Nanotechnology

Bruce K. Gale

Fundamentals of Micromachining

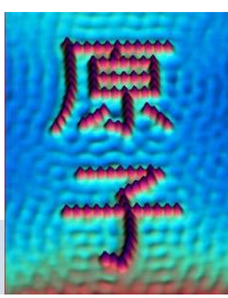
Outline

- Introduction
- History:
  - Richard Feynman
  - Development of the field
- Uses:
  - Current applications and methods
  - Future applications
- Research
  - Nanotubes
  - Quantum structures
- Conclusion

Richard Feynman

Introduction: Definition

- Nanoscience refers to the world as it works on the atomic or molecular scale, from one to several hundred nanometers.
- Nanometer = 10^{-9} meters: roughly the size of 10 hydrogen atoms lined up or the width of DNA.



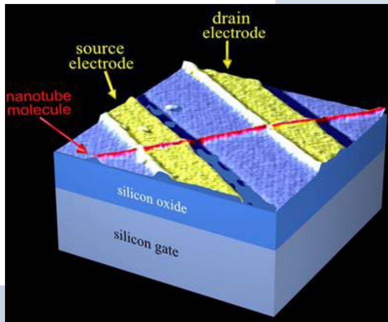
Introduction: Philosophy

- Old philosophy of creating things was to start with something big, and make it smaller. Nanoscience starts with something atomic and builds things with it.
- *"Nanotechnology has given us the tools… to play with the ultimate toy box of nature – atoms and molecules. Everything is made from it… The possibilities to create new things appear limitless."*

  \- Nobel Laureate Horst Stormer

History: Feynman On Computing

- *"…Why can't we make them very small, make them of little wires… the wires could be 10 or 100 atoms in diameter, and the circuits could be a few [hundred nanometers] across."*
  – Richard Feynman on computers.

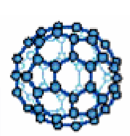


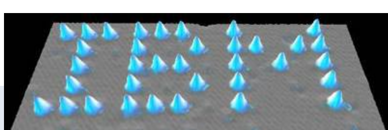
Roots of NanoScience

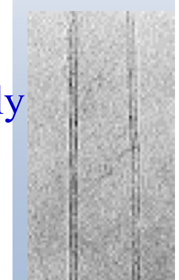
- 1981 – SPM (Scanning Probe Microscopes)
  – Allowed us to image individual atoms
  – Small tip (a few atoms in size) is held above the conductive surface. Electrons "tunnel" (STM's) between the probe and surface (by Quantum Mechanics).
  – The tip is scanned across the surface measuring the current to create the image.

Roots of NanoScience

- C60 – Buckminster Fullerene – Bucky balls are discovered in 1985. Stable molecule entirely made of carbon.
- With STM's, IBM researchers in 1990 positioned atoms on a surface.
- Carbon nanotubes – tubes made entirely carbon rings. 1991

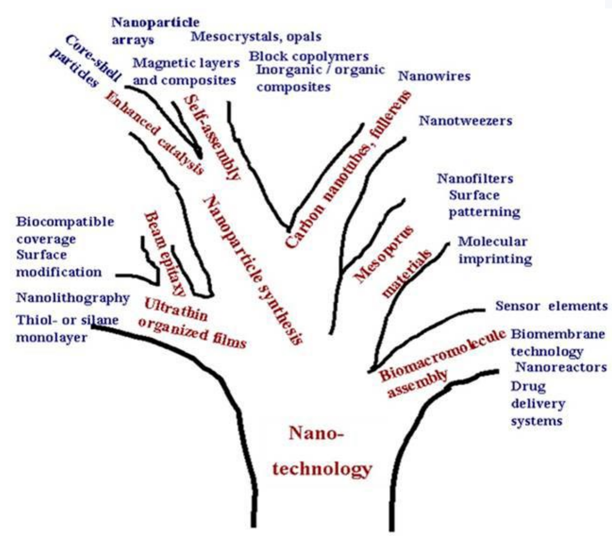






Nano – Tree

"What is essential is invisible to the eye" A. de Saint-Exupery, "La Petit Prince"



Uses: Current Application

Electronics:

Disk Drives
Semi-Conductors Manufacture

Automotive:

Body Panels
Fuel Systems

Composites of nanotubes in plastics are used in automotive fuel systems and sensitive electronics environments to control and dissipate the build-up of dangerous static charges. Nanotube loaded automobile body panels can be electro-statically spray painted, eliminating the need for a costly primer coat.

