Introduction To Nanotechnology

What is Nanotechnology?

Nanotechnology involves manipulating matter at very small scales to create new or improved products that can be used in a wide variety of ways.

While many definitions for nanotechnology exist, the NNI* calls it "nanotechnology" only if it involves all of the following:

1. Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range.

2. Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

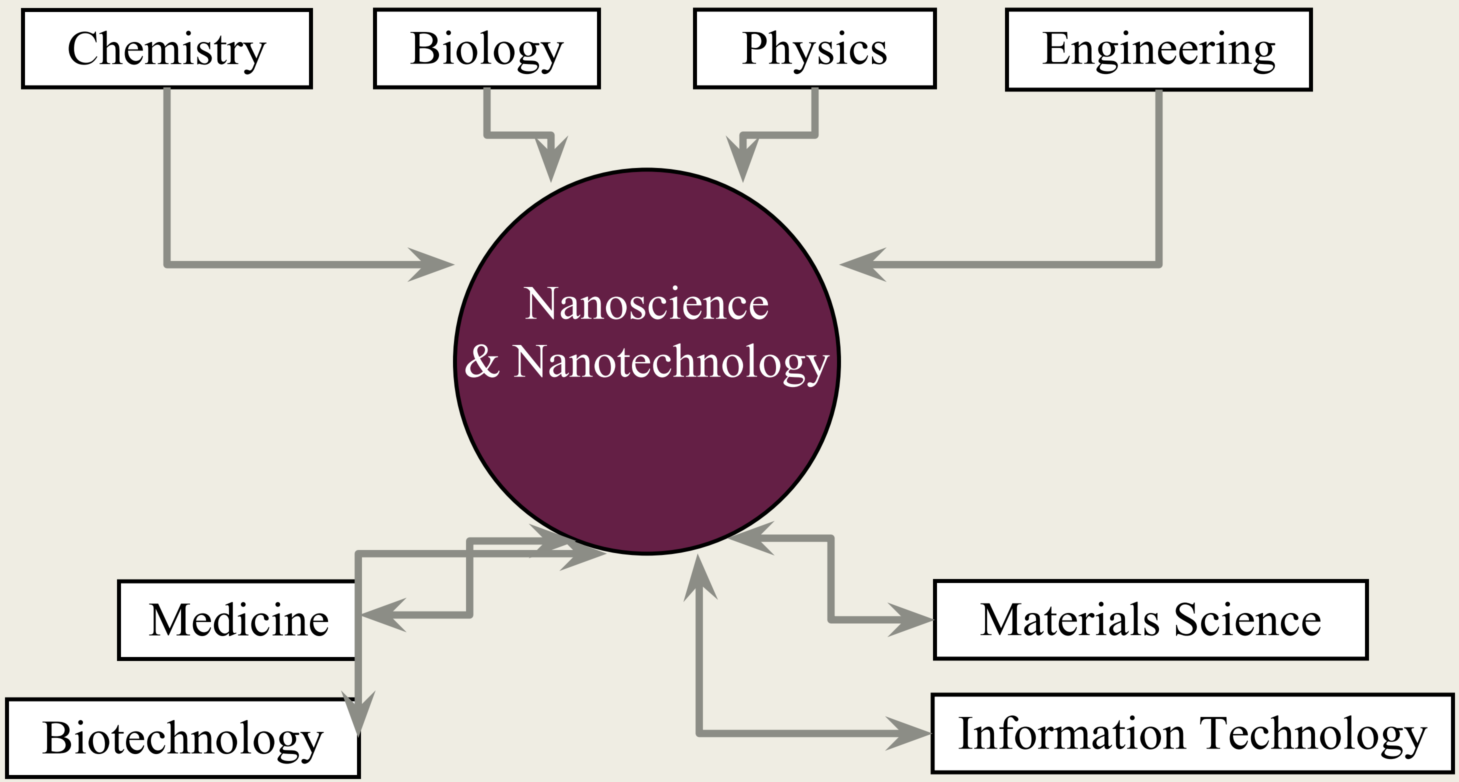
3. Ability to control or manipulate on the atomic scale.

Nanotechnology: Small, Different, New

Key ideas:

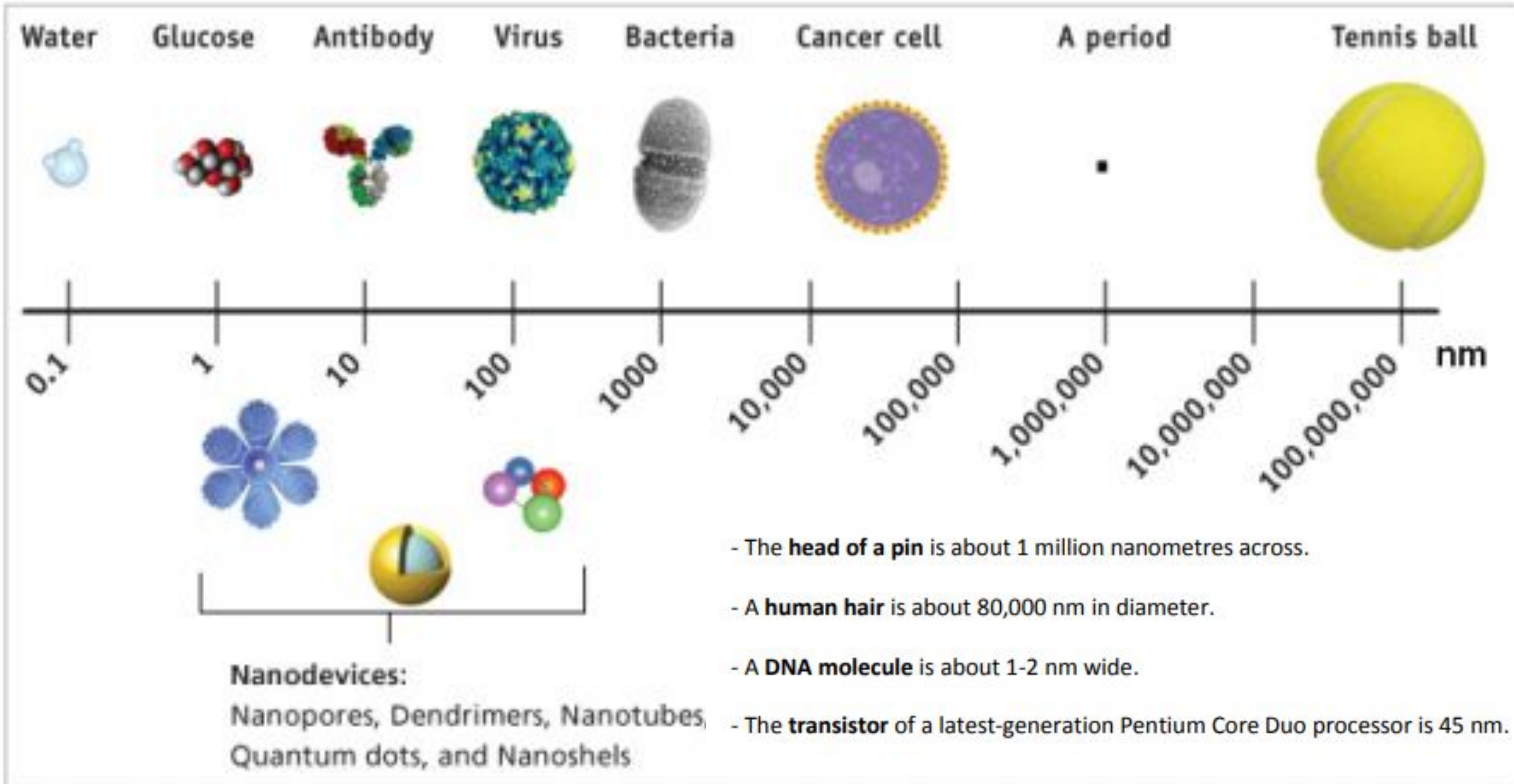
1. The nanometer is extremely small.
2. At the nanometer scale, materials may behave differently.
3. We can harness this new behavior to make new technologies.

