Introduction to Nanotechnology

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Topics

- Nanotechnology Terms and Definitions
- History of Nanotechnology
- Current and Future Trends, Research and Applications

Definition of Nanotechnology

"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

What is Nanometer?

“The nanometre (International spelling as used by the International Bureau of Weights and Measures; SI symbol: nm) or nanometer (American spelling) is a unit of length in the metric system, equal to one billionth of a metre. The nanometre is often used to express dimensions on an atomic scale

The name combines the SI prefix nano- (from the Ancient Greek νάνος, nanos, "dwarf") with the parent unit name metre (from Greek μέτρον, metron, "unit of measurement"). It can be written in scientific notation as 1×10−9 m, in engineering notation as 1 E−9 m, and is simply 1/1,000,000,000 m. One nanometre equals ten angstroms.

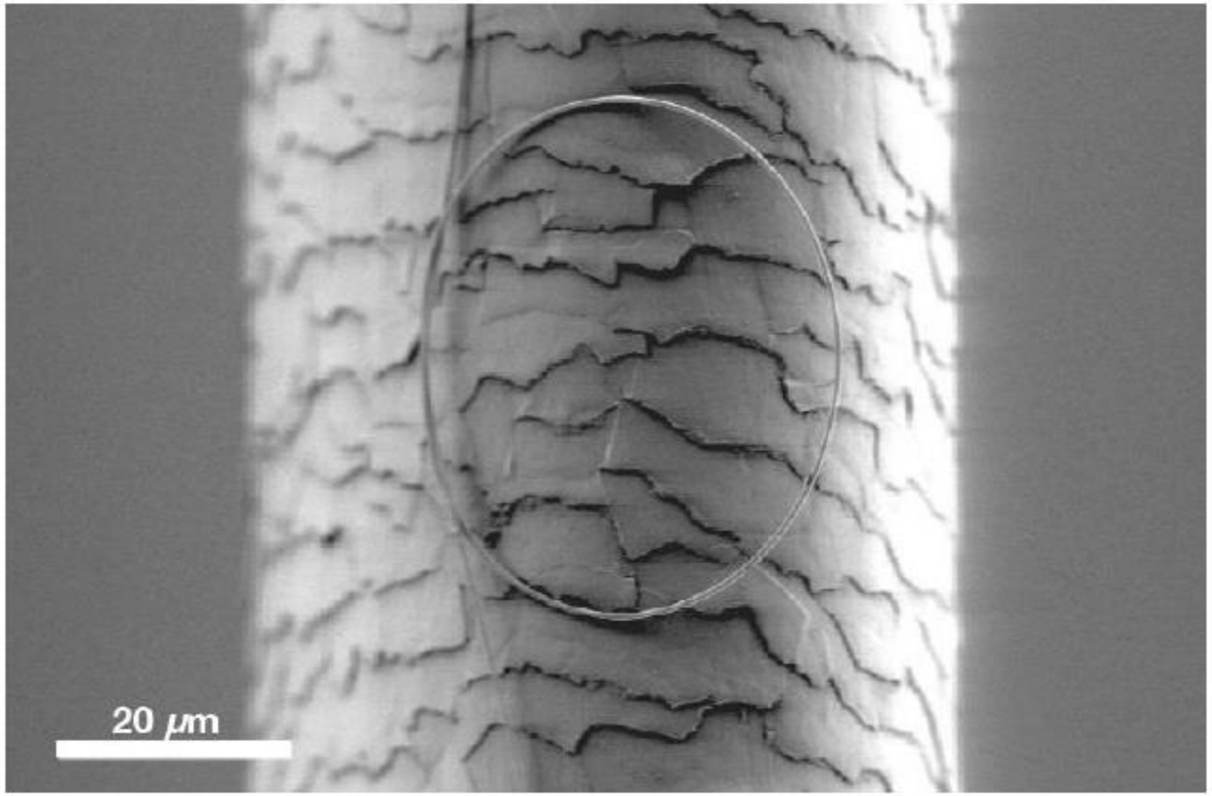
1 nanometer =
1×10^{-9} meter
1×10^{-3} µm
3.281×10^{-9} feet
39.37×10^{-9} inches

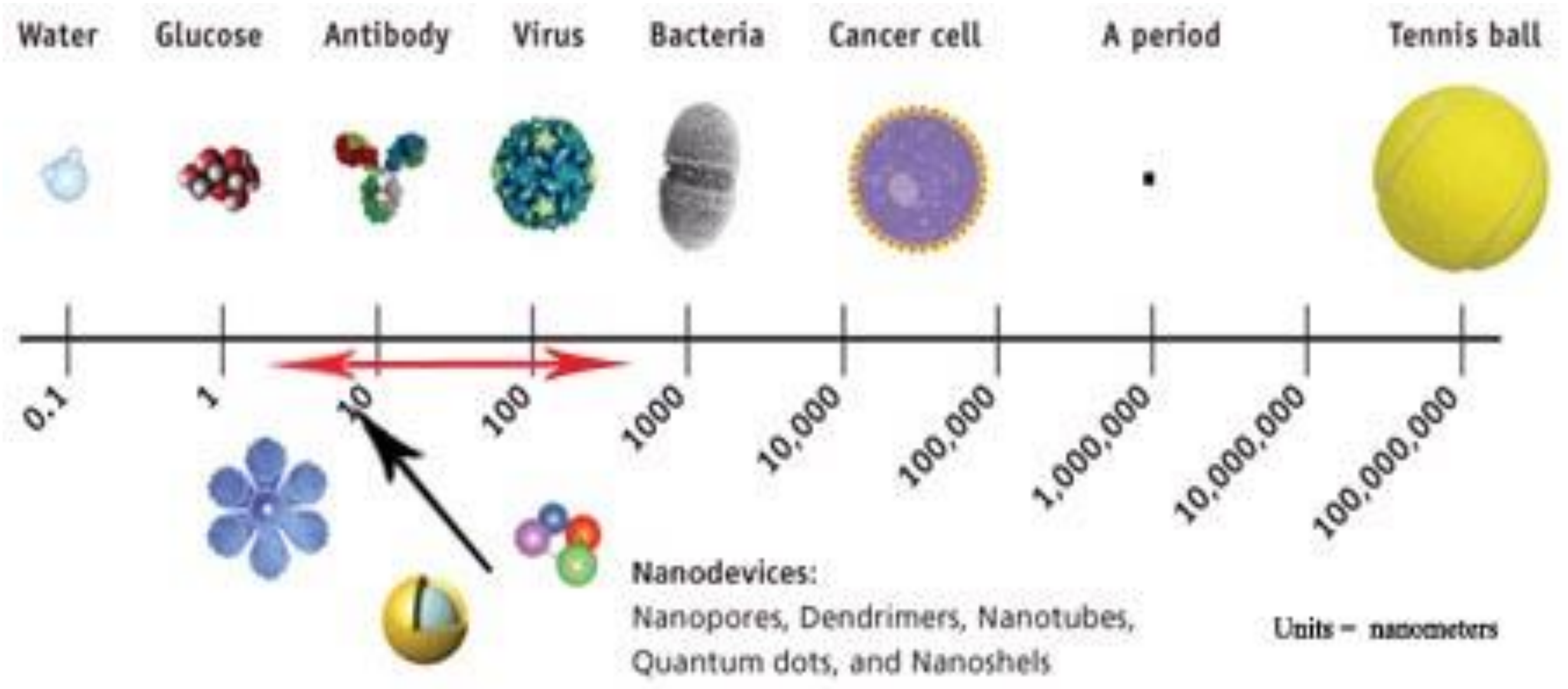
How big is a nanometer?

