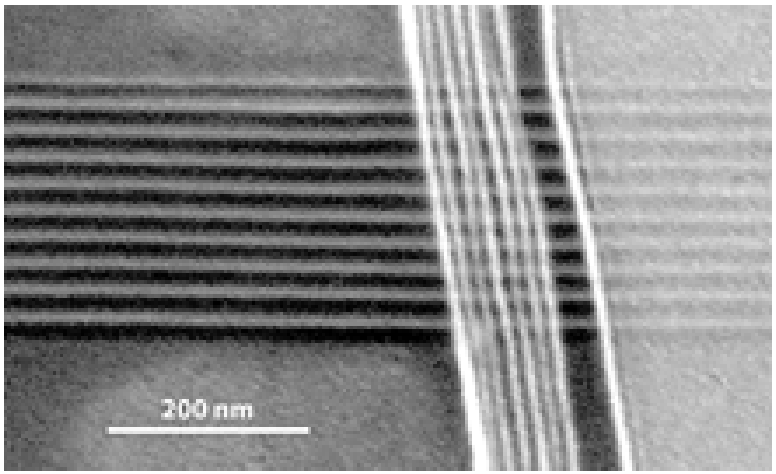


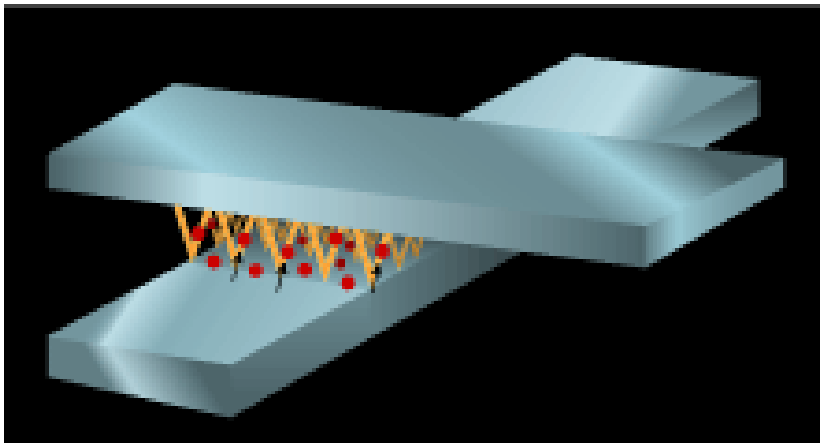

Emulsions

For creams and lotions


20 ml ampule of 1% propofol emulsion suitable for intravenous injection. The manufacturers emulsify the lipid soluble propofol in a mixture of water, soy oil and egg lecitin.

