

ChE 6842 - Developments and Applications of Nanostructured Materials

Instructor: Hongta Yang (hyang@nchu.edu.tw), 711 ChE

Lecture: Monday, Period 2-4, 305 ChE

Office hours: Monday, 3 PM-5PM or by appointment.

Website: <http://web.nchu.edu.tw/~hyang/>

References:

- 1). Nanochemistry: A Nanochemistry by Geoffrey A. Ozin and Andre C Arsenault (2005)
- 2). Nanomaterials: Synthesis, Properties and Applications by A. S. Edelstein and R. C. Cammarata (2002)

Course Grading

Midterm Exam:

25 %

Final Exam:

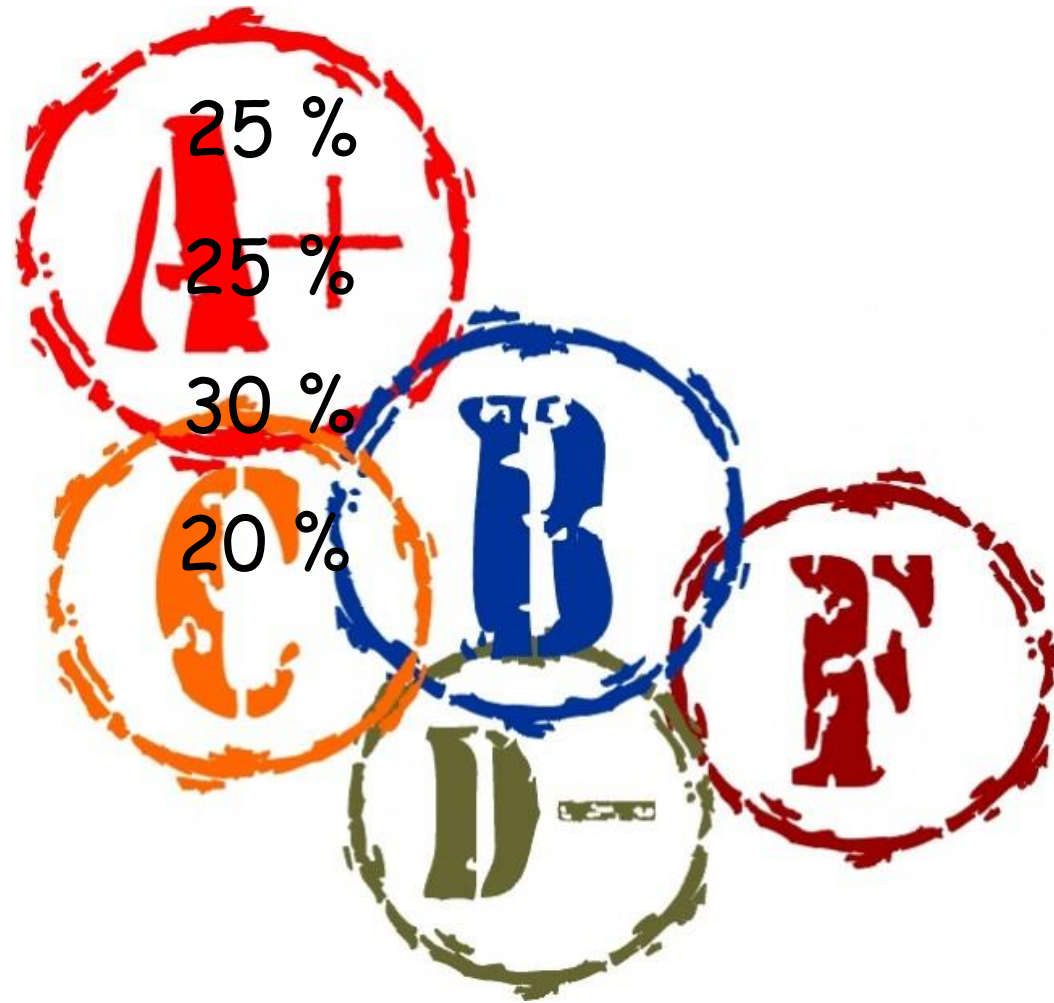
25 %

Presentation:

30 %

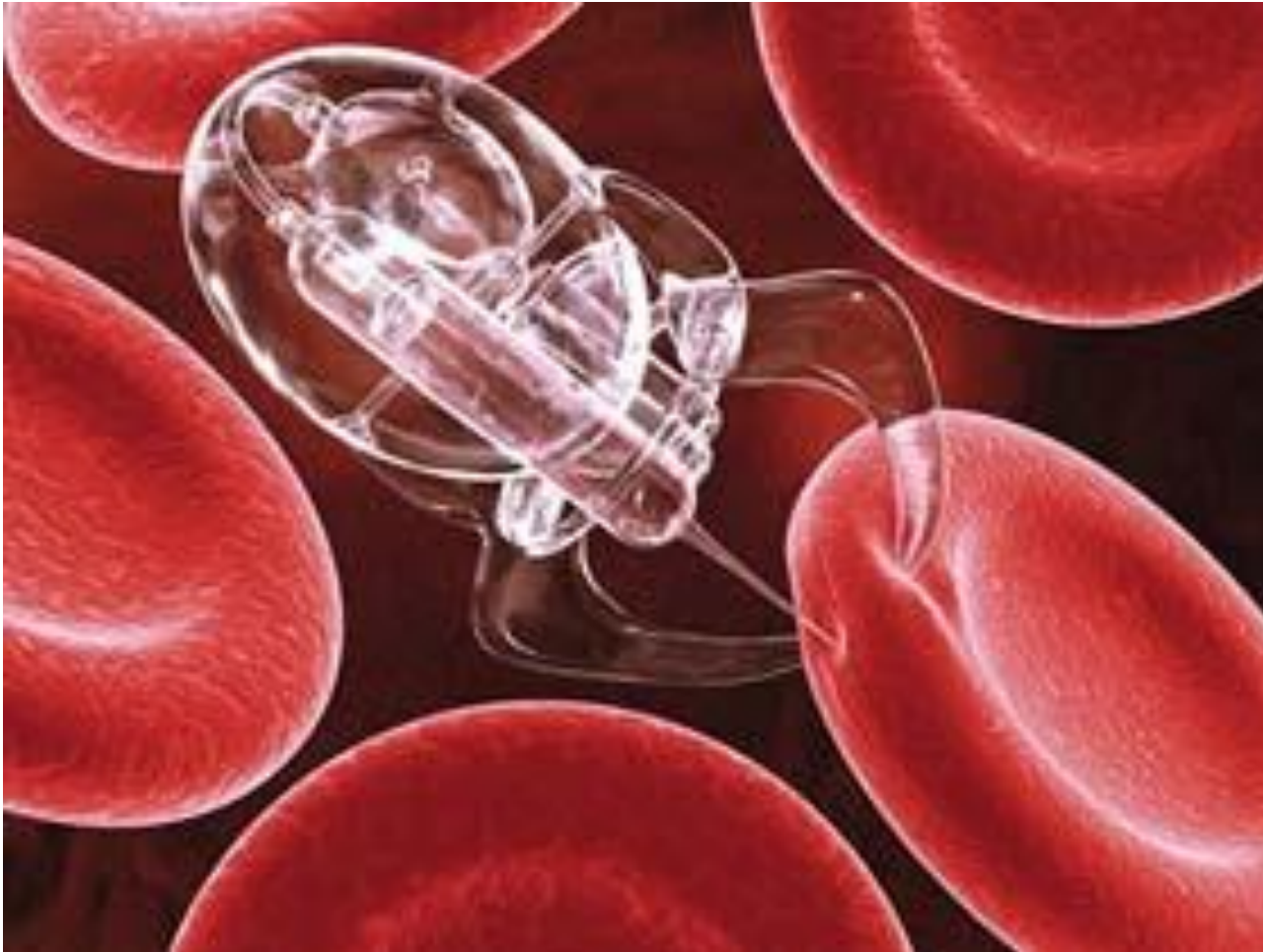
Classroom Performance:

20 %

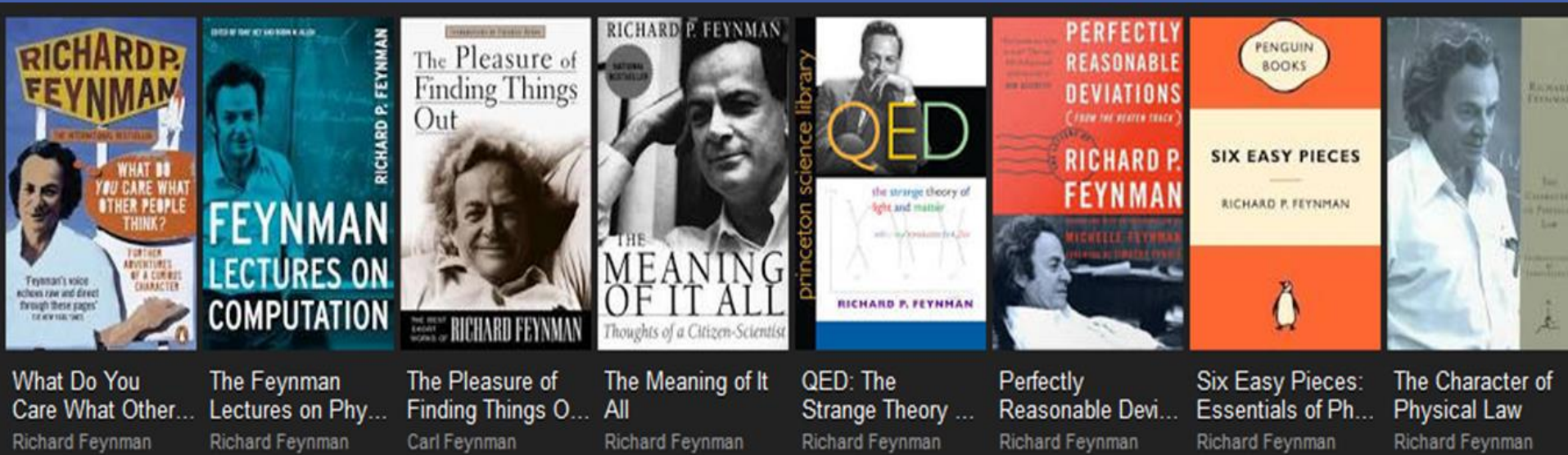


Introduction :

Definition of Nanotechnology



A 55-Year Old Prediction



Nobel Prize Winner Richard Feynman on **nanotechnology** at the physics national conference (AIP):

"There's Plenty of Room at the Bottom"

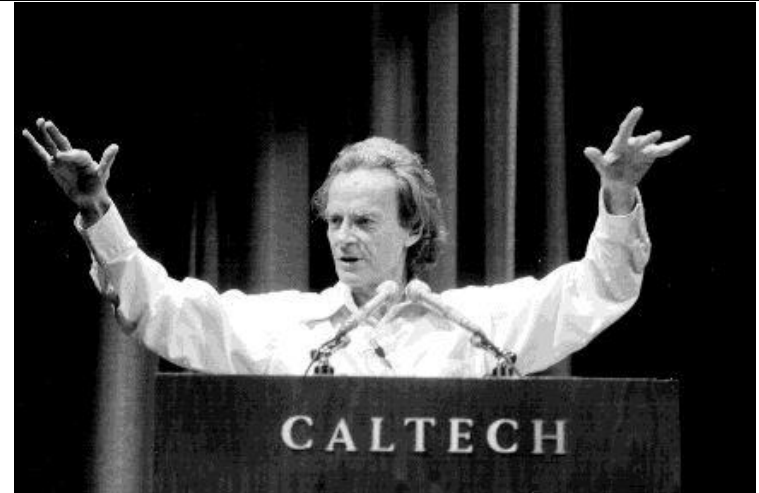
..considered the possibility of direct manipulation of individual atoms as a more powerful form of synthetic chemistry.

..the world of quantum mechanics with discrete energy, wave-like behavior, and statistical existence.



Richard Feynman

Richard Feynman's talk "There's Plenty of Room at the Bottom." at the 1959 meeting of the American Physical Society at Caltech.



There's Plenty of Room at the Bottom
An Invitation to Enter a New Field of Physics

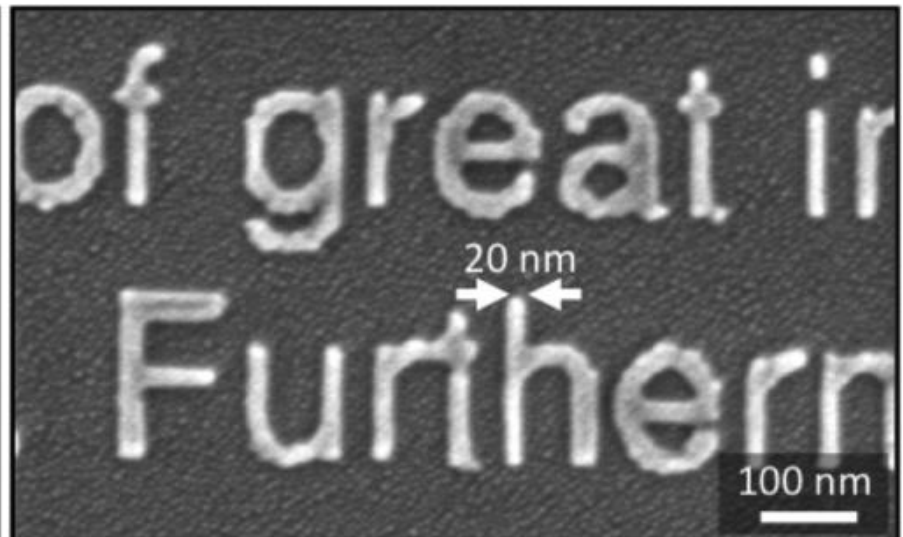
By Richard P. Feynmann

I imagine experimental physicists must often look with envy at men like Kamerlingh Onnes, who discovered a field like low temperature, which seems to be bottomless and in which one can go down and down. Such a man is then a leader and has some temporary monopoly in a scientific adventure. Percy Bridgman, in designing a way to obtain higher pressures, opened up another new field and was able to move into it and to lead us all along. The development of ever higher vacuum was a continuing development of the same kind.

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? 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.