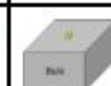
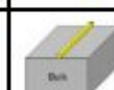
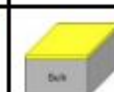
An Interdisciplinary Endeavor



What is Nano?

Prefixes for SI Units			
Prefix	**Symbol**	**Meaning**	**Notation**
exa-	E	1,000,000,000,000,000,000.	1.E+18
peta-	P	1,000,000,000,000,000.	1.E+15
tera-	T	1,000,000,000,000.	1.E+12
giga-	G	1,000,000,000.	1.E+09
mega-	M	1,000,000.	1.E+06
kilo-	k	1,000.	1.E+03
hecto-	h	100.	1.E+02
deka-	da	10.	1.E+01
		1.	1.E+00
deci-	d	.1	1.E-01
centi-	c	.01	1.E-02
milli-	m	.001	1.E-03
micro-	µ	.000001	1.E-06
nano-	n	.000000001	1.E-09
pico-	p	.000000000001	1.E-12
femto-	f	.000000000000001	1.E-15
atto-	a	.000000000000000001	1.E-18



Nanomaterial Dimension	**Nanomaterial Type**	**Example**
All three dimensions < 100 nm	Nanoparticles, Quantum dots, nanoshells, nanorings, microcapsules	
Two dimensions < 100 nm	Nanotubes, fibres, nanowires	
One dimension < 100 nm	Thin films, layers and coatings	

How Big is a Nanometer?

- In the time it takes to read this sentence, your fingernails will have grown approximately one nanometer (1 nm).

How Big is a Nanometer?

- If you could paint a teaspoon of paint one nanometer thick, how much area would it cover?

?

Joon Han and Justin Smith / Wikimedia Commons

How Big is a Nanometer?

- To cover a football field with a 1nm thick layer of paint, you would need just **1 teaspoon** of paint!

Joon Han and Justin Smith / Wikimedia Commons

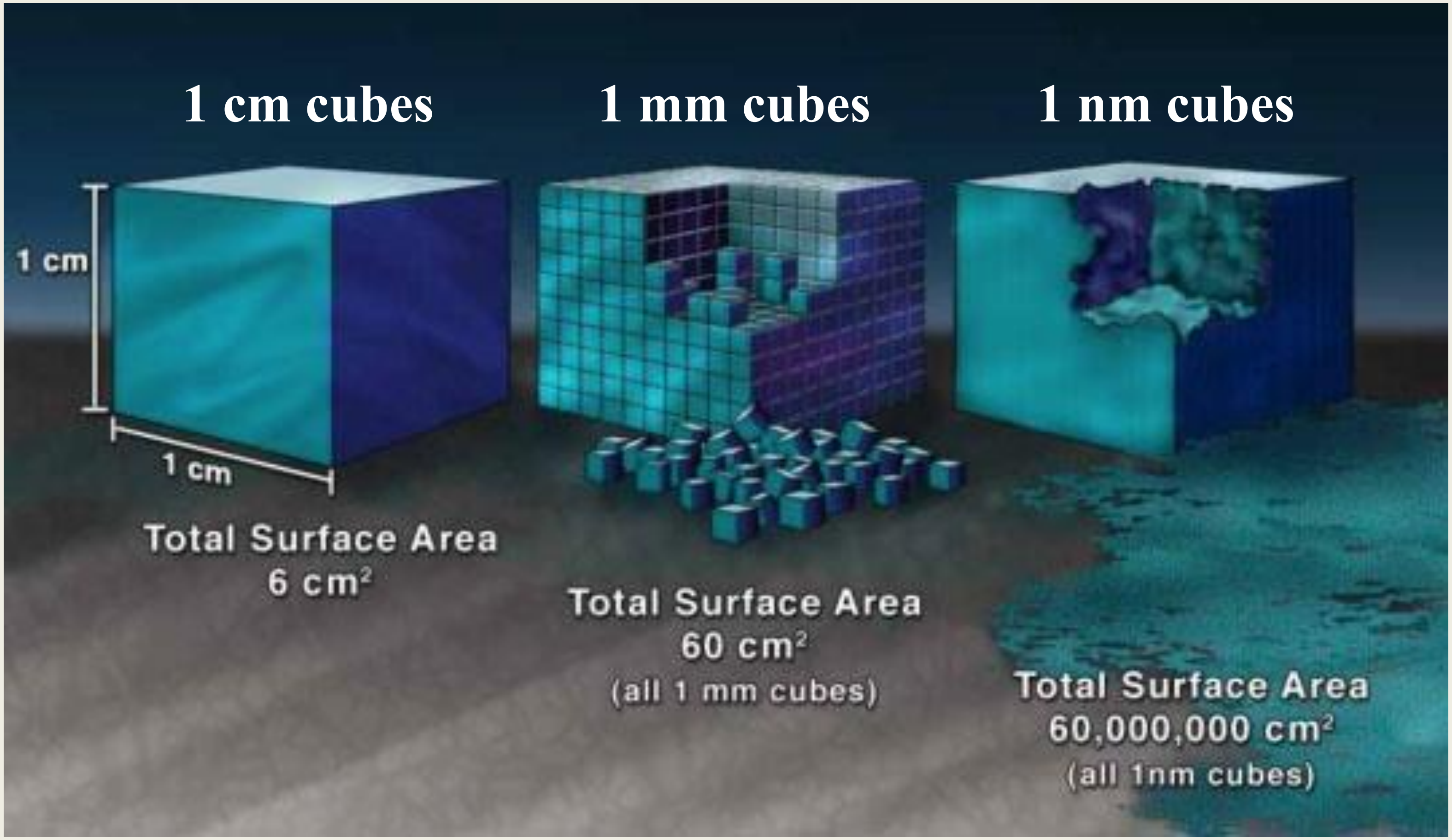
How Big is a Nanometer?

Sugar cubes

- **How many sugar molecules in a sugar cube?**
- **What do we need to know (estimate)?**
  - *Sugar cube = (1 cm)^3*
  - *1 sugar molecule = (1 nm)^3*
- *∴ 10^{21} sugar molecules in a sugar cube*