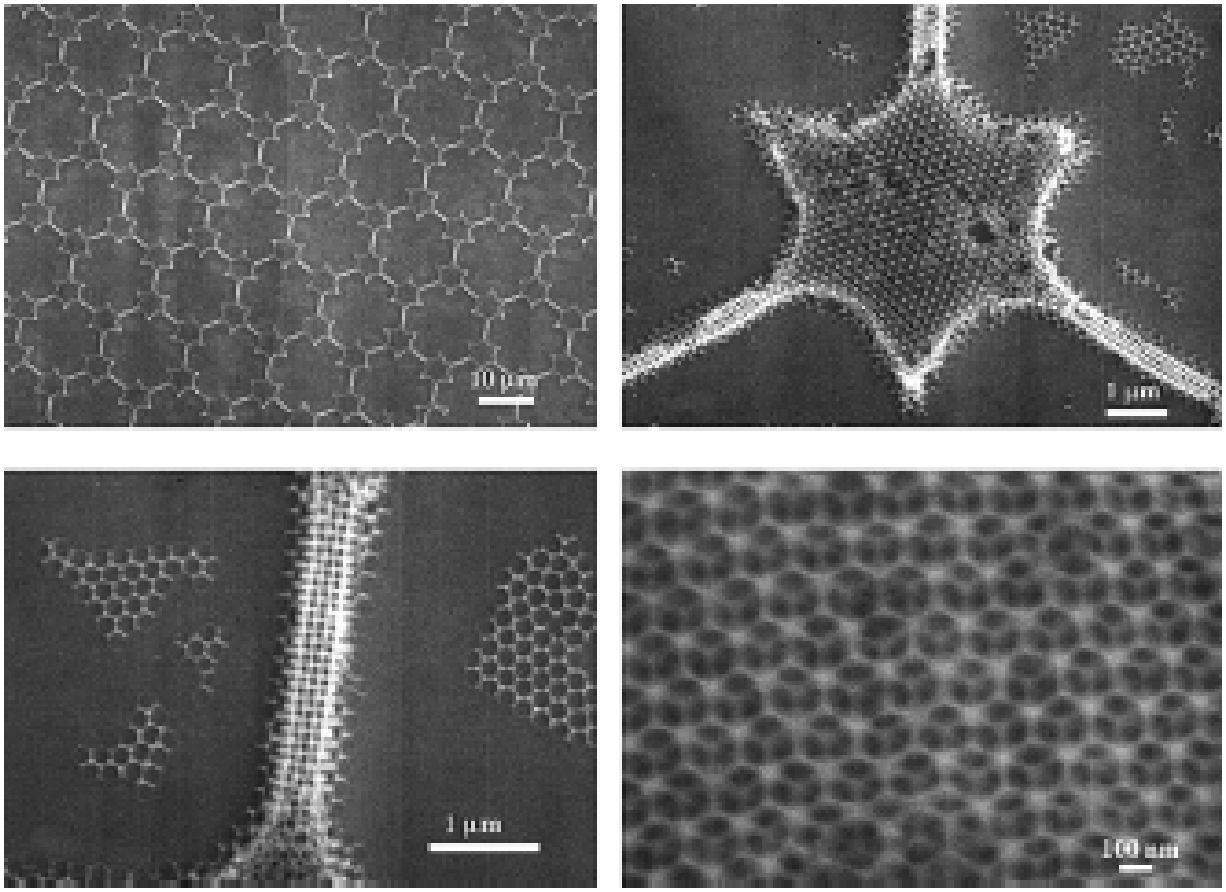
# Self-assembly: Molecular Electronics



Nanowires are assembled into crossbars (*left*).
Organic molecules between crossing wires serve as transistors (right)

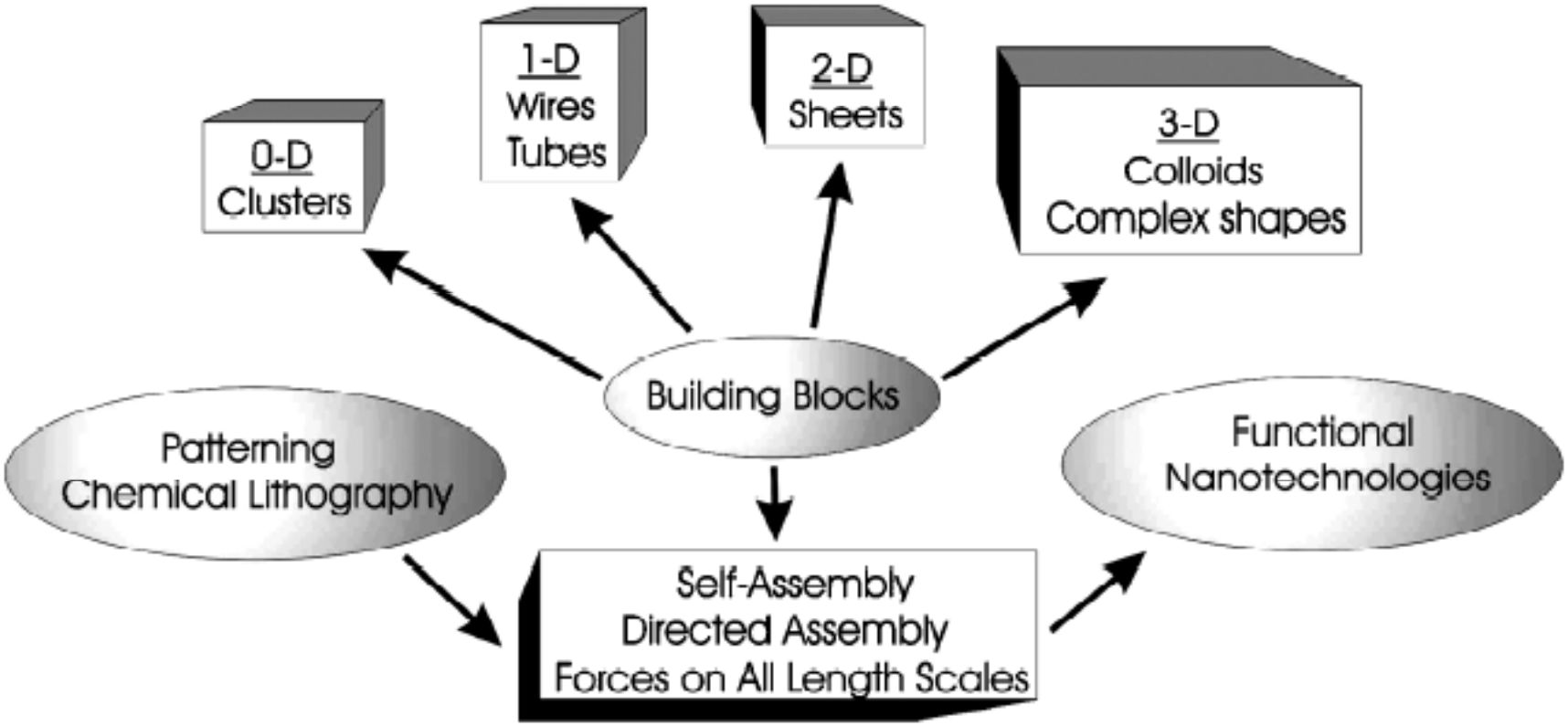
# Self-assembly: New Structures and New Materials