1 μm



The Scale of Things: Nanometers and More

Things Natural

Ant
~5 mm

Dust mite
200 μm

Human hair
~60-120 μm wide

Fly ash
~10-20 μm

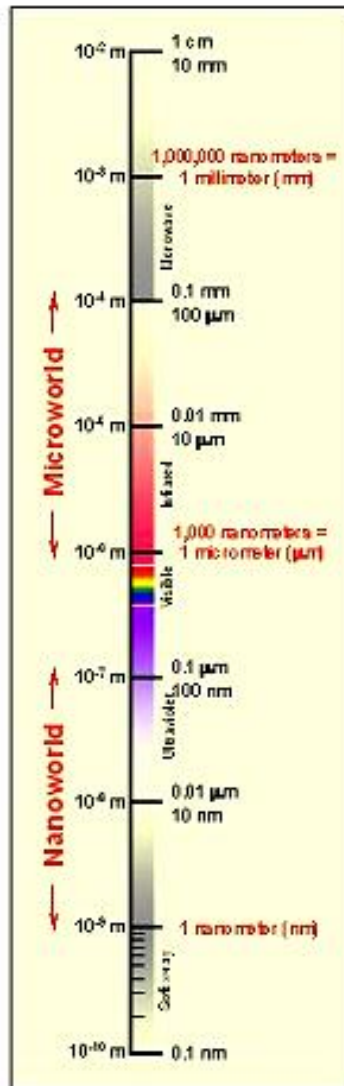
Red blood cells with white cell
~2-5 μm

~10 nm diameter

ATP synthase

DNA
~2-12 nm diameter

Atoms of silicon
spacing ~tenths of nm



Things Manmade

Head of a pin
1-2 mm

MicroElectro Mechanical (MEMS) devices
10 - 100 μm wide

Pollen grains
Red blood cells

Zone plate x-ray "lens"
Outerring spacing ~35 nm

Self-assembled,
Nature-inspired structure
Many 10s of nm

Nanotube electrode

Quantum dots of 48 iron atoms on copper surface
positioned one at a time within STM tip
Conical diameter 14 nm

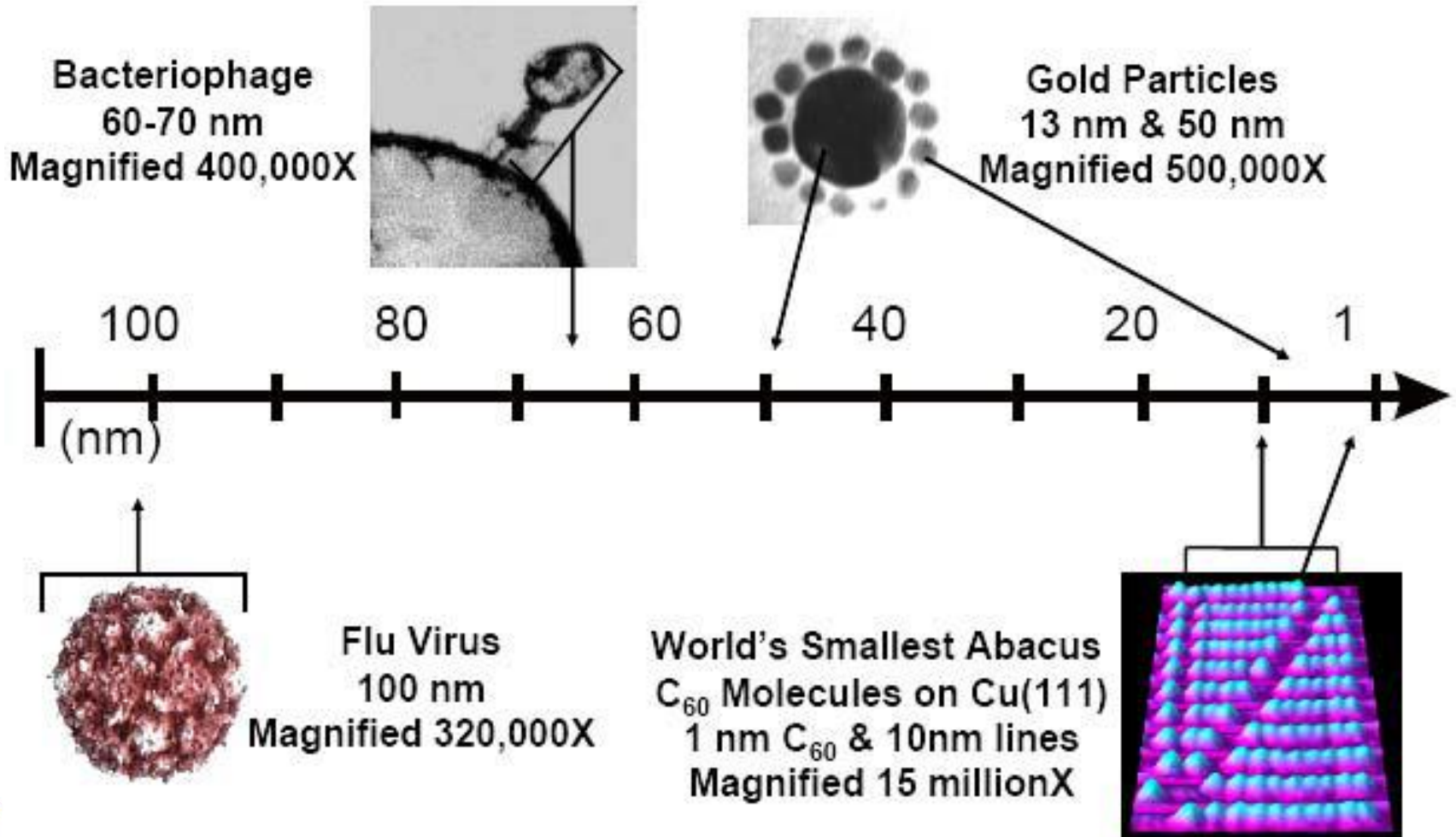
Carbon buckyball
~1 nm diameter

Carbon nanotube
~1.3 nm diameter

The Challenge

*Fabricate and combine
nanoscale building
blocks to make useful
devices, e.g., a
photocatalytic reaction
center with a catalytic
semiconductor layer, etc.*

Magnified "Nano" Length Scale

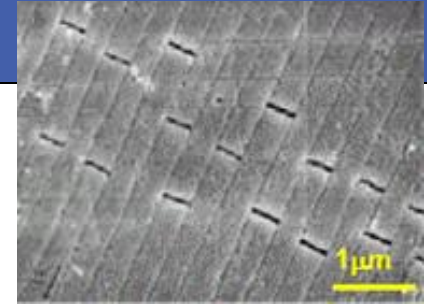


Definition of Nanotechnology

- It is the understanding and control of matter at dimensions of roughly **1 to 100 nanometers**, where unique phenomena enable novel applications.
- It involves imaging, measuring, modeling, and manipulating matter at this length scale.
- 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 is directed toward **understanding and creating** improved materials, devices, and systems that exploit these new properties.



Surprises at the Nanoscale

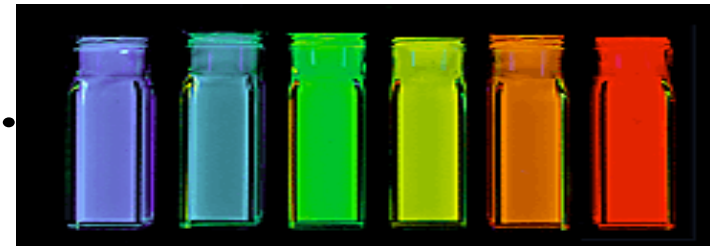


- **Ceramics are brittle.**

Seashell's nano structure gives 3000x damage tolerance.

- **Color is inherent to a material.**

Quantum Dots' color depends on size.