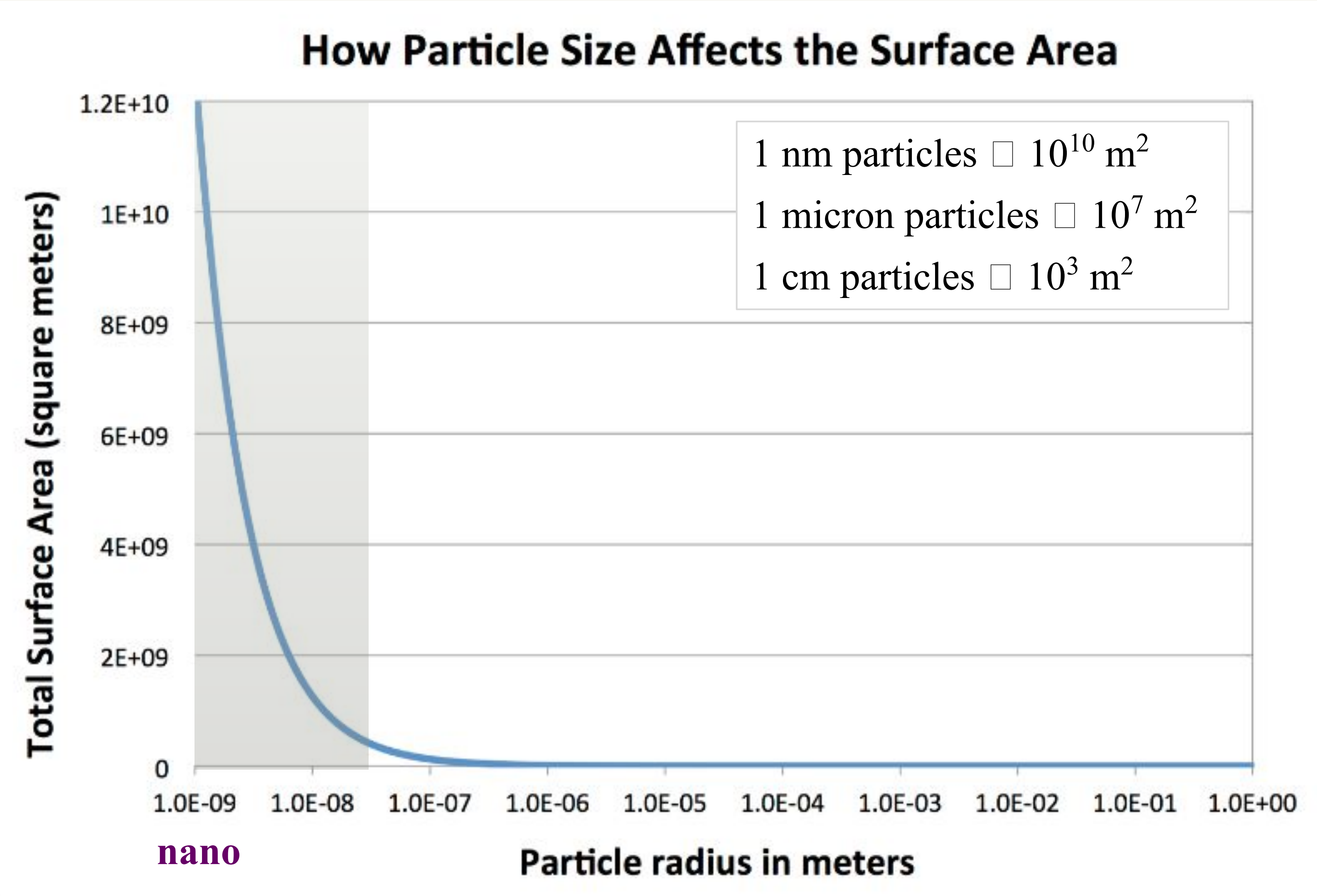
Biswarup Ganguly / Wikimedia Commons

Surface Areas at the Nanoscale



http://www.nano.gov/nanotech-101/special

How Surface Area Scales (Changes)



Smallness Leads to New Properties

Bulk Aluminum

Nano Aluminum

Reactivity

Melting point

Strength

Conductivity

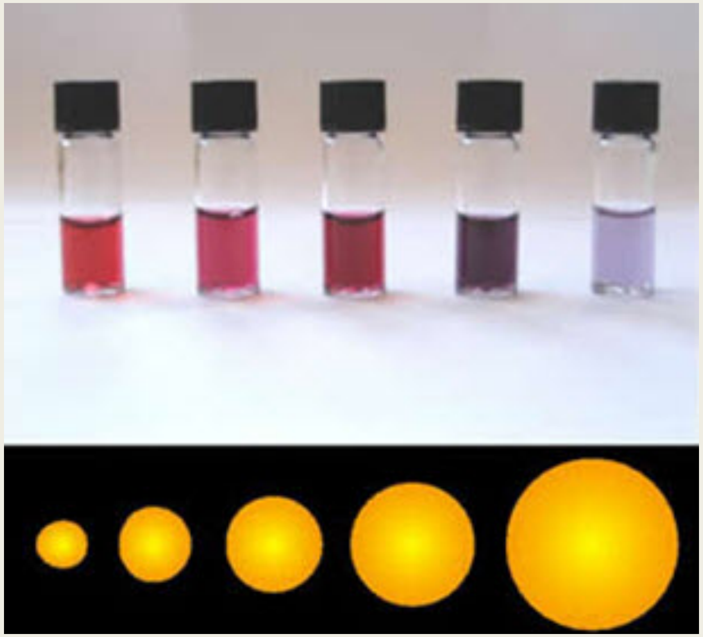
Color

Bulk Gold

Nano Gold

http://www.carterrecycling.com/myimages/aluminum_cans.jpg http://healthewoman.org/2008/11/11/how-healthy-is-your-workplace/
http://mrsec.wisc.edu/Edetc/nanolab/gold/images/goldp6.jpg http://texasenterprise.org/article/warren-buffet-and-new-calculus-gold

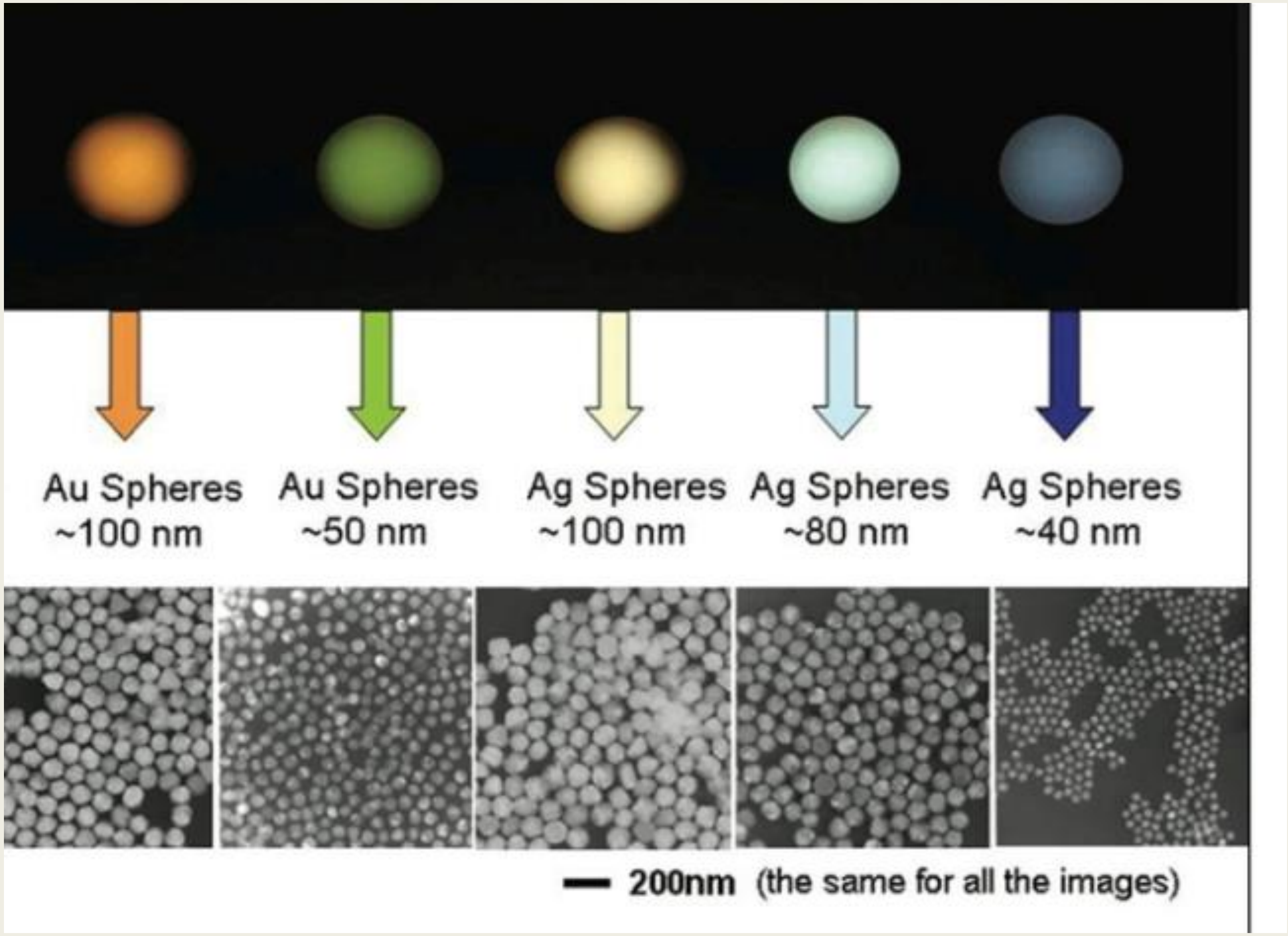
Stained Glass: Size Matters



Gold particles

http://www.cas.muohio.edu/nanotech/education/k_12.html http://www.horiba.com/scientific/