It is a million times smaller than the smallest measurement you can see on a ruler !!!!!

It is a millionth of millimeter or a billionth of a meter

This is a silver nanowire resting on a human hair.
Look at a strand of your own hair and imagine how small that is…



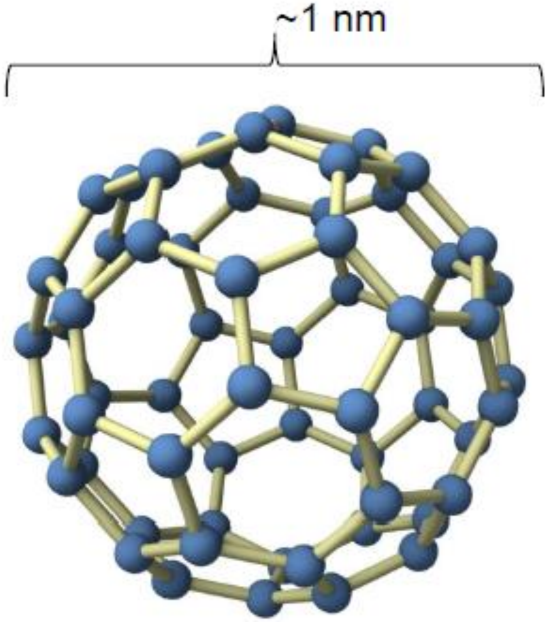


Units in nanometers (nm)

What is a nanoparticle?

An example is a bucky ball

- a fullerene



- 60 carbon atoms linked together in one unit.

- Roundest and most symmetrical molecule known to man
- Compressed – becomes stronger than diamond
- Third major form of pure carbon
- Heat resistance and electrical conductivity

How big is ‘nano’?

ratio earth / football = ratio football / fullerene

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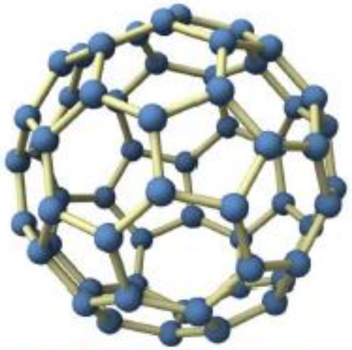
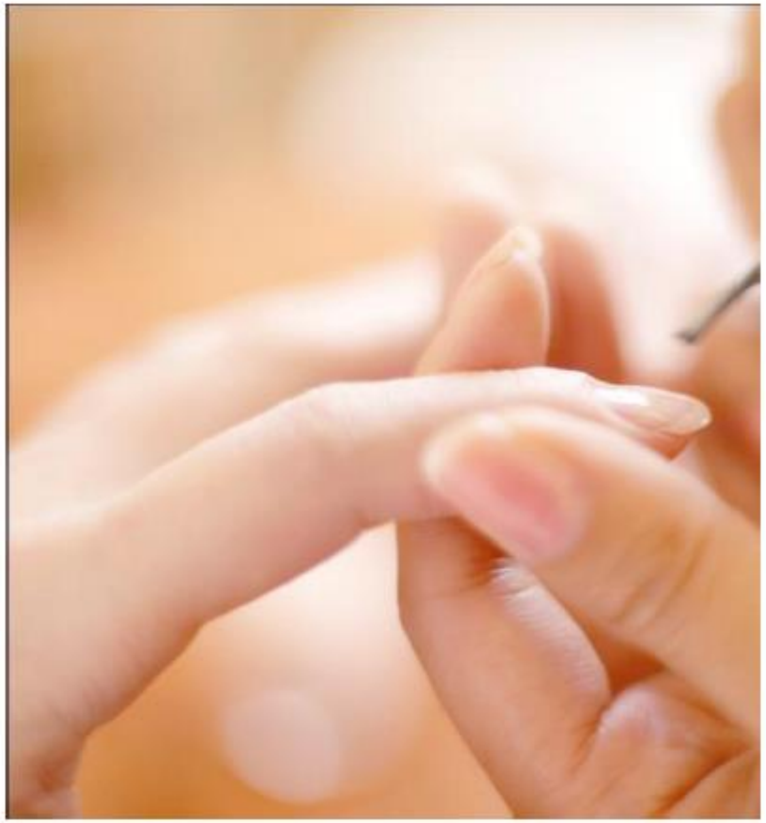
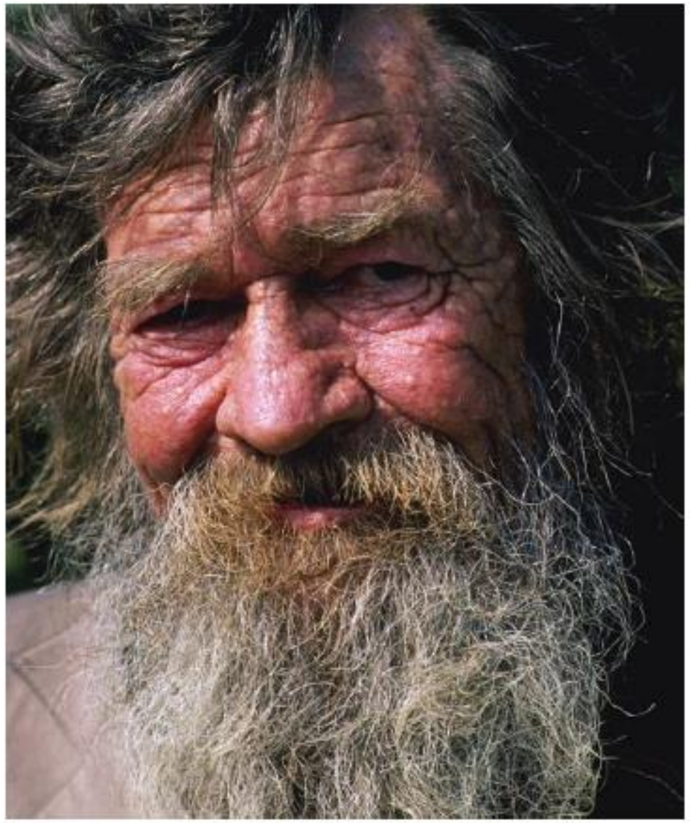