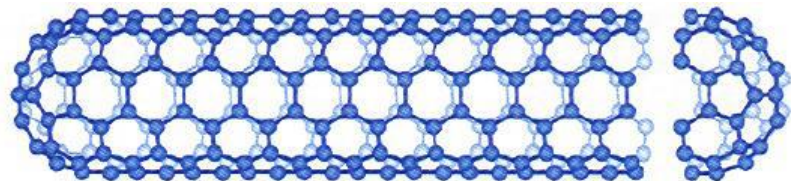
- **Liquids act like liquids.**

Magnetic nanoparticle solutions have shape.

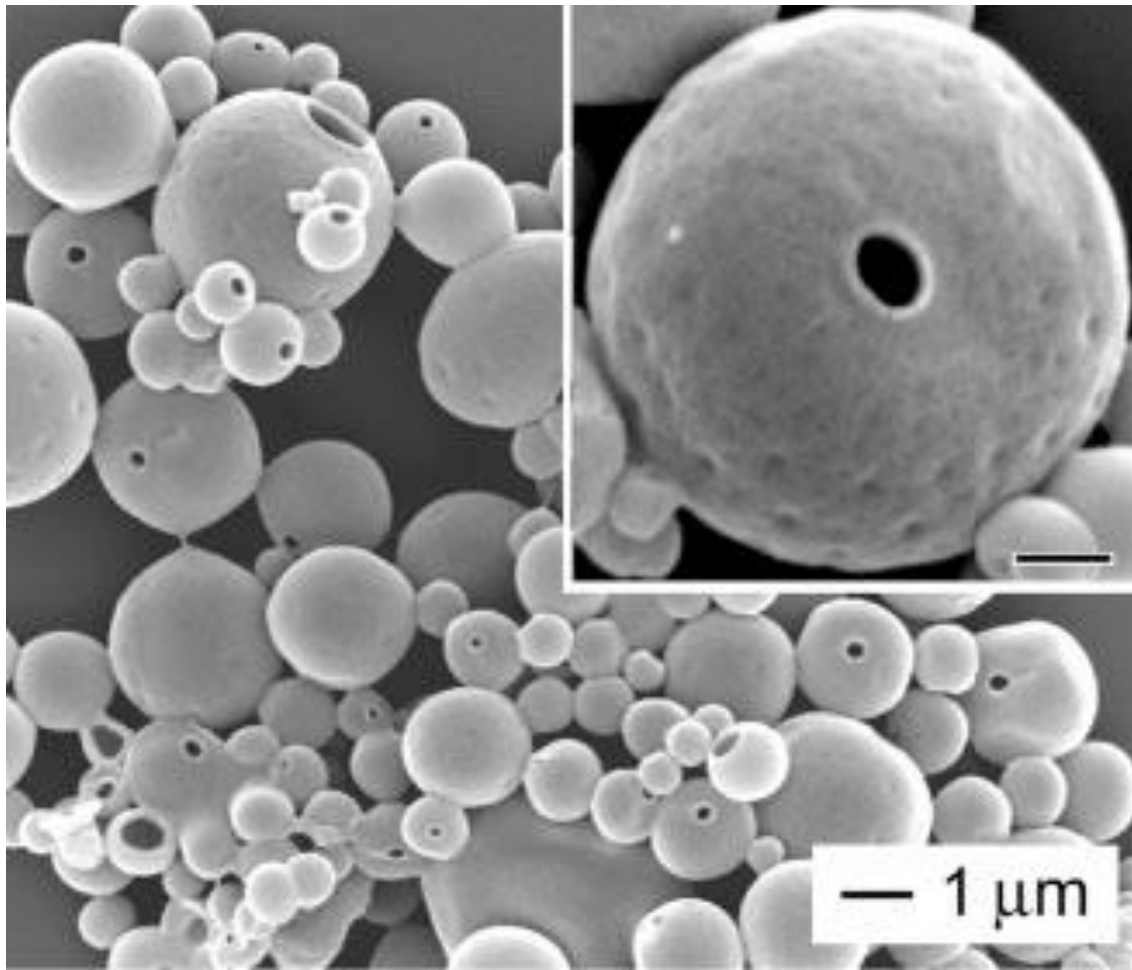


- **Copper & Silver are best electrical conductors.**

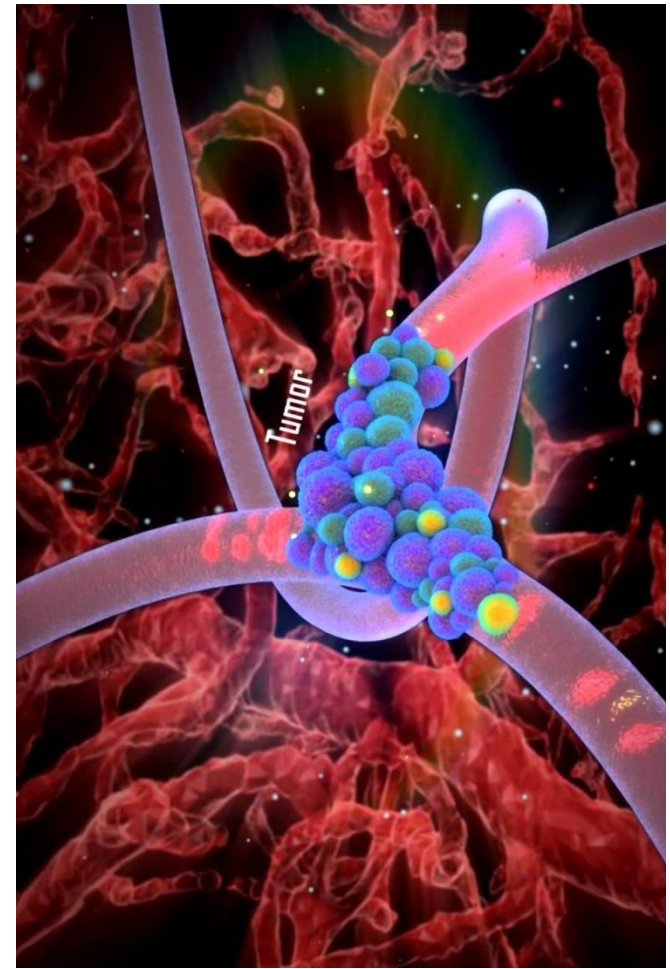
Carbon nanotubes are ballistic



Microscale vs. Nanoscale



Microscale Fish Bowl



Drug Delivery

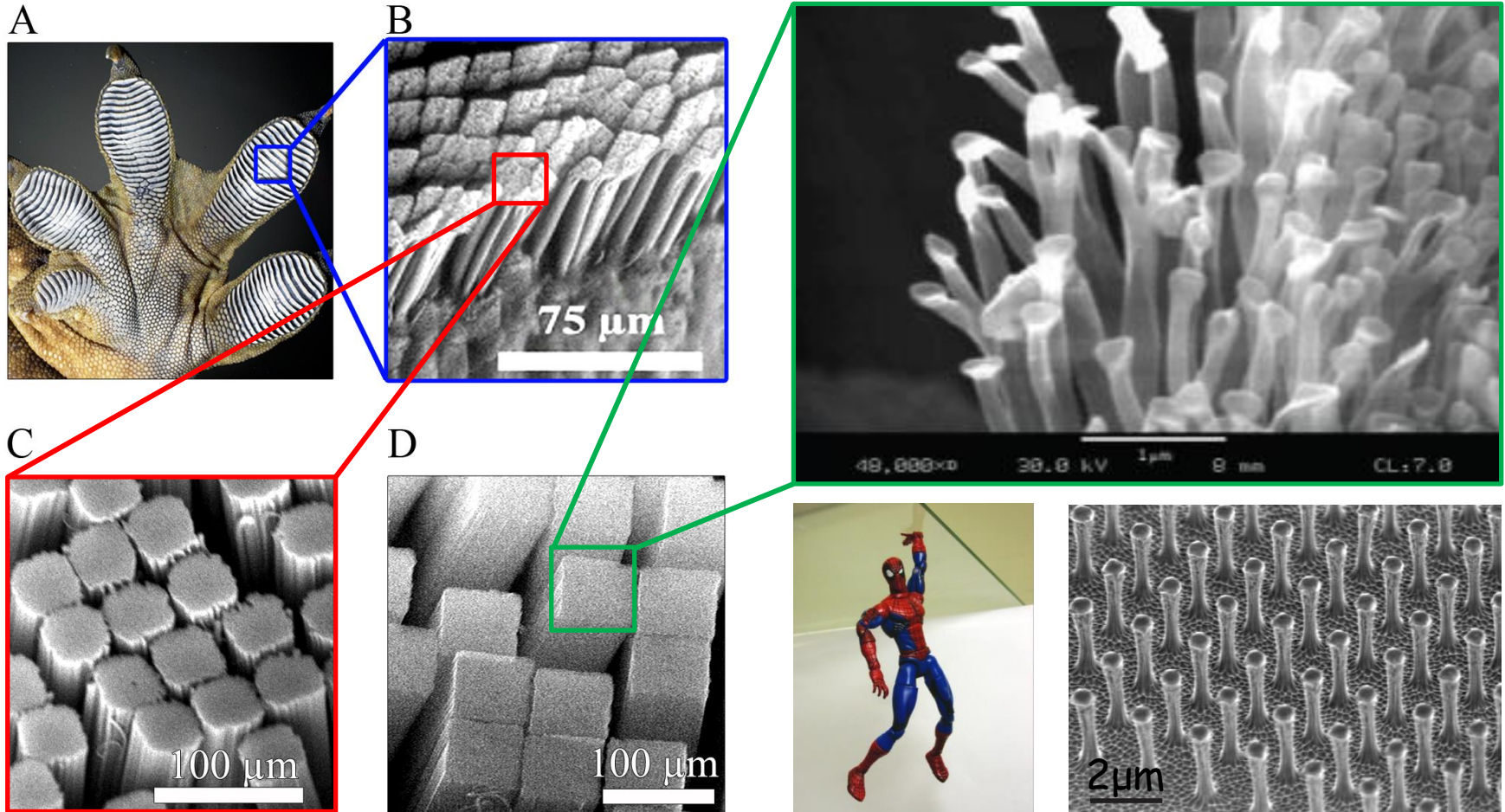
Nature is the Ultimate Nanotechnologist



Dry Adhesive (Gecko Feet)



Learning from Nature - Form is Function



"Gecko" Adhesive

Geim, A. K. et al, *Nature Letters* (2003)

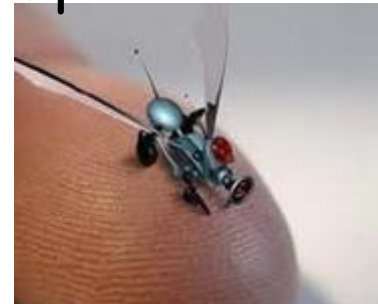


Timeline for Beginning Industrial Nanotechnology

Prototyping and Commercialization

- **First Generation:** passive nanostructures. in coatings, nanoparticles, bulk materials (nanostructured metals, polymers, ceramics):
~ 2001 —
- **Second Generation:** active nanostructures. such as transistors, amplifiers, targeted drugs and chemicals, actuators, adaptive structures:
~ 2005 —
- **Third Generation:** 3D nanosystems and systems of systems. with heterogeneous nanocomponents, complex networking and new architectures:

~2010 —



Alien Technology's Fluidic Self-Assembly



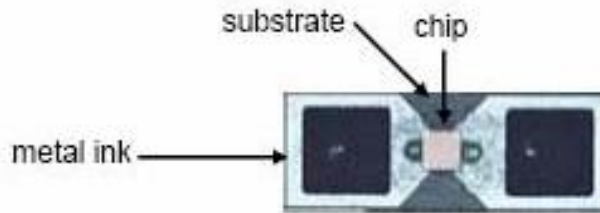
- 1. Wafer Fab**
Processed Silicon Wafers containing chips



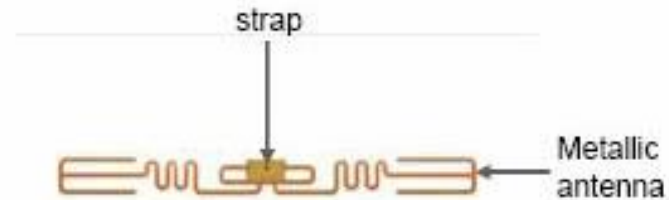
- 2. "NanoBlock" IC's**
Chip or Integrated Circuit is cut into a specific shape from the wafer



- 3. Fluidic Self-Assembly (FSA)**
Chips are placed into an indented plastic substrate



- 4. Strap**
Metal is printed on the substrate to connect to the chip, creating a strap



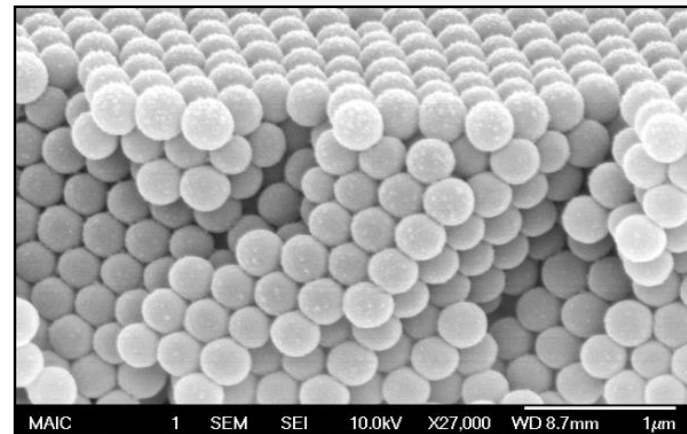
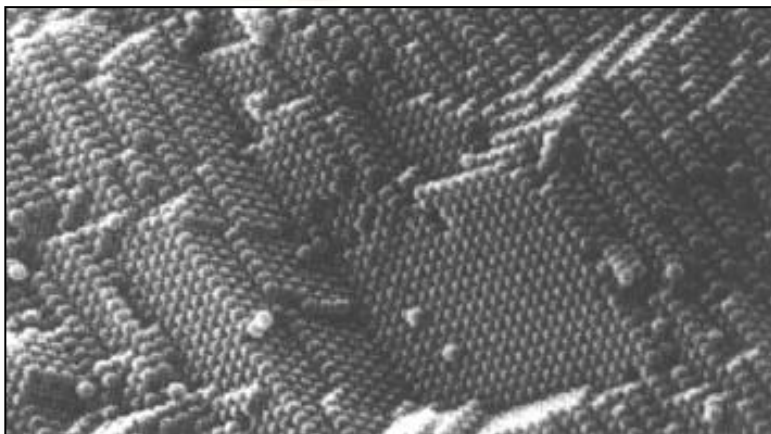
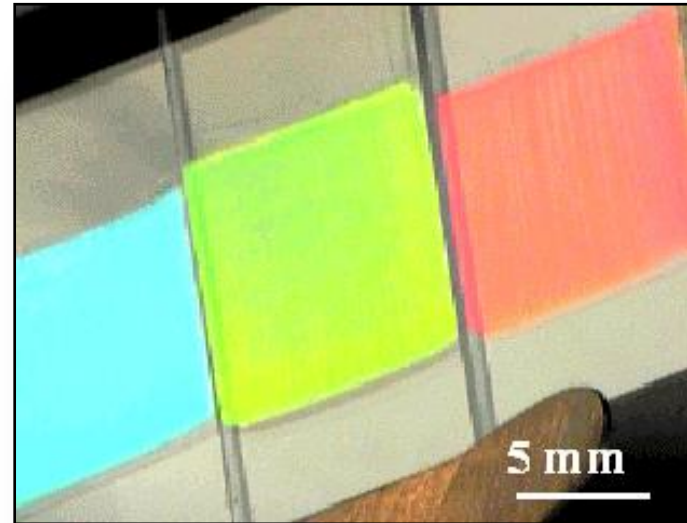
- 5. Inlay**
The strap is then attached to a metallic antenna and attached to an adhesive label – making an RFID tag