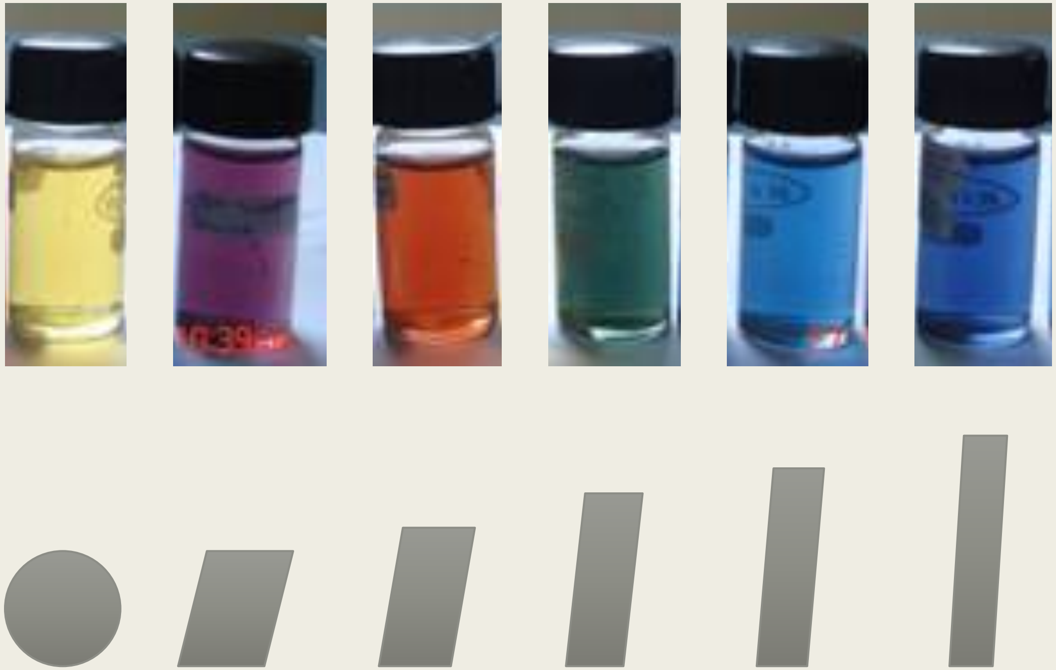
Stained Glass: Size and Shape Matter



Controlling the Quantum World: The Science of Atoms, Molecules, and Photons, 2007

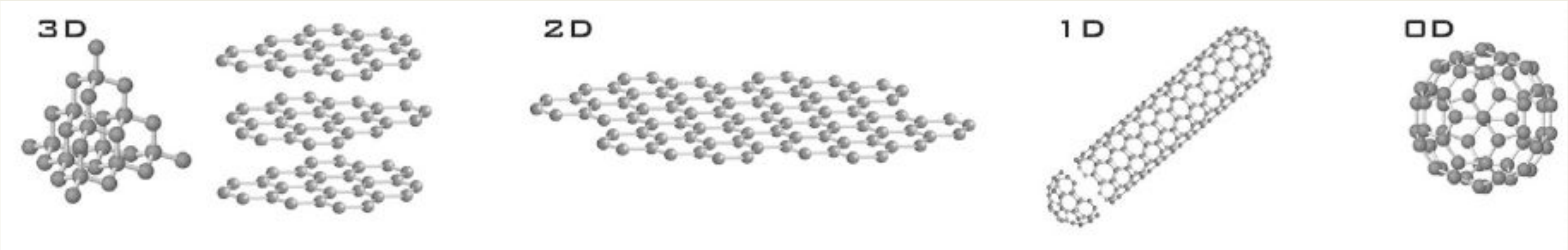
Stained Glass: Size and Shape Matter

Particle shape also affects the color!



http://commons.wikimedia.org/wiki/File:Native_gold_nuggets.jpg
http://www.cat.gov.in/technology/laser/lpas/pps.html

Forms of Carbon



Diamon
d

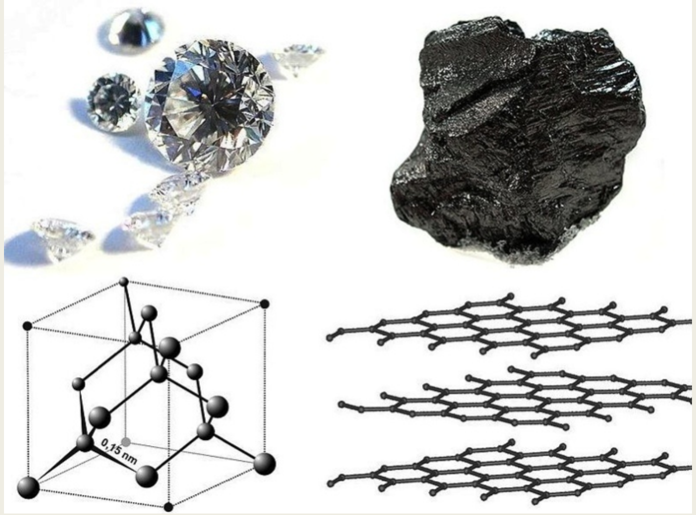
Graphit
e

Graphen
e

Nanotube

Buckybal
l

Diamond **Graphite**



Phase can be really important!

Structure/bonding really affect properties

- Diamond is one of the hardest materials
- Graphite is soft and slippery; it's a good lubricant

http://commons.wikimedia.org/wiki/File:Diamond_and_graphite2.jpg http://www.intechopen.com/source/html/16991/media/image2.png

Why We Need "Special" Microscopes

- Can you see nanoscale objects with a regular optical microscope?
- Let's say that the smallest object you can resolve with your eyes is about 0.1 – 0.2 mm which is 100,000 – 200,000 nm
- With a 100x objective, you should be able to resolve objects that are 1000 – 2000 nm

Types of “Special” Microscopes

Optical microscope

Scanning electron microscope

Transmission electron microscope

http://en.wikipedia.org/wiki/Optical_microscope http://en.wikipedia.org/wiki/Scanning_electron_microscope
http://itg.beckman.illinois.edu/microscopy_suite/equipment/TEM/