Hierarchically ordered oxide through a combination of microchannel, microsphere, and block-copolymer templating

Ozin and Arsenault. Nanochemistry: A Chemical Approach to Nanomaterials. RSC Publishing, 2005

# Self-assembling route to Nanotechnology

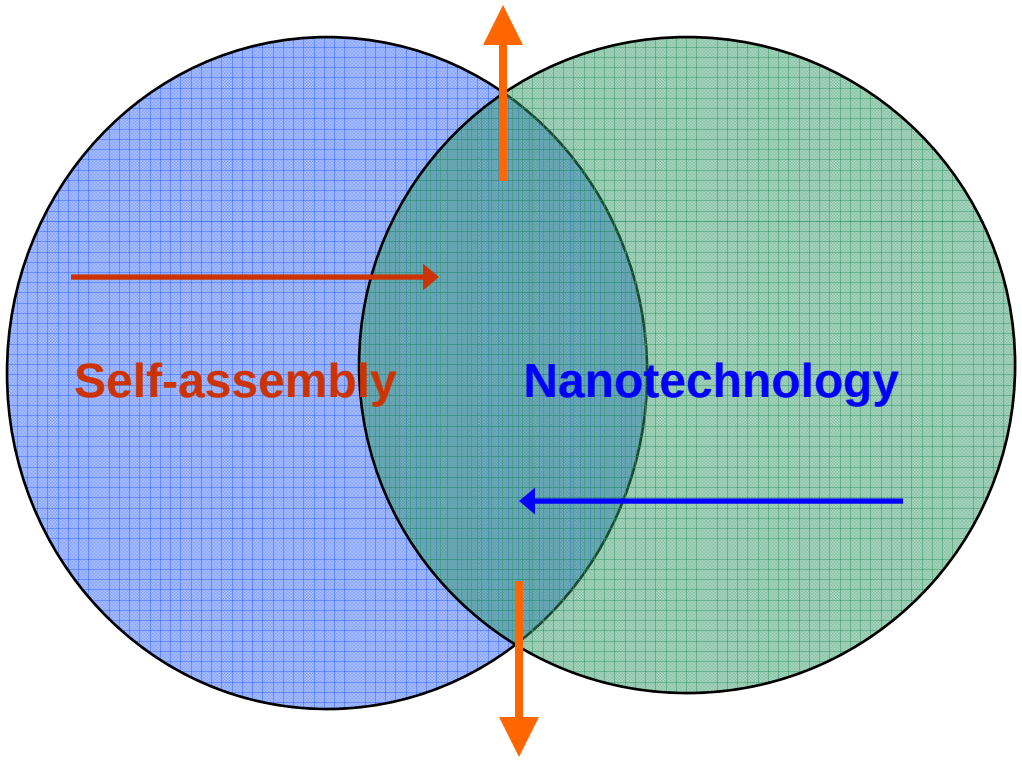



A flowchart delineating the factors that must be considered when approaching the self-assembly of a nanoscale system

Ozin and Arsenault. Nanochemistry: A Chemical Approach to Nanomaterials. RSC Publishing, 2005

# Self-assembly and Nanotechnology

New materials, new technologies ●●●




New applications, new products ●●●



nano
manufacturing center at UML

# Perspectives, Potentials and Challenges

- Trillions of dollars business in the next ten years or so
- Energy
- Information storage
- ●●●●●●●●
- Does everything have to be nano??
- Is nano good or not?
- Nanotoxicity
- Environment, health and safety

# Course Project

- **Literature search methods;**
- **1-page Abstract/Outline, due on Feb. 6 (third week), preferred by email**
- **Literature review due, Feb. 27**
- **Project update presentation and discussion, Progress report (I) due, March 27.**
- **Final presentations, May 1**
- **Final Report Due on exam day, sent by email**