- \$0.5/piece radio frequency identification (RFID)
- 10B tags/yr production capacity



Bottom-Up Fabrication

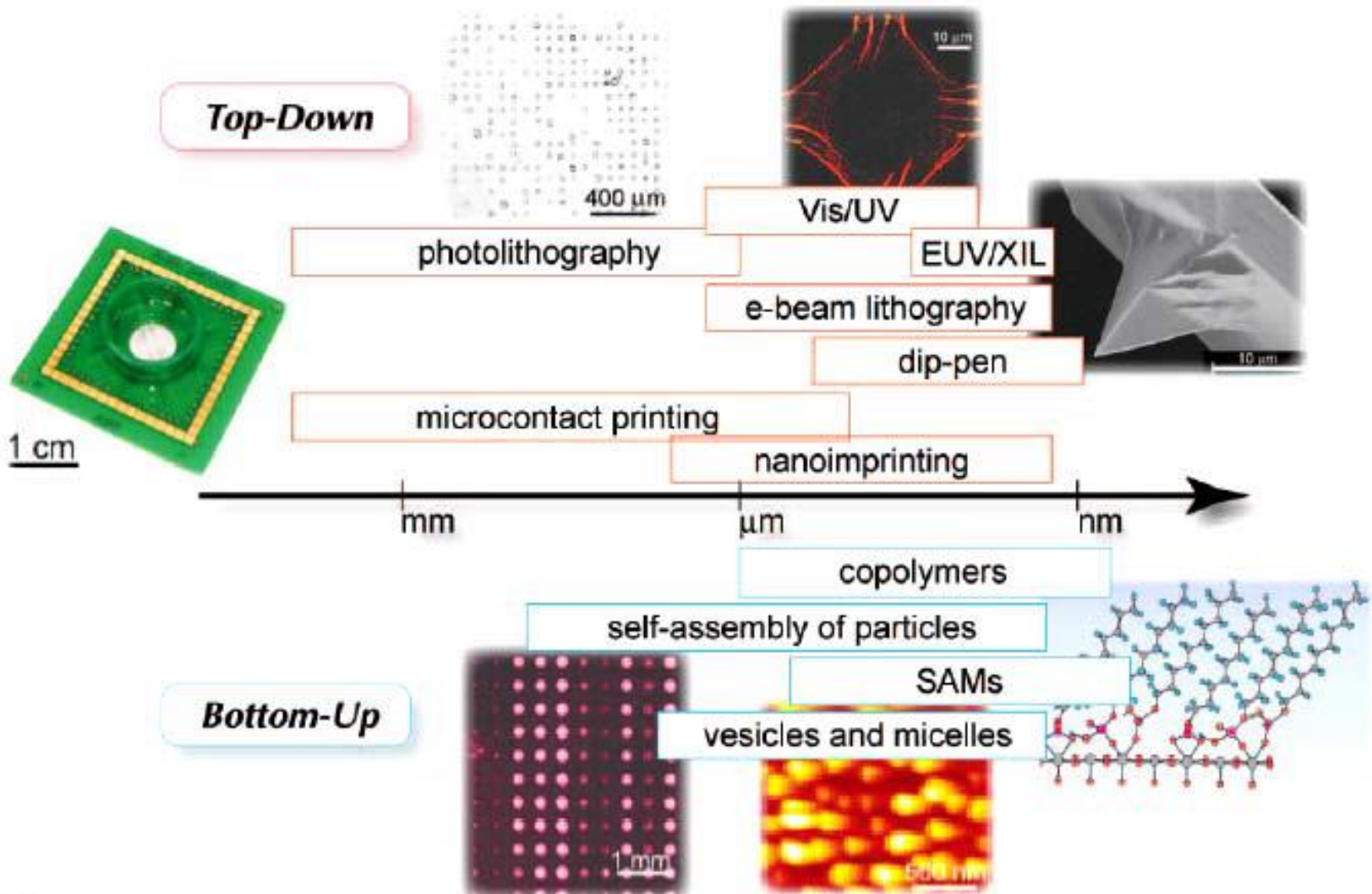
Bottom-Up Self-Assembly



(<http://aussie-opal.com/lr2mulbl.jpg>)

Jiang, P. et al, *Chem. Mater.* (1999)

Current Patterning Technologies



(MRS Bulletin, 30, 202, 2005)



What Does Assembly Mean?



Storage Unit



Picky Style

or



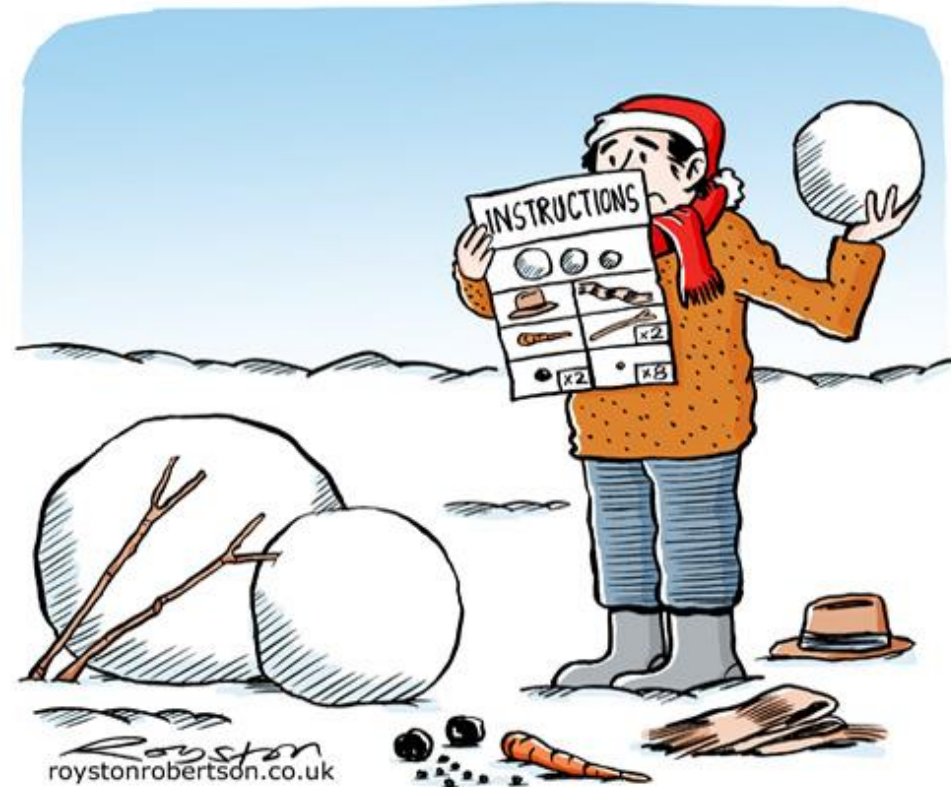
Free Style



What Does Self-Assembly Mean?