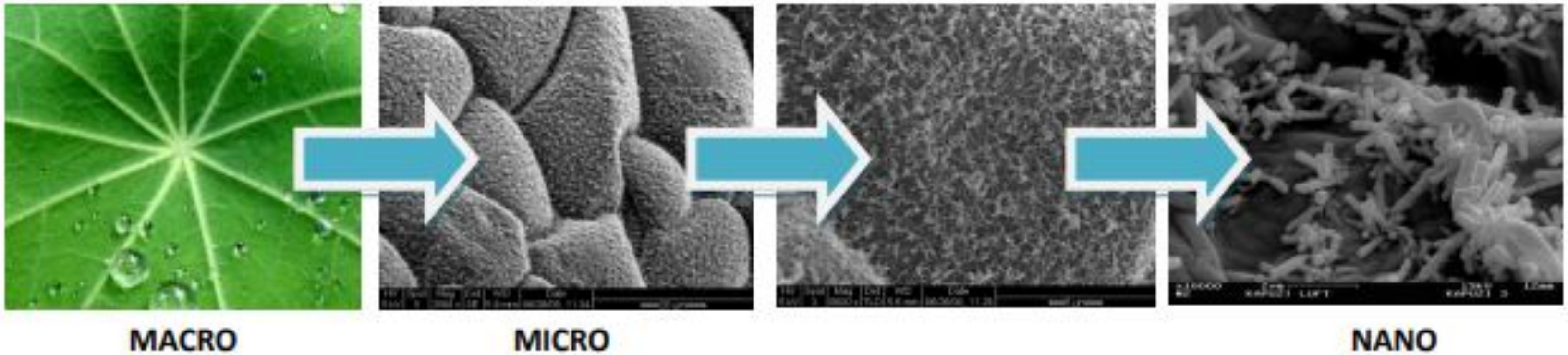
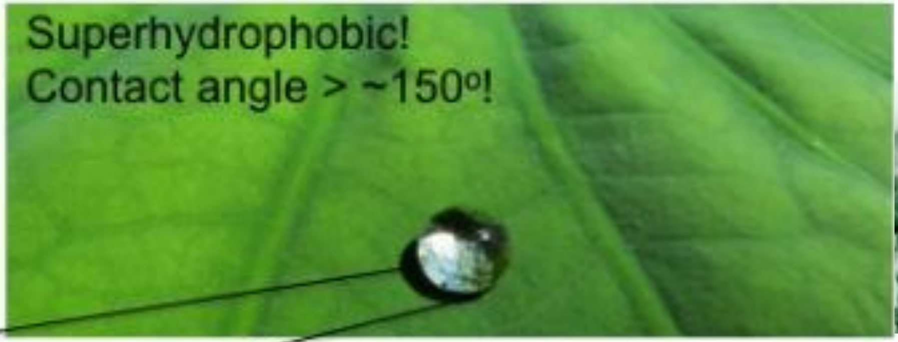
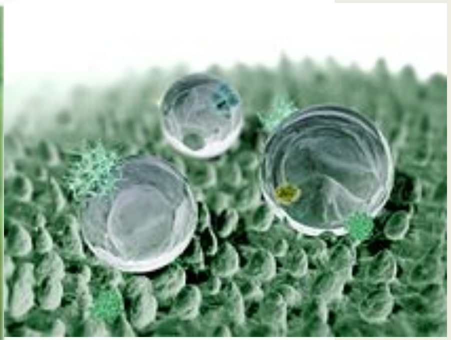
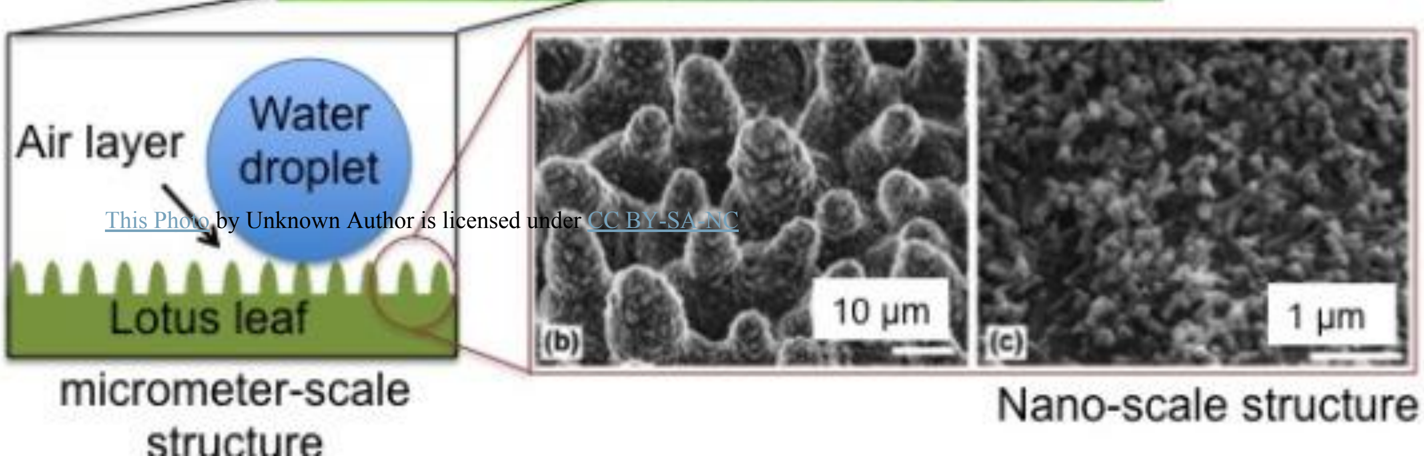


Figure 5. Close-up views at progressive magnification of a nasturtium leaf revealing the presence of surface nanocrystals (image on the far right). (Image credit (A): A.Snyder, Exploratorium; (B, C): A.Marshall, Stanford University, (D): A. Otten and S. Herminghaus, Göttingen, Germany, all images are material of the NISE Network, reprinted under NISE network terms and conditions).

https://www.researchgate.net/publication/329138904_3D_Reconstruction_in_Scanning_Electron_Microscope_from_image_acquisition_to_dense_point_cloud/figures?lo=1&utm_source=google&utm_medium=organic

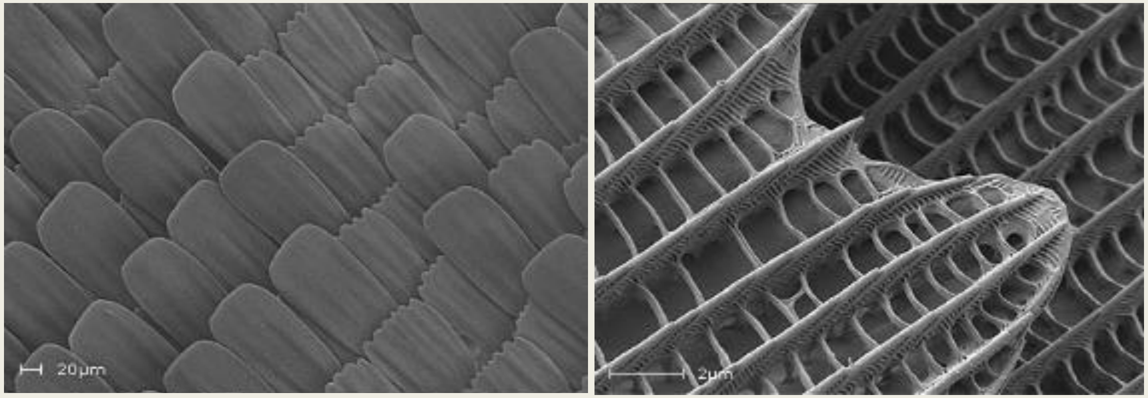




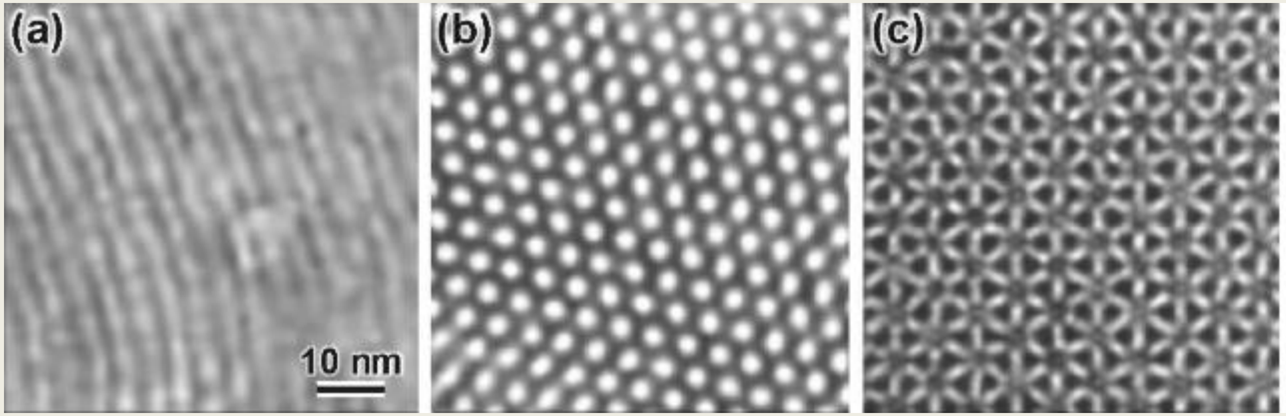


Types of “Special” Microscopes

Scanning electron microscope



Transmission electron microscope



http://www.nhm.ac.uk/research-curation/science-facilities/analytical-imaging/imaging/high-resolution-sem/ultra-plus/examples/index.ht
http://www.princeton.edu/~cml/html/research/templated_ceramics.html