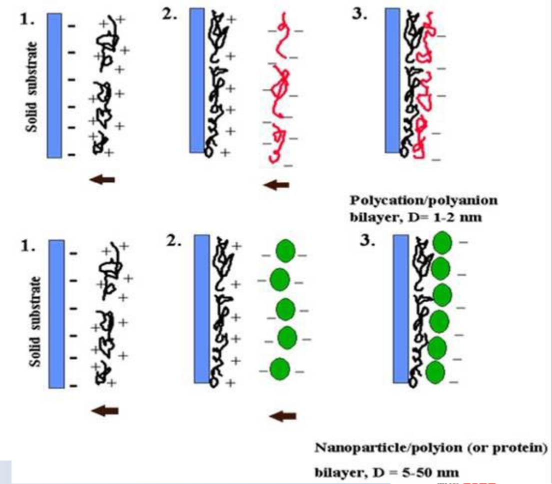
Polymer in which the Nanotubes are Dispersed *	Disk Drive Components	Clean Room PODS, WANDS etc.	Fuel Systems	Electro-Static Spray Painting
Polybutylene terephthalate (PBT)	X			X
Polycarbonate (PC)	X	X		X
Polystyrene (PS)	X			
Polyether imide (PEI)		X		
Polyether ether ketone (PEEK)		X		
Nylon 6				X
Nylon 6,6				X
Nylon 12			X	

THE UNIVERSITY OF UTAH

Scheme of Layer-by-Layer Assembly by Alternate Adsorption of Oppositely Charged Linear Polyions and Nanoparticles or Proteins

{Poly(styrenesulfonate/ Poly(allylamine)} x n;
n = 1 – 200.

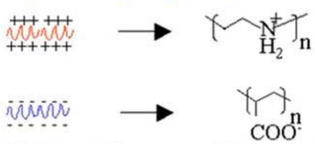
{Glucose oxidase / Poly(ethyleneimine)} x n
or
{20-nm Silica / Poly(ethyleneimine)} x n



THE UNIVERSITY OF UTAH

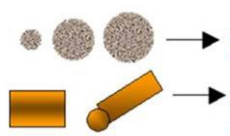
Self-Assembly Building Blocks

Polymers (polyions)



20 different linear and branched polyions were used in the assembly

Particles (5 - 50 nm diameter)



SiO2, TiO_2, Au

Clay Tubules, Sheets

Proteins, Viruses

Glucoamylase, Glucose Oxidase, and 17 other enzymes were used in the assembly, as well as Carnation Mottle virus and TMV

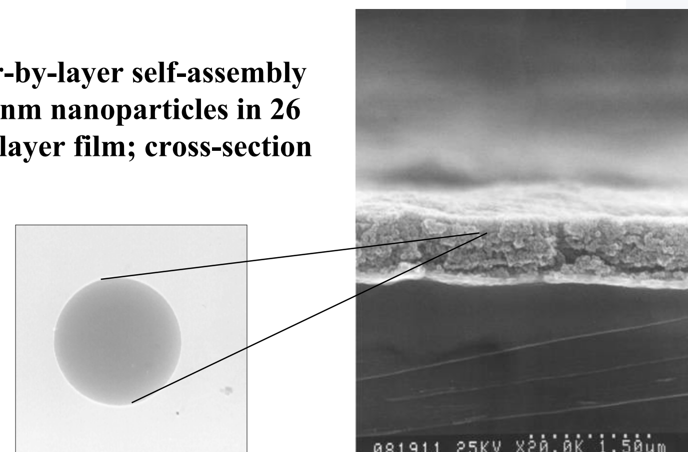
Substrates:

Any Solid Surfaces, Macroporous Filters, Microtemplates (spheres, tubules)

THE UNIVERSITY OF UTAH

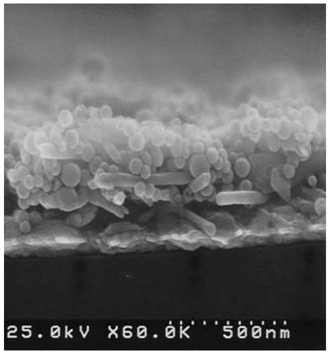
Nanofabrication Technologies

Layer-by-layer self-assembly of 40-nm nanoparticles in 26 monolayer film; cross-section



THE UNIVERSITY OF UTAH

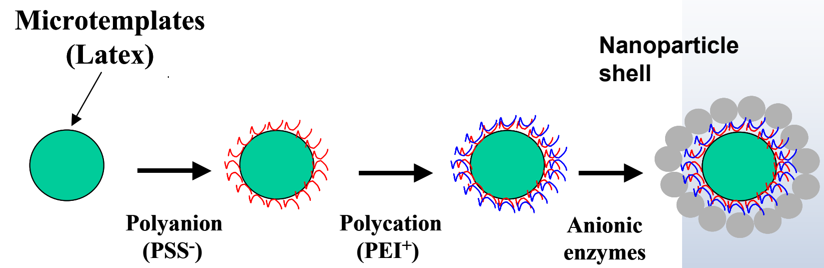
Alternation of Spherical Nanoparticles and Nanotubules "Glued" by Polycations