Pyramid



I need a "Self-Assembly" technology.

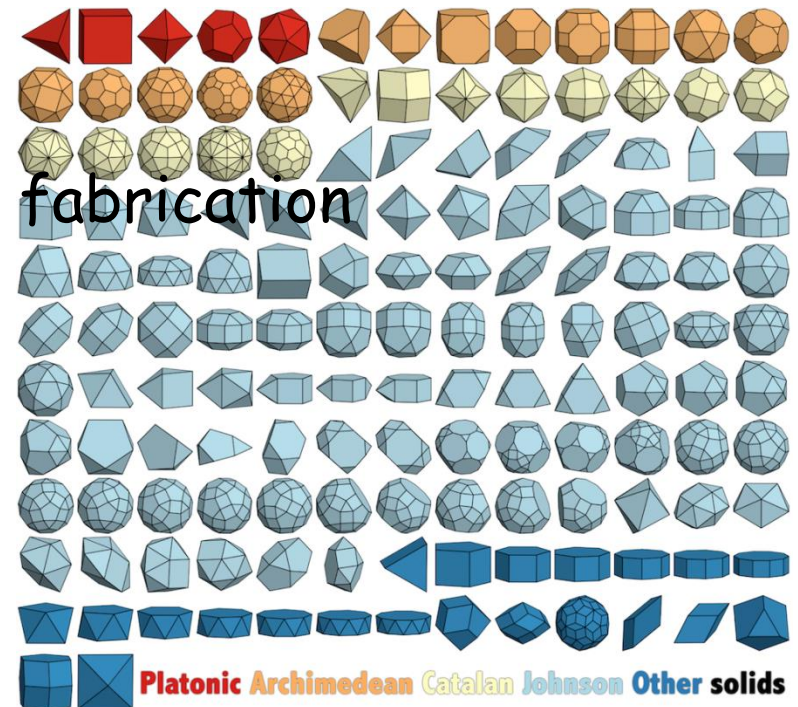


Why Shall We Care About Self-Assembly?

Advantages of Self-Assembly Over

Top-Down Fabrication:

- Inexpensive - less equipment investment
- Simple to implement
- Inherently parallel - large scale fabrication
- High throughput



5 Principles Governing Self-Assembly

1. Building blocks, scale, shape, surface structure.
2. Attractive and repulsive interactions between building blocks, equilibrium separation
3. Reversible association-dissociation and/or adaptable motion of building blocks in assembly, lowest energy structure.
4. Building block interactions with solvents, interfaces, templates.
5. Building-block dynamics, mass transport and agitation.

OBEY
THE  RULES



Molecular vs. Materials Self-Assembly

Driving Forces:

- Molecular self-assembly: ionic, covalent, hydrogen, non-covalent and metal-ligand bonding interactions.

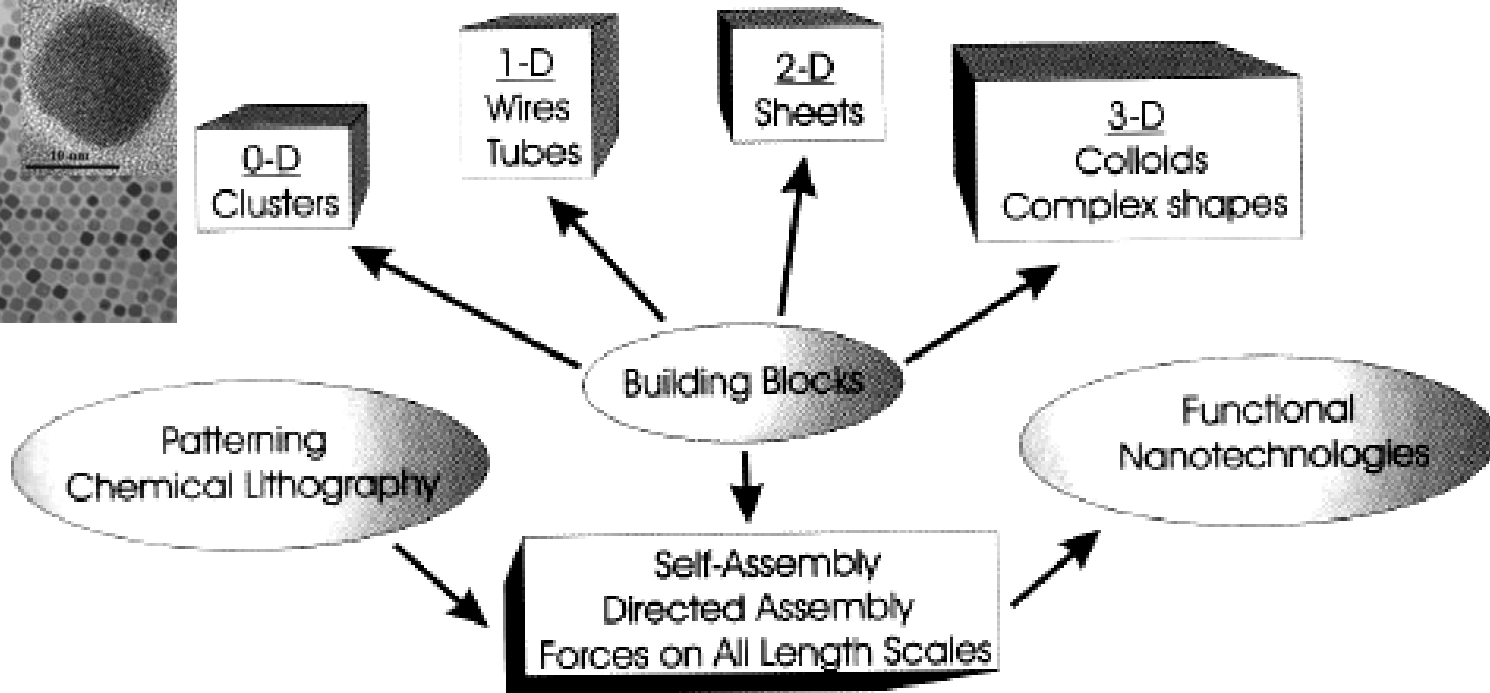
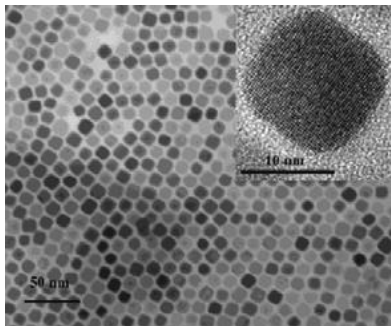
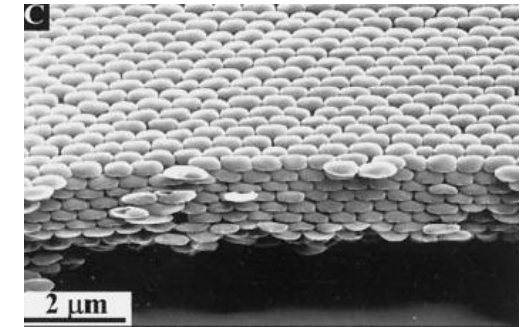
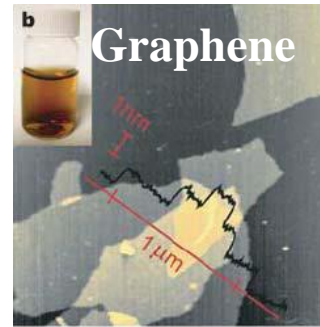
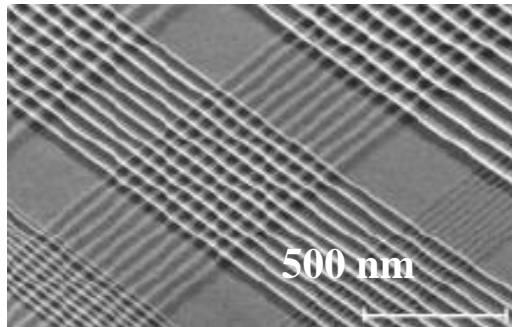
Lower free energy & greater structural stability



- Materials self-assembly: capillary, colloidal, elastic, electric, magnetic and shear, etc.