Applications of Nanotechnology

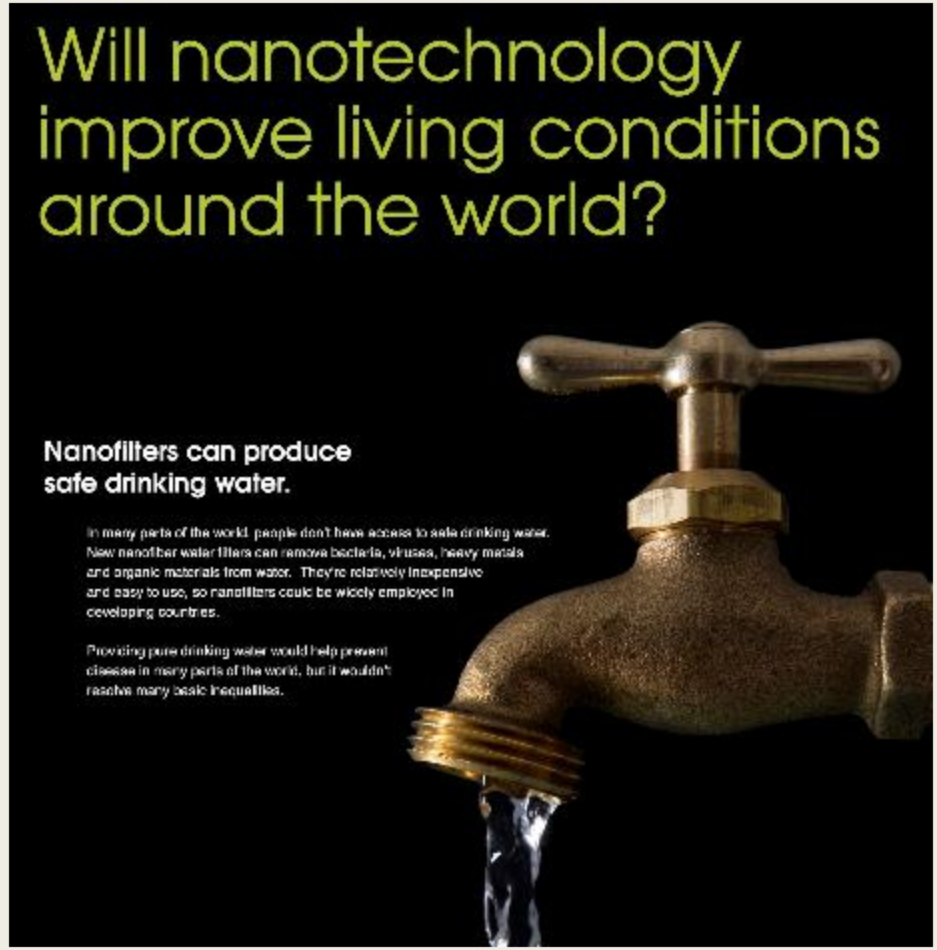
Nanotechnology could change how we create, transmit, store, and use energy

Examples:
super-efficient batteries, low-resistance transmission lines, cheaper solar cells

New flexible, thin film solar cells are easier to produce and install, use less material, and are cheaper to make

http://www.nisenet.org/catalog

Nanofiltration for Clean Water



In many places, people do not have access to clean water

Nanofiltration systems are a promising solution to this problem

http://www.nisenet.org/catalog

Agriculture Applications

- Nanotechnology enables delivery of agriculture chemicals (fertilizers, pesticides, herbicides, plant growth regulators etc).
- Field sensing system to monitor the environmental stresses and crop condition.
- Nanotechnology enables the study of plant disease mechanisms.
- Improving plant traits against environmental stresses and diseases.

Nanobiosystems, Medical, and Health Applications

- Enhanced biological imaging for medical diagnostics (Quantum dots).
- Early diagnosis of atherosclerosis or the build up of plaque in arteries.
- Detection of early-stage Alzheimer's disease (Gold particles).
- Detect rare molecular signals associated with malignancy.
- Multifunctional therapeutics.

Electronics and Information technology Applications

- Nanoscale transistors.
- Magnetic random access memory (MRAM) enabled by nanometer-scale magnetic tunnel junctions.
- Displays for electronic items incorporate nanostructured polymer films known as organic light-emitting diodes (OLEDs).
- Flash memory chips for iPod nanos.
- Ultraresponsive hearing aids.

How to prepare Nanomaterials

- **Top-down methods**

begin with a pattern generated on a larger scale, then reduced to nanoscale.

-By nature, aren't cheap and quick to manufacture

- Slow and not suitable for large scale production.

- **Bottom-up methods**

start with atoms or molecules and build up to nanostructures

-Fabrication is much less expensive

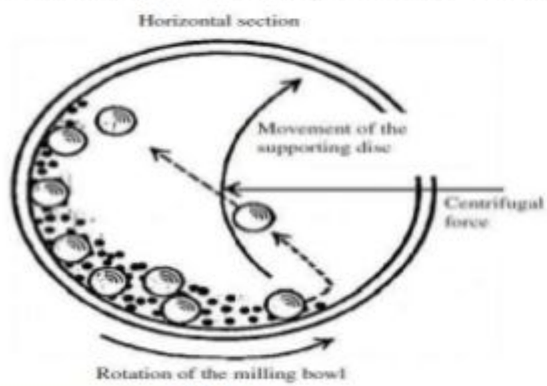
Ball Milling

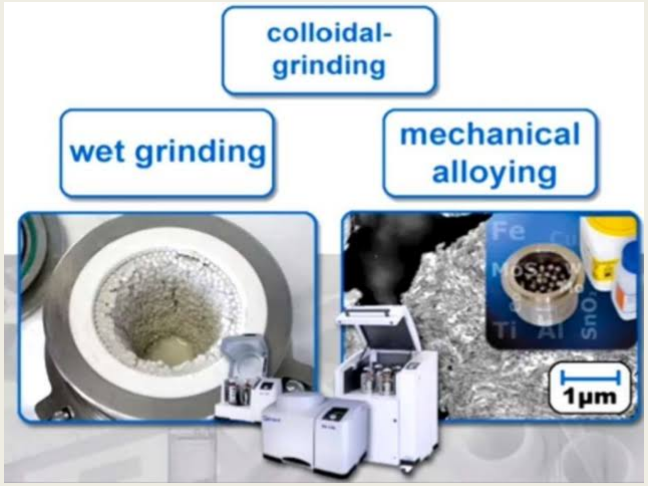
DEFINITON:

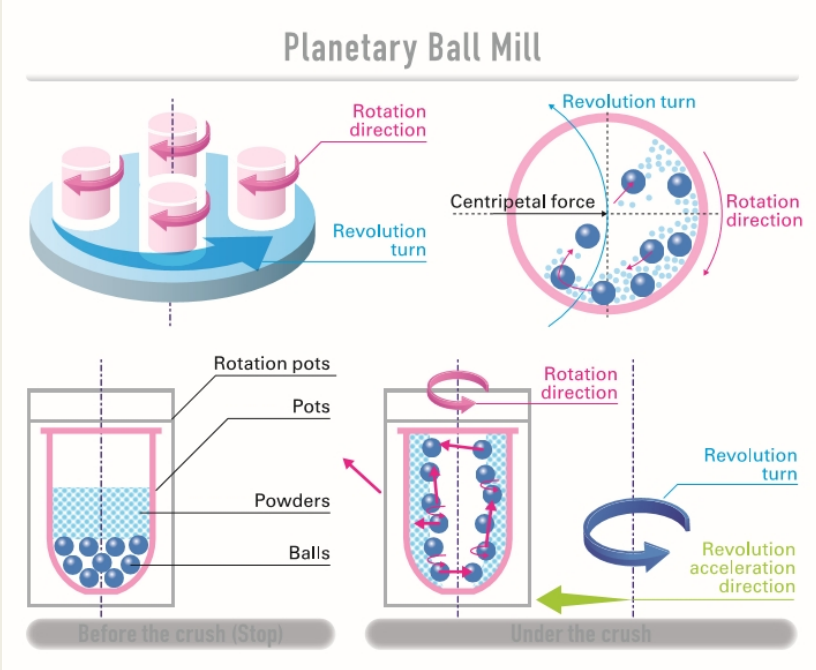
- A **ball mill** is a type of grinder used to grind and blend materials for use in mineral dressing processes, paints, pyrotechnics, ceramics and selective laser sintering etc.