nanotechnologyuniverse.com



A human fingernail grows
1 nanometre every second.



A man's beard grows
5 nanometres every second.

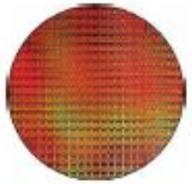
Why is Small Good?

- Faster

- Lighter

- Can get into small spaces

- Cheaper



- More energy efficient

- Less waste products, and uses less energy and materials to produce

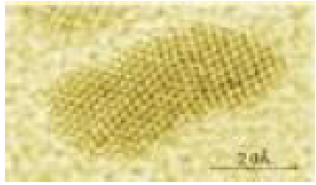
- Different properties at very small scale

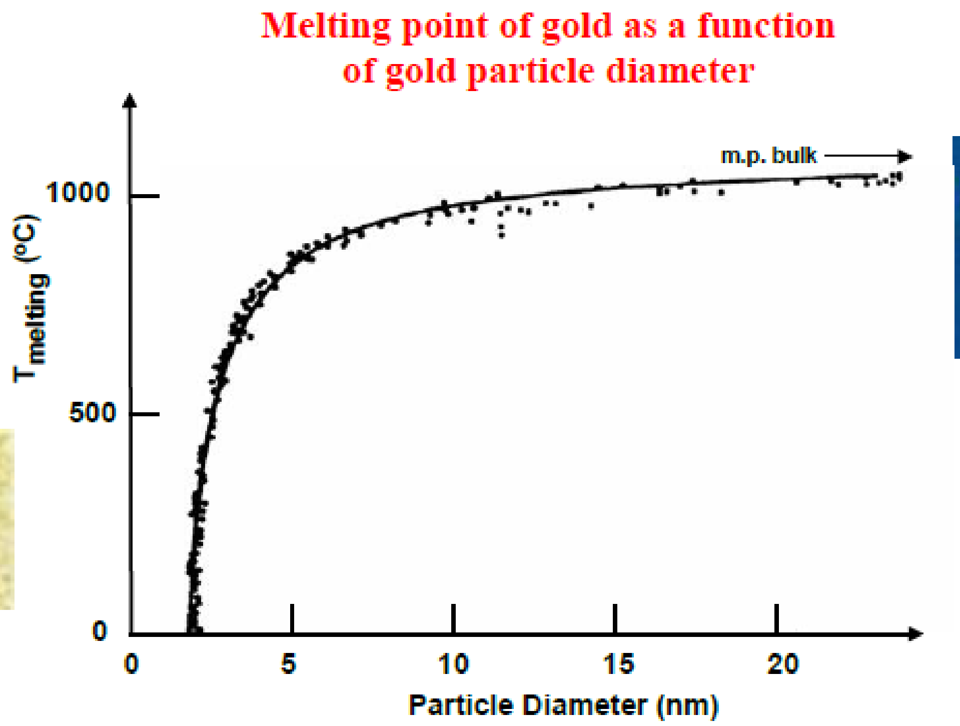
Why Nanotechnology??

At the nanoscale, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter.

Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

- The melting point of gold decreases rapidly as the particle dimension reaches the nanometer scale.

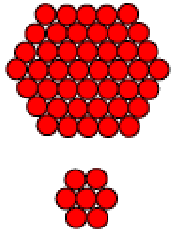




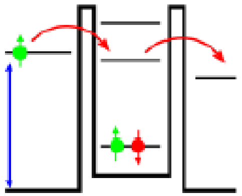
Reference: Buffat and Borel, Phys. Rev. A, vol. 13, p. 2287,1976.

Why might properties of materials/structures be different at the nanoscale?

Two of the reasons:

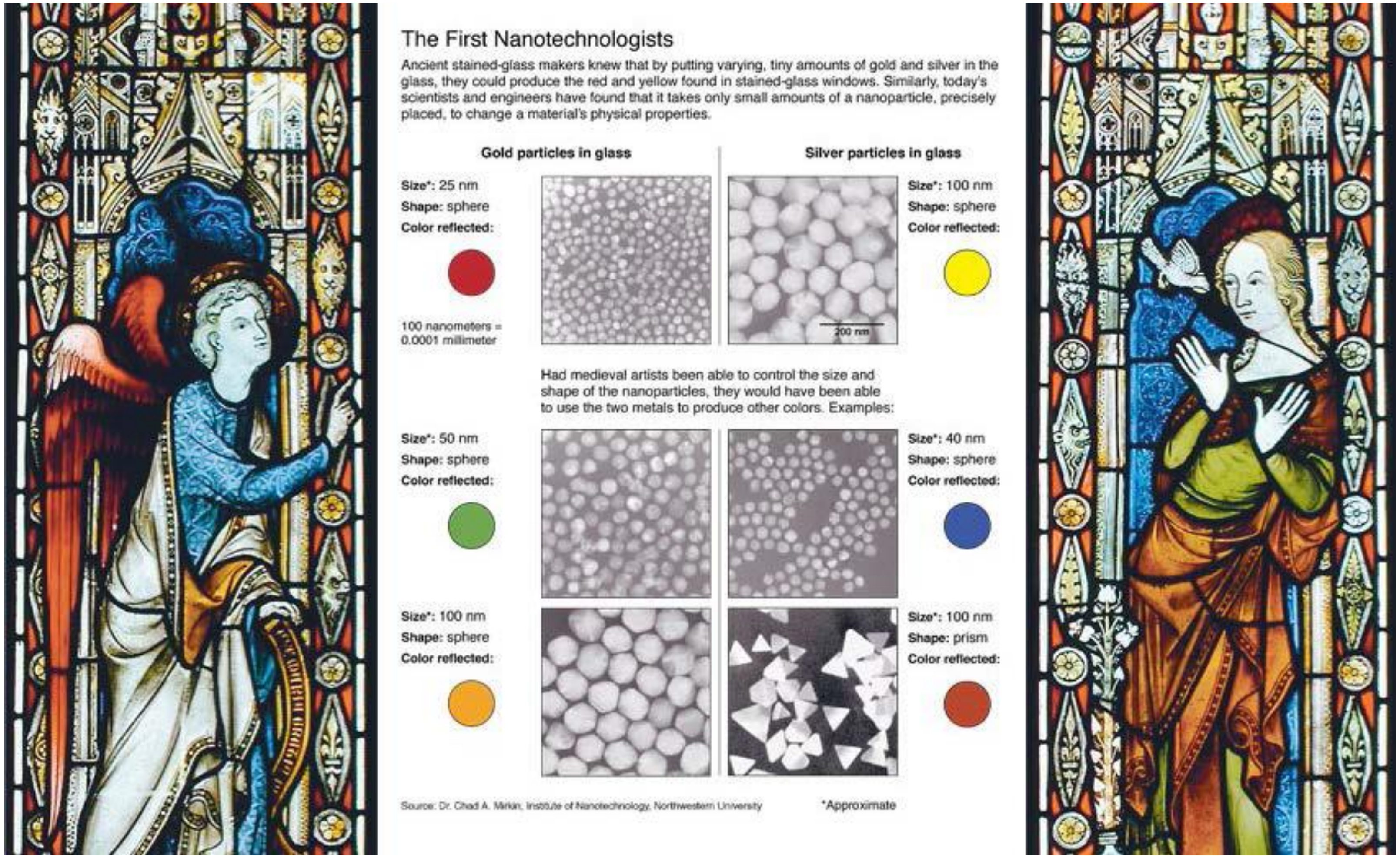


1. Ratio of surface area-to-volume of structure increases
   (most atoms are at or near the surface, which make them more weakly bonded and more reactive)



2. Quantum mechanical effects are important
   (size of structure is on same scale as the wavelengths of electrons, and quantum confinement occurs resulting in changes in electronic and optical properties)

History of Nanotechnology



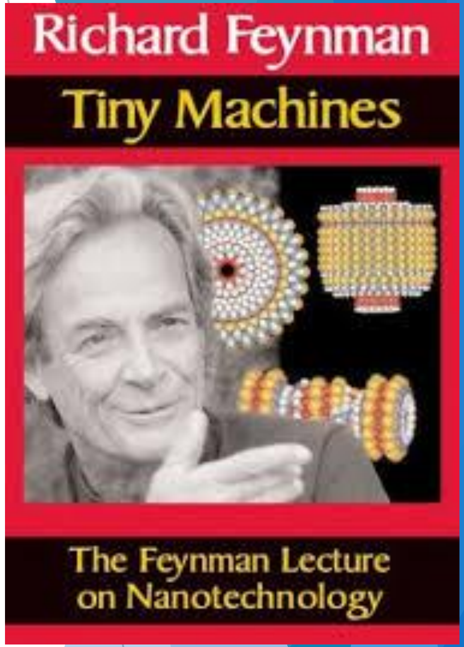
The color of gold changes as the particle size changes at the nanometer scale.

History of Nanotechnology

Richard Feynman’s famous presentation “There’s Plenty of Room at the Bottom” was in the 1959 at the American Physical Society.

Here he asked:

- Why can’t we manipulate materials atom by atom?
- Why can’t we control the synthesis of individual molecules?
- Why can’t we write all of human knowledge on the head of a pin?
- Why can’t we build machines to accomplish these things?

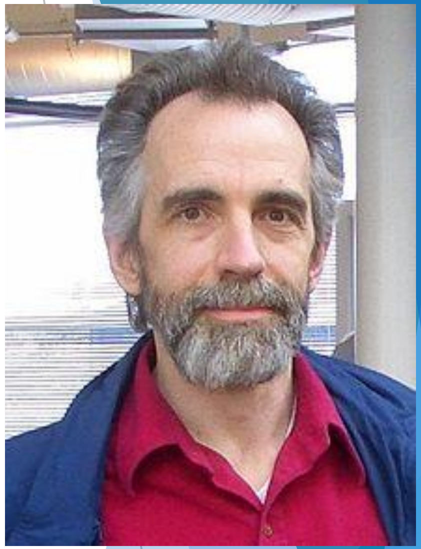


History of Nanotechnology

Norio Taniguchi was a professor of Tokyo University of Science. He coined the term *Nano-technology* in 1974 to describe semiconductor processes such as thin film deposition and ion beam milling exhibiting characteristic control on the order of a nanometer: "Nano-technology' mainly consists of the processing of separation, consolidation, and deformation of materials by one atom or one molecule.

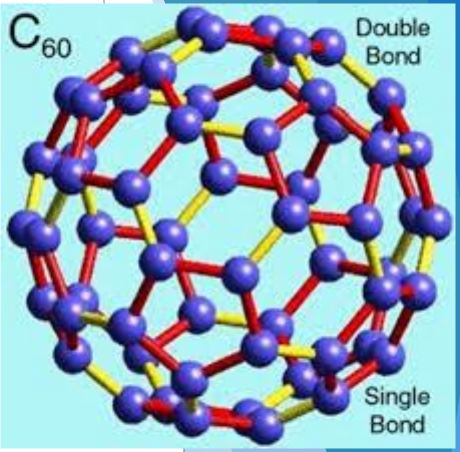
History of Nanotechnology

Kim Eric Drexler is an American engineer best known for popularizing the potential of molecular nanotechnology (MNT), from the 1970s and 1980s. His 1991 doctoral thesis at Massachusetts Institute of Technology was revised and published as the book *Nano systems: Molecular Machinery Manufacturing and Computation* (1992), which received the Association of American Publishers award for Best Computer Science Book of 1992.