($Halloysite/PEI^+/Silica/PEI^+)_5$ film on silver electrode, cross-section

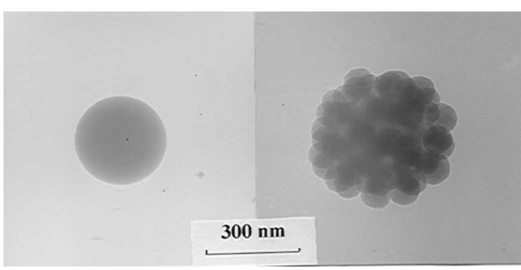
- **The nanotubes of halloysite of 50 nm in diameter, 500 nm in length and with 20-nm hollow inner lumen were used in the assembly by alternate adsorption with poly(ethyleneimine) (PEI). The tubule / sphere super-lattices were assembled through alternation of halloy-site, 45-nm diameter silica and PEI.**

Nano-Assembly on Microtemplates



Ordered shells on 200-nm diameter latex. At pH 2 latex can be dissolve, what gives empty shells (polymer or inorganic) with wall thickness 20-50 nm and needed composition.

Ordered Silica Shell on 250-nm Core



Assembly: 250-nm latex + PEI$^+$ / PSS$^-$ /PEI$^+$ + 40-nm diameter silica

Urease Encapsulation in Nano/Organized Polyion Microshells

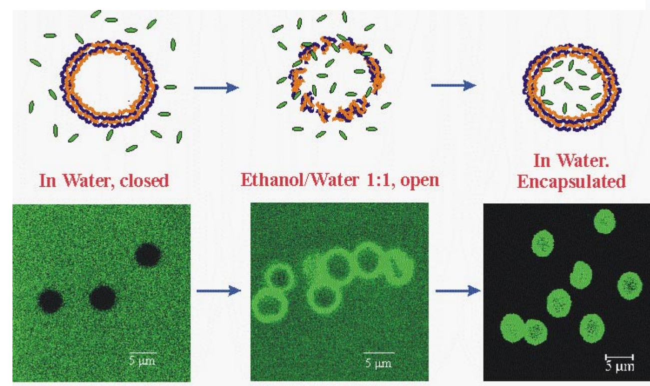
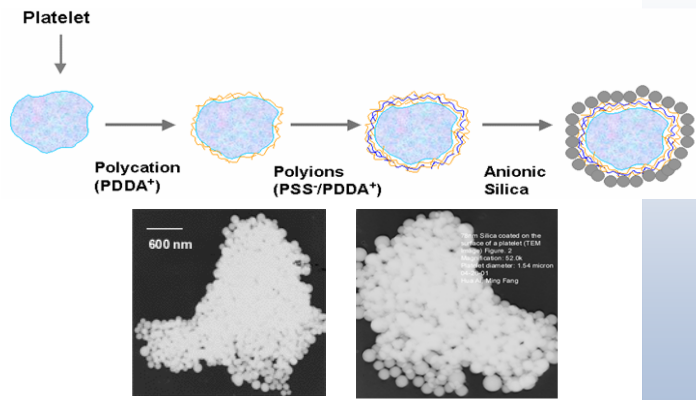


Fig.1.

5-μm diameter (polyallylamine/polystyrenesulfonate)$_5$ shells, wall thickness 20 nm, loaded with enzymes by opening-closing pore procedure. The procedure is general and may be applied for loading and release of different macromolecules.

Nanoparticle Replication of Platelets



We used platelet cells as microtemplates for an assembly of the nanoparticle shell by LBL-method: PDDA + PSS + PDDA +78-nm silica TEM images of two platelets silica replica are presented above.

Uses: Future Applications

- Optics – pure crystals for lasers, optical transistors, artificial photosynthesis,
- Industrial Catalysts – small particle size means large surface area. Nanotube shaped catalysts may one day find application as industrial catalysts (speeds up certain chemical processes)

Uses: Future Applications (2)

- Selective membranes – membranes functioning like biological membranes – allowing certain chemicals/molecules to transport across them – desalinization, chemical sorting etc.
- Medicine – selective membranes, nerve repair (using nanotubes), blood substitutes, DNA repair/modification etc.

Uses: Future Applications (3)

- Materials – it is possible to create new types of plastics and ceramics with specialized and tunable properties based on structure.
  - Temperature range
  - Thermal/electrical conductivity
  - High strength
  - Lighter weight
  - And other specific properties

Uses: Future Applications (4)

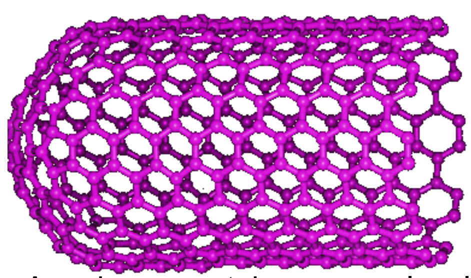
- Electronics/computers –
  - New scale of carbon based nanoelectronics will replace silicon based electronics
    - Higher speeds (1,000,000X or more), much smaller (1/1000), low power
  - Quantum processors – using quantum mechanical effects

Research: Electronics

- Nanotube based transistor – earlier this year
- Nano scale NOT gate (one of 3 logic gates) announced on 8/25/01 (1). Two more logic gates are needed (NAND and NOR) to build processors.
- Nanotube wires – ballistic electron transport. Electrons travel at 1/10 c through wire with no resistance.