PRINCIPLE:

- A ball mill works on the principle of impact and attrition.
- size reduction is done by impact as the balls drop from near the top of the shell.

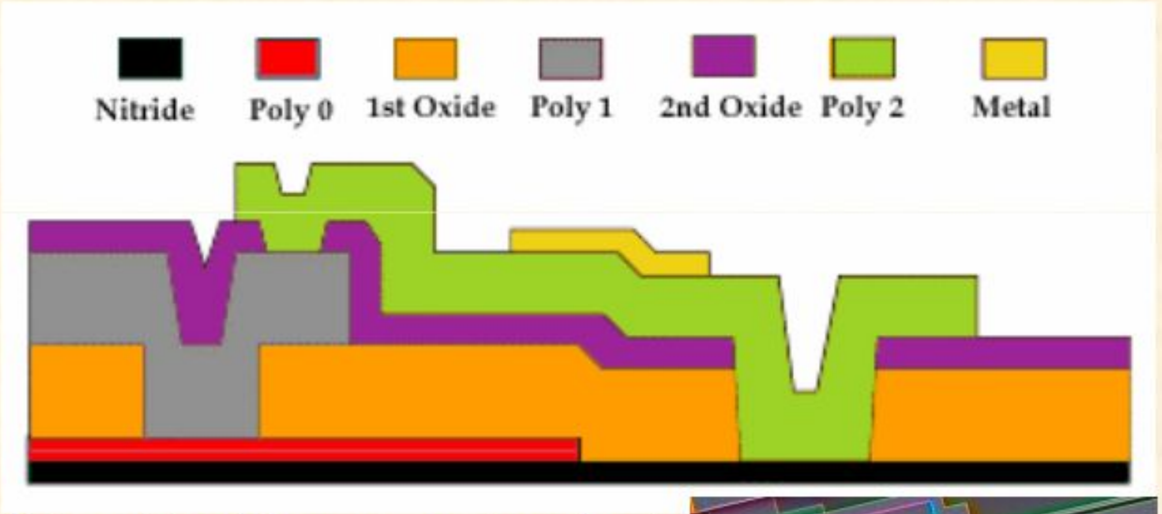




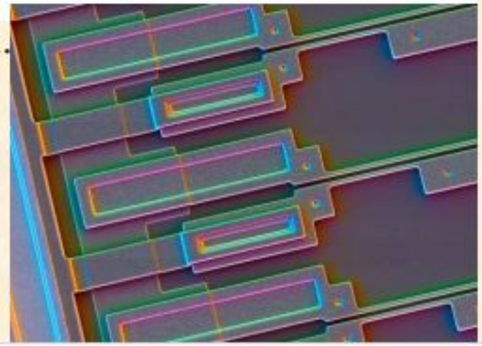


Top-Down: lithography

At the moment, the most used top-down approach is photolithography.
It has been used for a while to manufacture computer chips
and produce structures smaller than 100 nm.

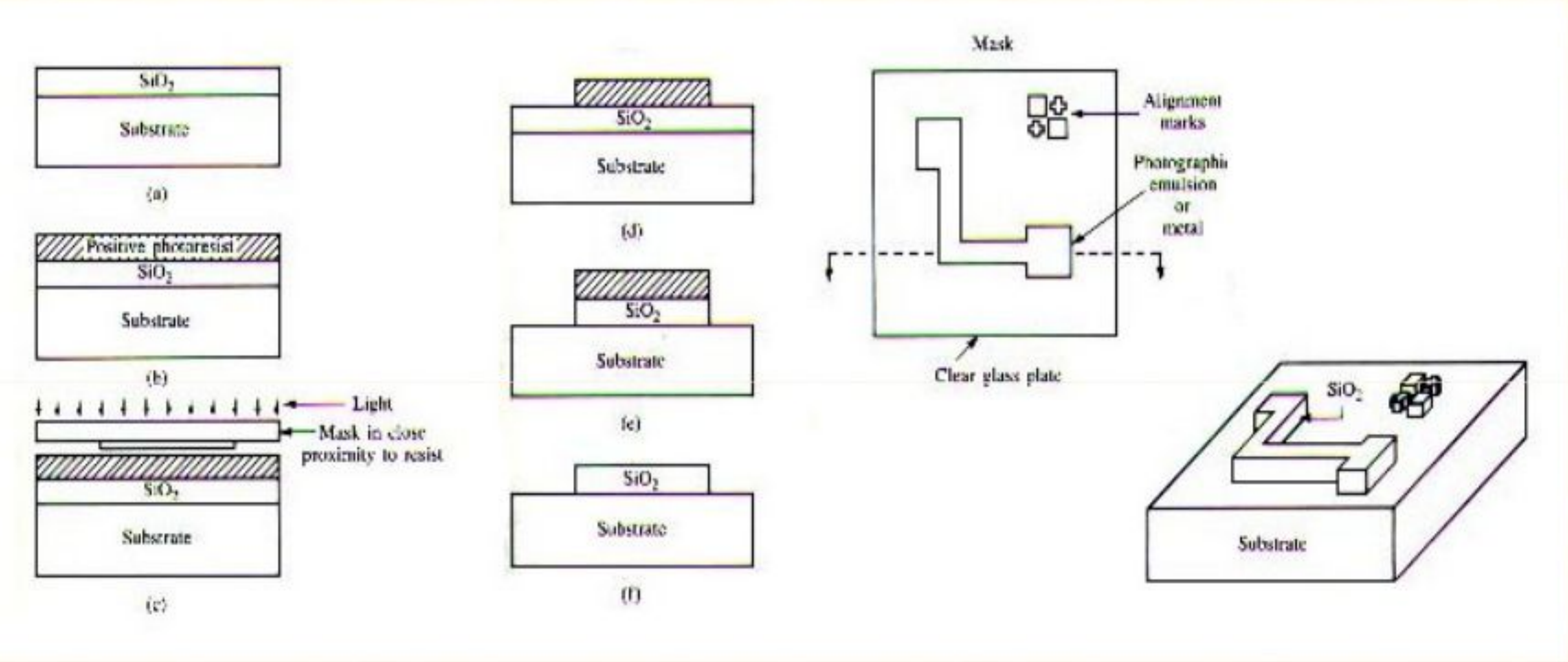


Strip resist and do process again and again.
Eventually, a 3-D structure is built up



Typically, an oxidized silicon (Si) wafer is coated with a 1μm thick photoresist layer. After exposure to ultraviolet (UV) light, the photoresist undergoes a photochemical reaction, which breaks down the polymer by rupturing the polymer chains. Subsequently, when the wafer is rinsed in a developing solution, the exposed areas are removed.

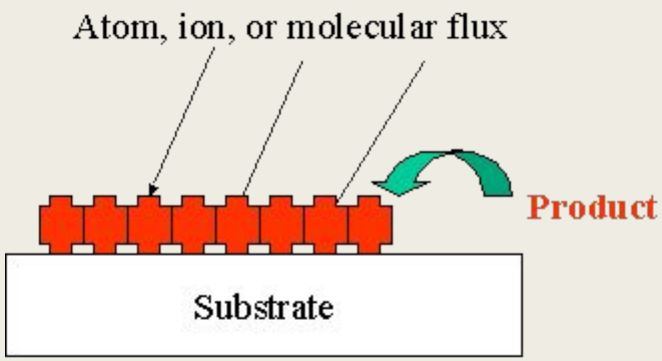
Basic idea behind lithographic processing



Coat, protect, expose, etch, repeat…

Result:
Multiple patterned layers of different materials.