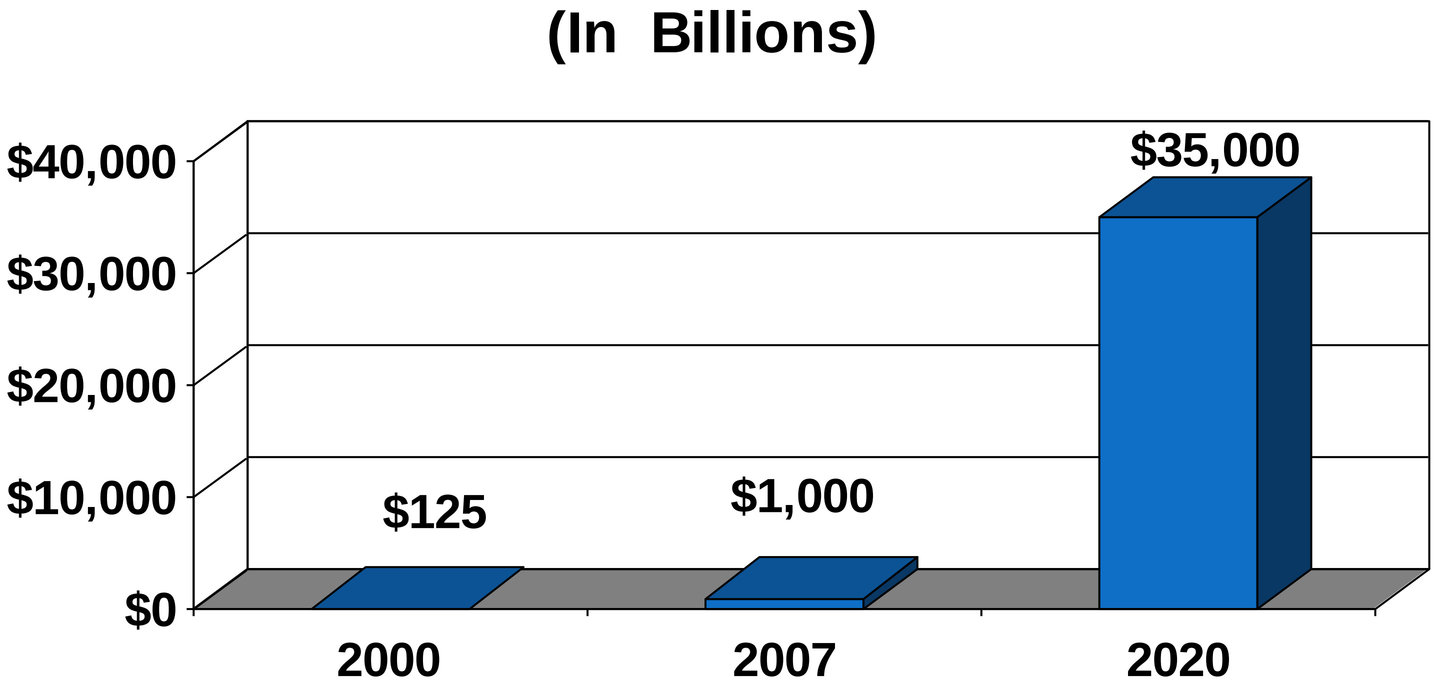


History of Nanotechnology

- In 1985, fullerenes, or “Bucky balls”, were discovered (Kroto et al. 1985)
- In 1990, the first academic nanotechnology journal was published,
- in 1993 the first Feynman Prize was awarded, and
- by 2000 President Bill Clinton announced the U.S. National Nanotechnology Initiative (NNI).



USA Market Nanomaterials Projections



Source: The Fredonia Group

Risks of Nanomaterials

Health Risks

- Ultrafine particles can catalyze chemical reactions in the body
- Carbon nanotubes can cause infections of lungs
- They could easily cross the blood-brain barrier, a membrane that protects the brain from harmful chemicals in the bloodstream.

Social and Ethical Risks

- More powerful weapons
- Privacy
- What happens to all the manufacturing jobs?

How do you build something so small?

"Top-down" – building something by starting with a larger component and carving away material (like a sculpture).

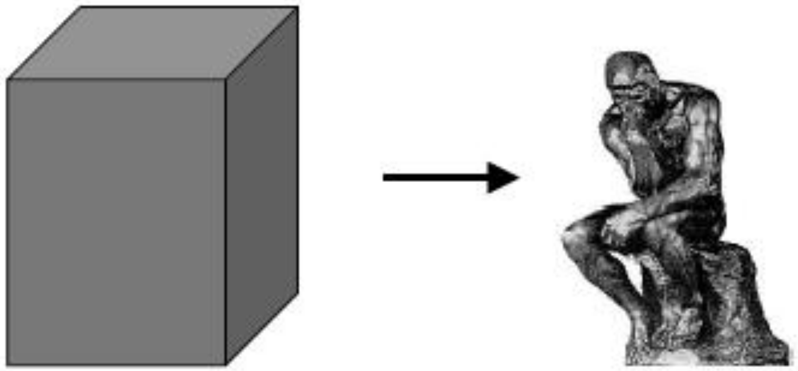
In nanotechnology: patterning (using photolithography) and etching away material, as in building integrated circuits

"Bottom-up" – building something by assembling smaller components (like building a car engine).

In nanotechnology: self-assembly of atoms and molecules, as in chemical and biological systems

How do you build something so small?

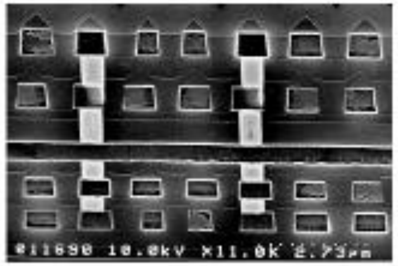
"**Top-down**" – building something by starting with a larger piece and carving away material (like a sculpture).



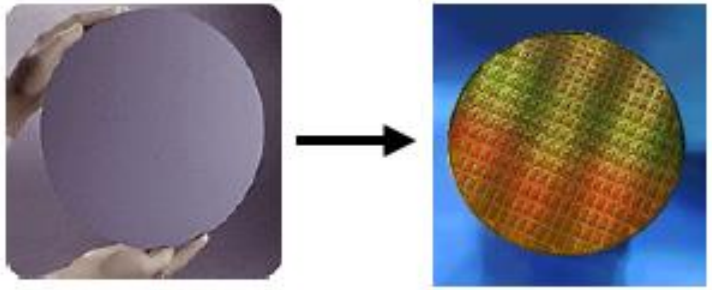
"**Bottom-up**" – building something by putting together smaller pieces (like building a car engine).