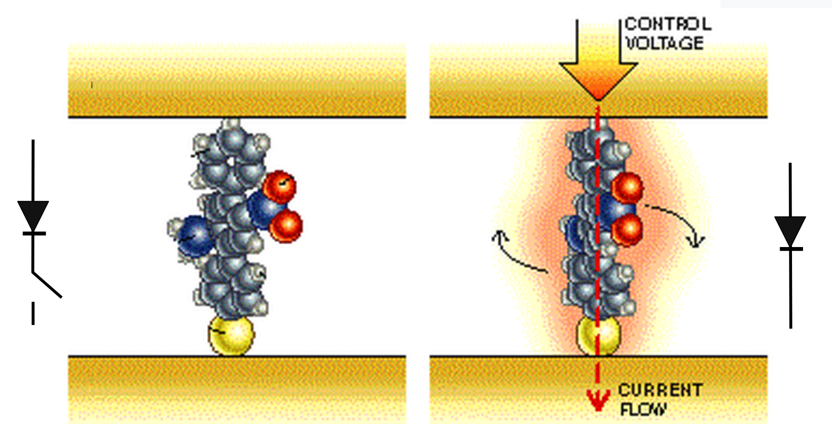
Nano-wires

- carbon nanotubues, Si, metal
- >2nm diameter, up to mm length
- excellent electrical properties

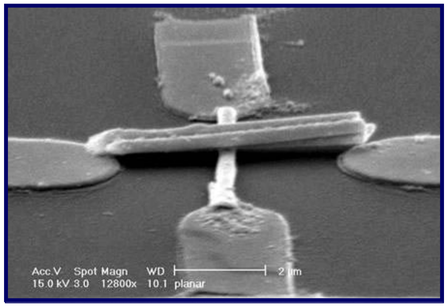


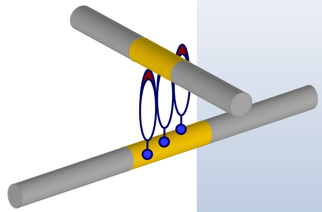
A carbon nanotube: one molecule

Nano-switch

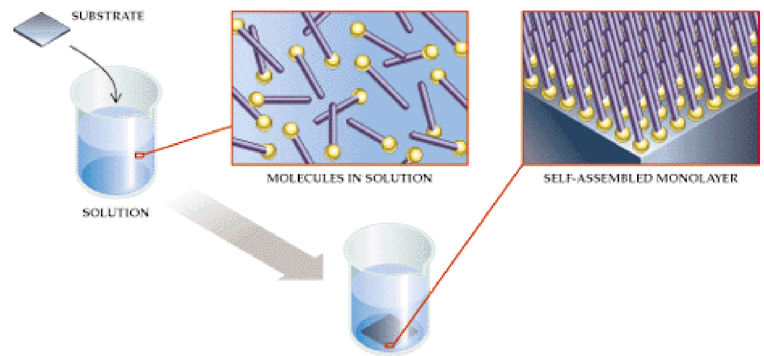


Nano-switch Between Nano-wires



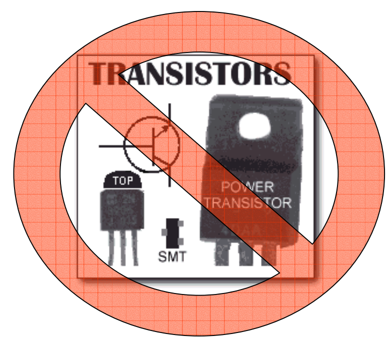


Self-assembly

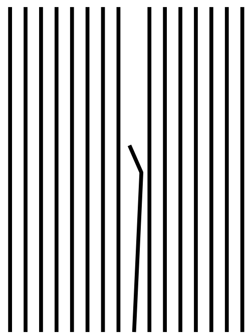


No Complex Irregular Structures

No Three-Terminal Devices



High Defect Rate



Conclusion: The Future

- "No one knows how much of nanotechnology's promise will prove out. Technology prediction has never been too reliable. In the March 1949 edition of Popular Mechanics… experts predicted computer of the future would add as many as 5000 numbers per second, weigh only 3000 pounds, and consume only 10 kilowatts of power."