Bottom-Up Approach

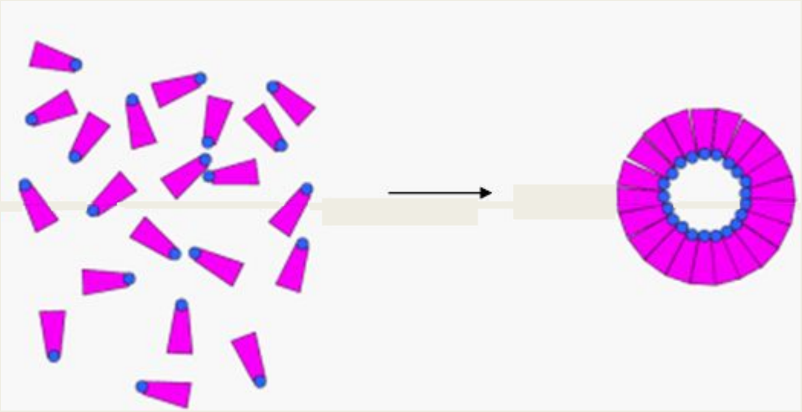


http://idol.union.edu/~malekis/ESC24/KoskywebModules/sa_topd.htm

- The opposite of the top-down approach.
- Instead of taking material away to make structures, the bottom-up approach selectively adds atoms to create structures.

The Ideas Behind the Bottom-up Approach

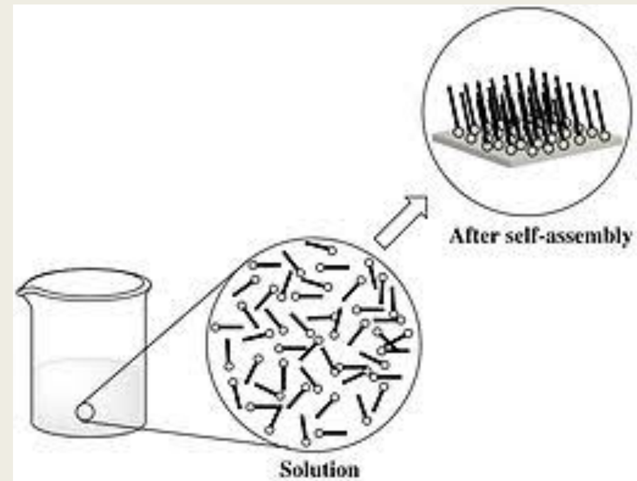
- Nature uses the bottom up approach.
  - *Cells*
  - *Crystals*
  - *Humans*
- Chemistry and biology can help to assemble and control growth.



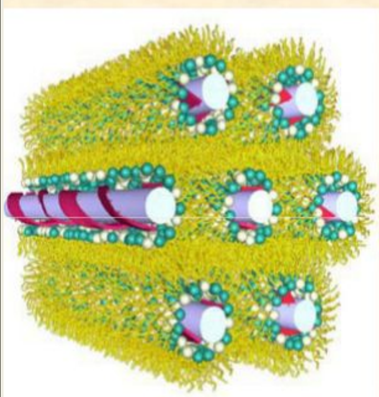
http://www.csacs.mcgill.ca/selfassembly.htm

Bottom-Up approach

Self-assembly: phenomenon where the components of a system assemble themselves to form a larger functional unit. This spontaneous organization can be due to direct specific interaction, collective effects, and/or occur indirectly through their environment.

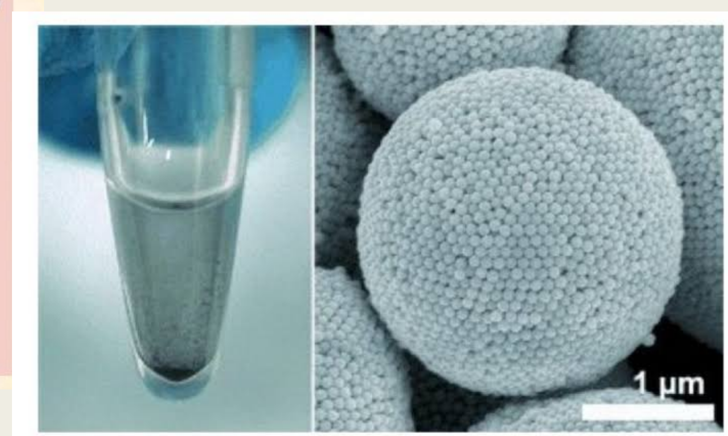


Bottom-Up: Molecular self-assembly

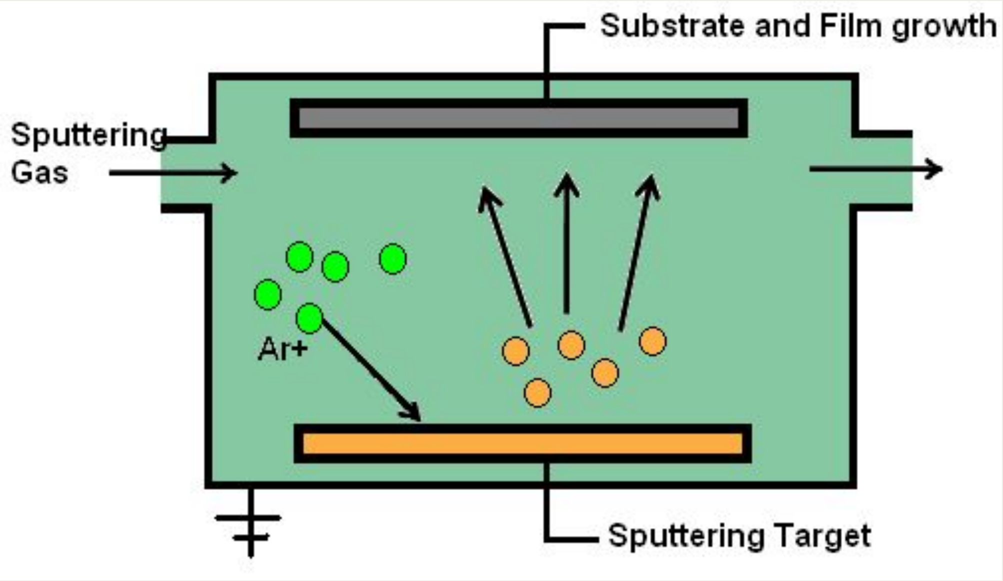


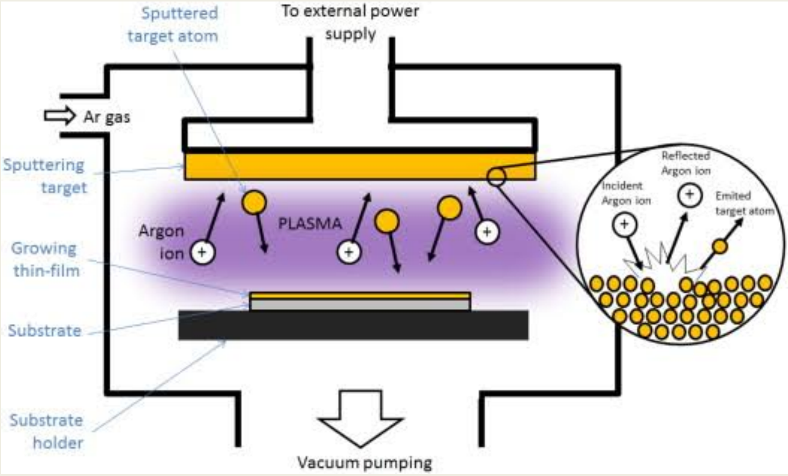
Polythiophene wires

- Nature uses self-assembly in infinitely subtler ways; indeed, the whole of the natural world is self-assembled.
- Spontaneous organization of molecules into stable, structurally well-defined aggregates (nanometer length scale).
- Molecules can be transported to surfaces through liquids to form self-assembled monolayers (SAMs).



Sputtering





- *In this example of sputtering, a film is being deposited on the substrate by argon ions (green).*
- *These ions act as hammers knocking film atoms (orange) off the target (orange too).*
- *A negative voltage attracts the Ar ions to the target.*
- *Plasma used for sputtering can be AC or DC generated.*
- *Deposition process can be purely physical or it can be physical and chemical.*