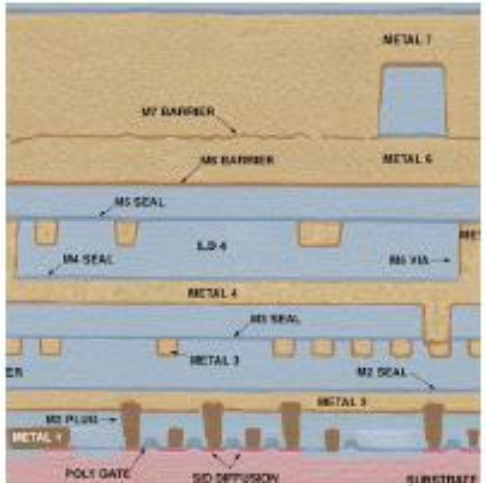
Top-down fabrication

Method used by integrated circuit industry to fabricate computer chips down to ~ 15 nm size



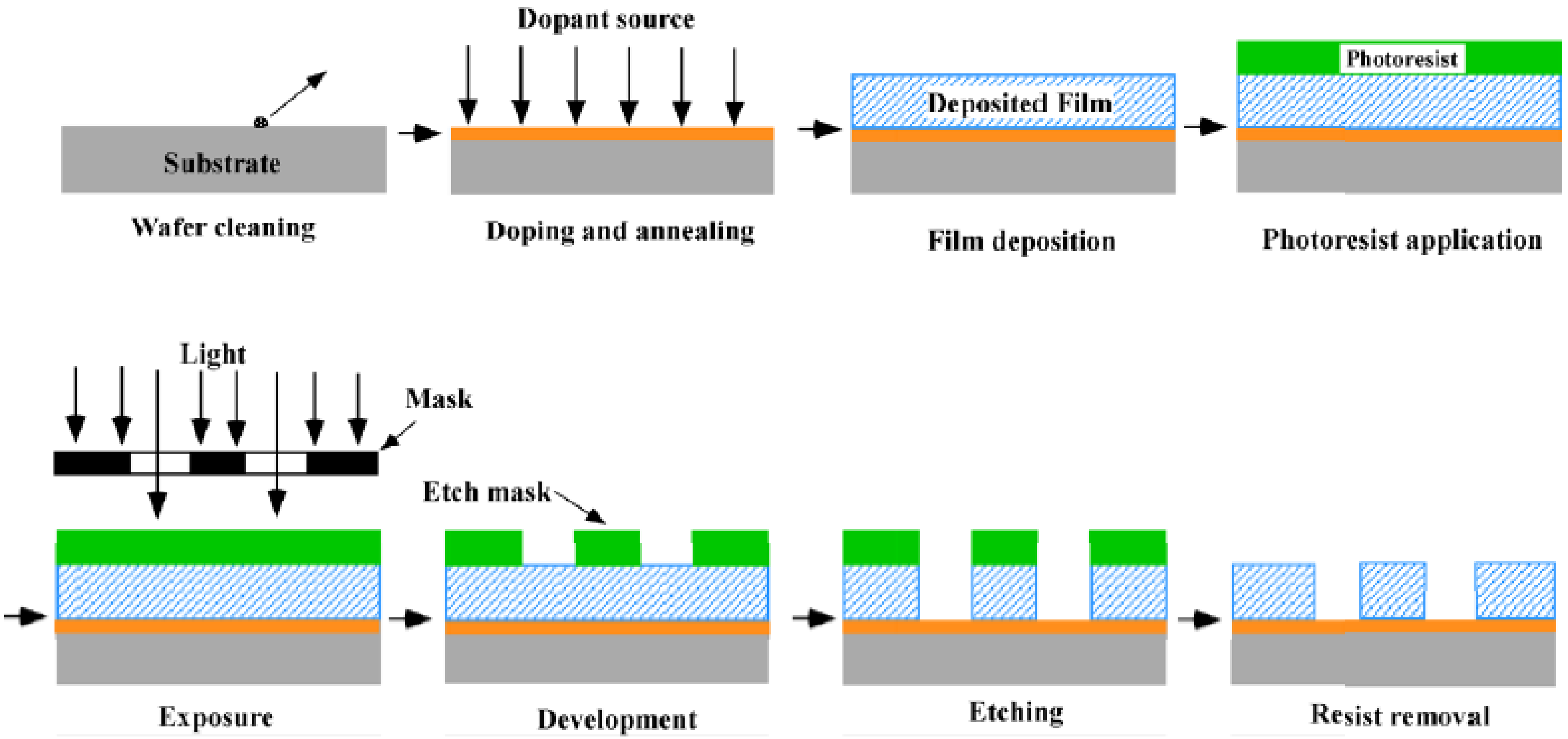
- Makes use of depositing thin films, then “photolithography” and plasma etching to make films into desired patterns on a silicon wafer.





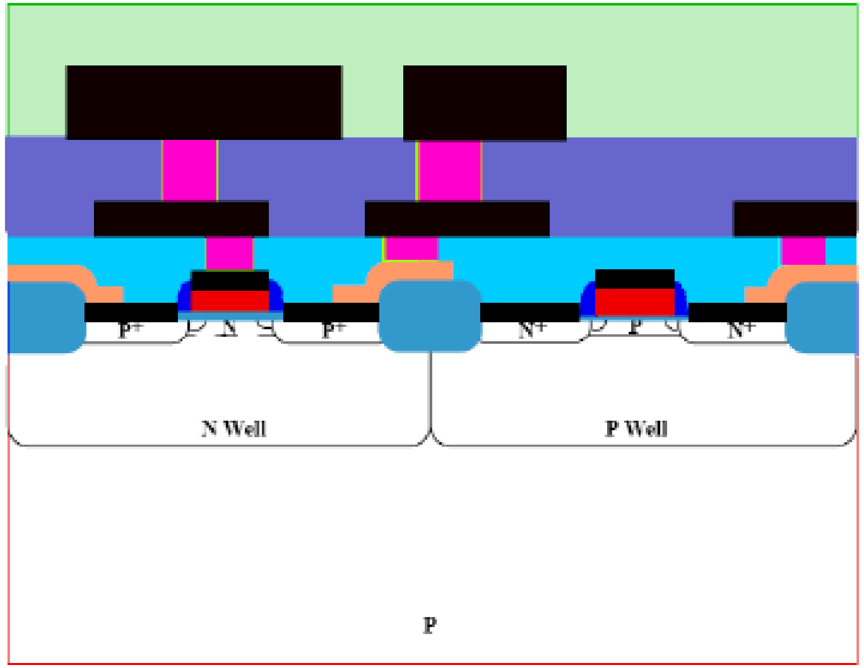
M. Deal, Stanford

Top-down fabrication



Repeat process with different thin films and different patterns (each aligned to lower layer) to produce desired structure.

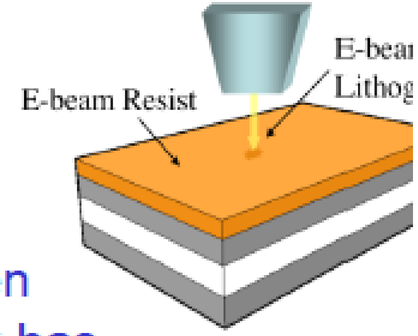
Use scanning electron beam to produce masks with very small feature sizes.



Limitations of top-down fabrication

• Due to diffraction effects, the practical limit for optical lithography is around 100 nm. Can use lithography and processing "tricks" to get feature sizes even smaller (as in Intel devices).

• To define much smaller features, electron beams, or "e-beams," (which have smaller wavelengths) can be used. Feature sizes smaller than 15 nm can be patterned.



•But e-beam projection systems using masks have not been fully developed – instead, "direct-write" e-beam lithography has been used.

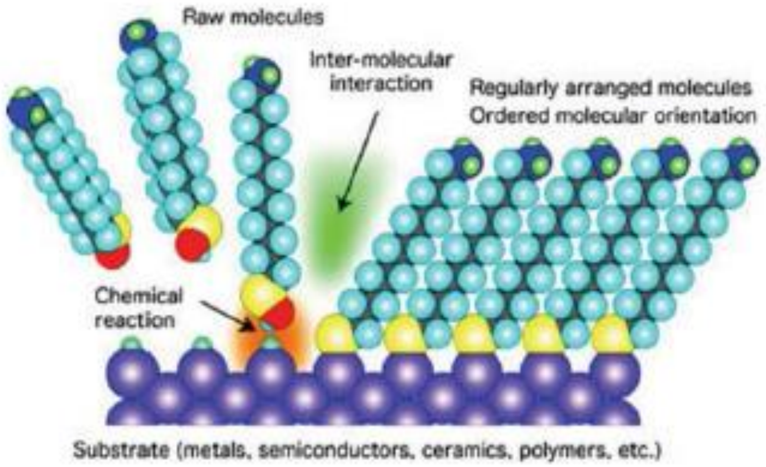
• While optical lithography works in parallel over the wafer (with high throughput), direct-write e-beam lithography works as a series process (with very low throughput).

• An alternate method is "bottom-up" fabrication.

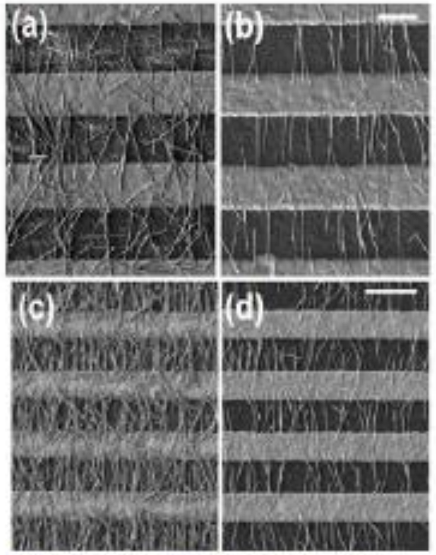
Bottom-up fabrication

- Adding atoms to atoms, molecules to molecules
- "Self-assembly" of atoms and molecules
- Use of chemical and biological processes

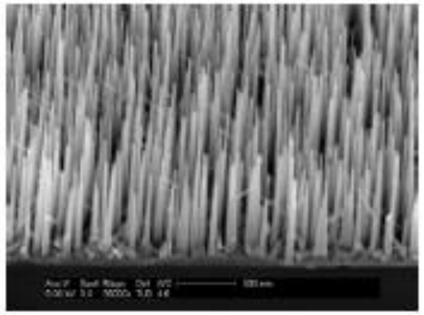
Current day examples:



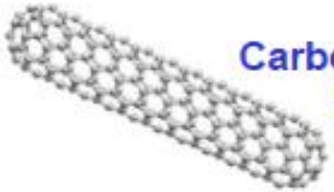
Self-assemble of organic monolayers for molecular transistors, etc. (Florida)



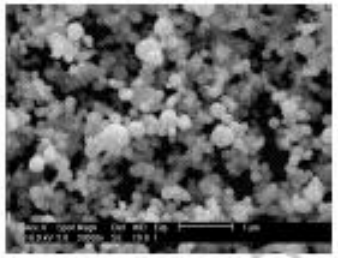
Electric field aligning of nanowires (U. Mass)



Vertical growth of nanowires for electronic devices (Stanford)



Carbon nanotul growth



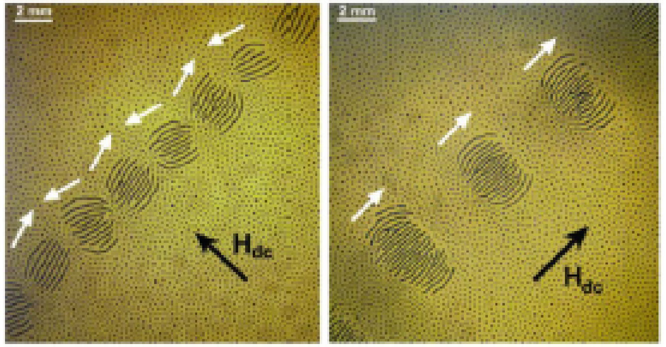
Nanoparticles by flame pyrolysis (Princeton)

More extreme example: Self-replicating robots.

M. Deal, Stanford

Bottom-up fabrication

- A way to make nanometer size features, and lots of them, letting "nature" work for you.
- But some challenges:
  - Getting the structures to always grow exactly how and where you want them to
  - Making complicated patterns



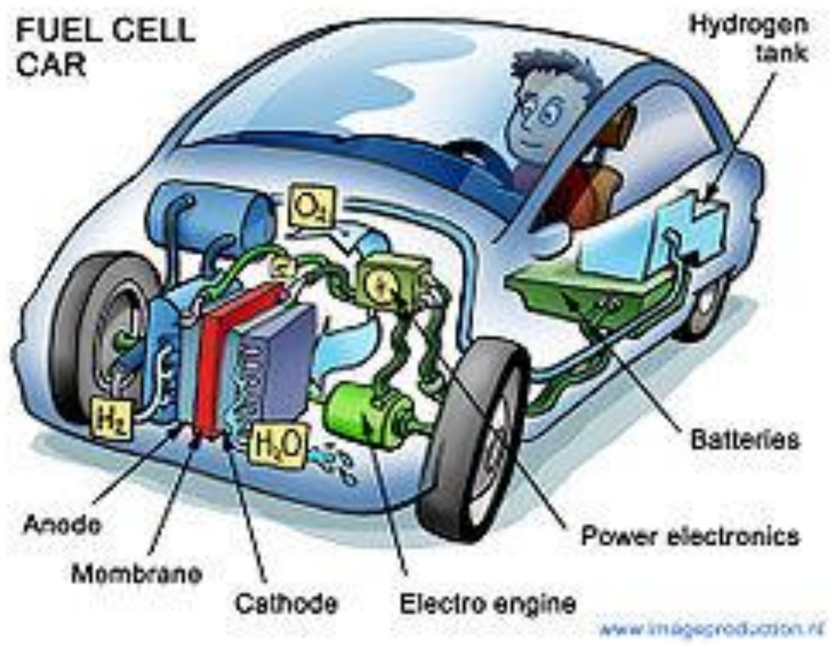
Ferromagnetic microparticles (Argonne Nat'l. Lab)

Some common strategies:

- Use catalysts, stress fields, electric/magnetic fields, capillary forces, etc. to achieve selective growth or placement
- Use top-down processes in conjunction with bottom-up processes, and build on silicon substrates

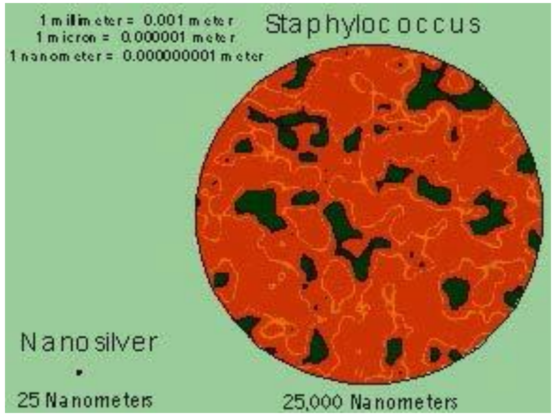
Examples of Nanotechnology Applications

Clean and Cheap Energy



Examples of Nanotechnology Applications

Using “Nano-silver” (solutions of silver nanoparticles) to coat medical tools, and in burn and surgical dressings, which protects against bacteria and fungus by inhibiting cellular metabolism and growth (Nanotech)



Examples of Nanotechnology Applications

- Superhydrophobic Coatings
- Self-cleaning surfaces

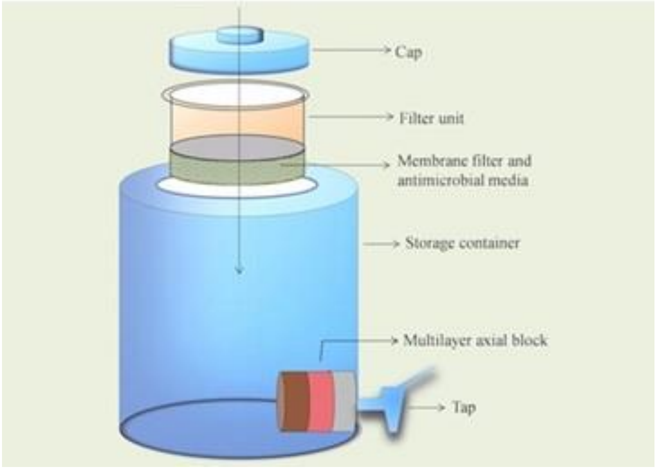
Examples of Nanotechnology Applications

Water Purification

Using Nanotechnology

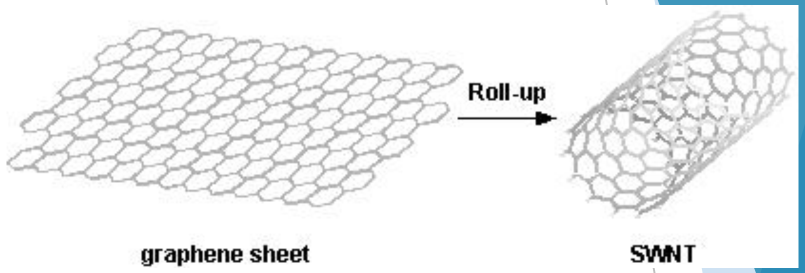
10 liters per hour

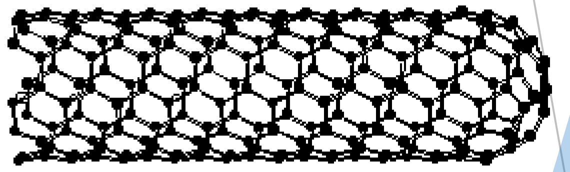
Cost: 16 $



http://www.pnas.org/content/110/21/8459.abstract

Carbon Nanotubes





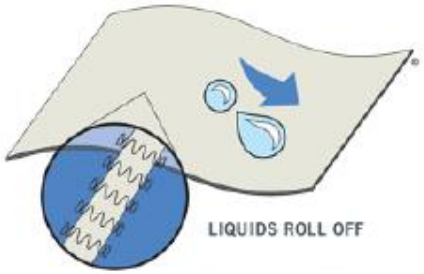
- 4 nm width (smaller diameter than DNA)
- 100x's stronger than steel 1/6 weight
- Thermal/electrically conductive
- Metallic and Semi-Conductive

Some Currently Available Nanotechnology Products

Easton CNT (carbon nanotube) baseball bat

ArcticShield "stink-proof" socks with silver nanoparticles

Nano Wear sunblock with TiO_2/ZnO_2 nanoparticles



Nanopants that repel liquids by nanowhiskers attached to cloth fibers

Zelens Fullerene C-60 (buckyball) Face Cream to "attract and neutralise the damaging free radicals"

Summary

- Nanotechnology is inherently an interdisciplinary field that encompasses physics, chemistry, biology, and engineering.
- Recent years have seen significant scientific and technological advances in nanotechnology.
- The federal government and industry are investing heavily in nanotechnology research and development.
- Many future developments and technologies have been promised. Are they realizable?