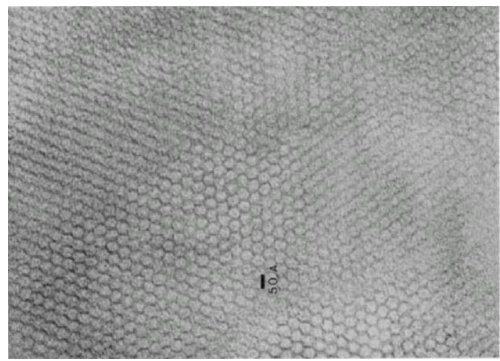


Scope of Material Self-Assembly

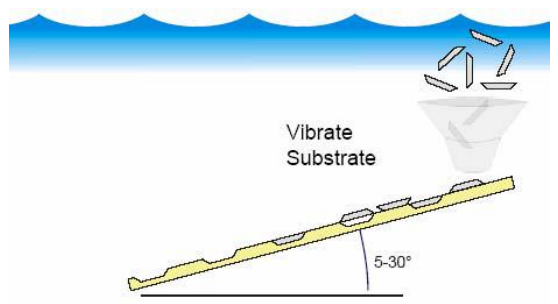


Directing and Hierarchical Self-Assembly

Directing Assembly

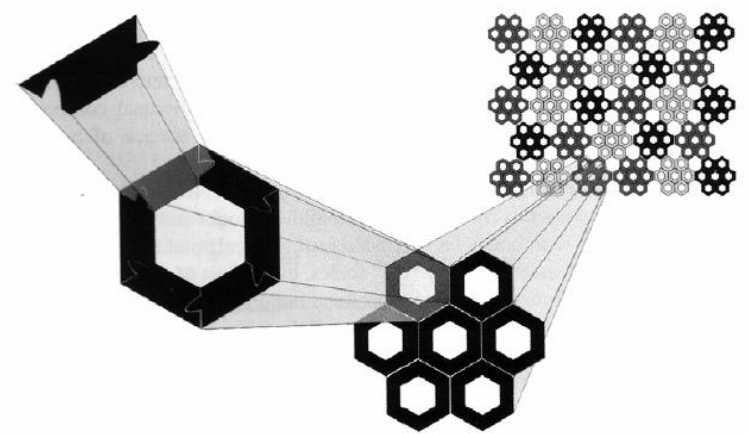


Type I. Structure-directing additives induced assembly



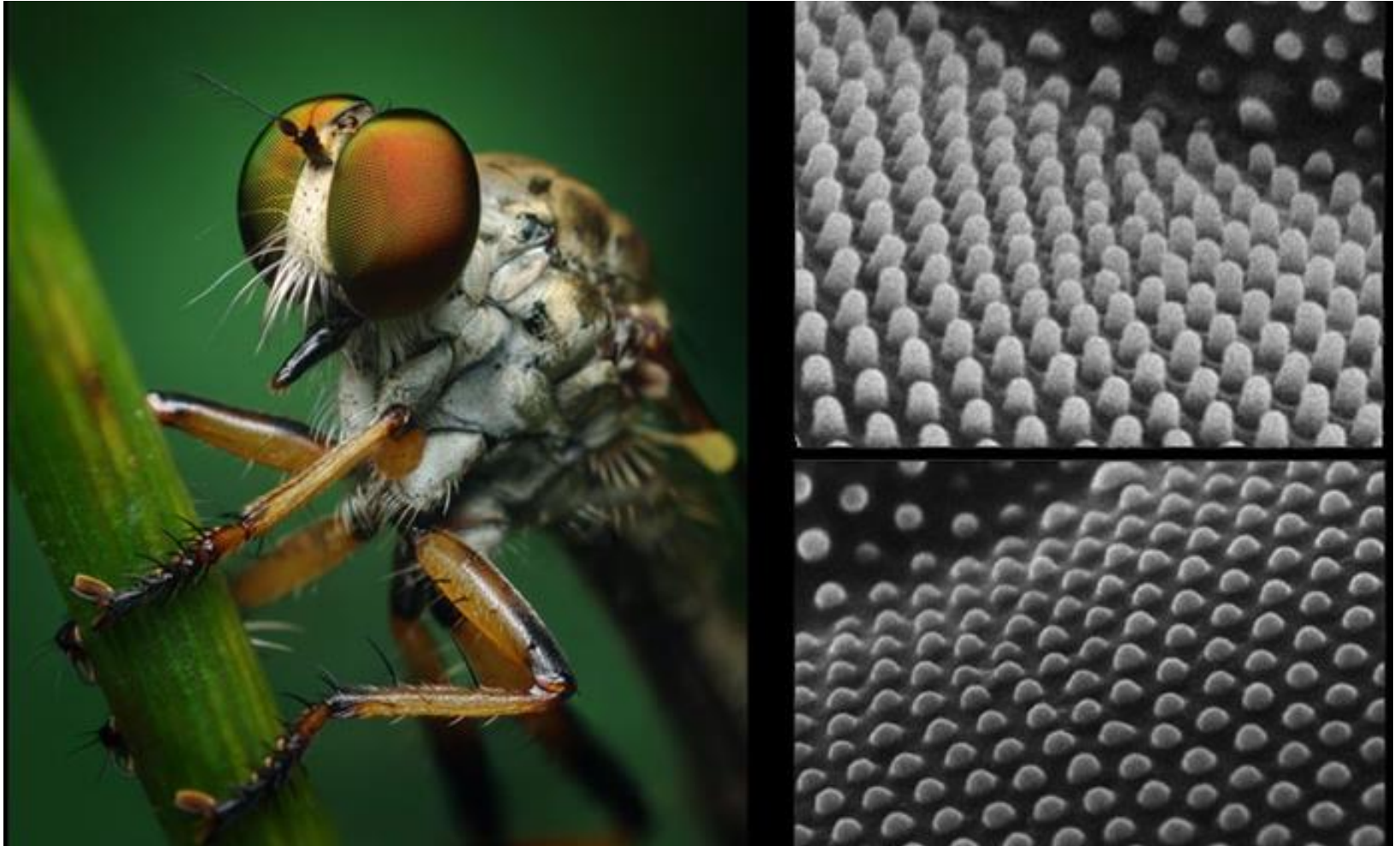
Type II. Template directed assembly

Hierarchical Assembly



Primary building blocks associate into more complex secondary structures that are integrated into the next size level in the hierarchy.

Dragonfly Compound Eyes



Directing and Hierarchical Self-Assembly

- **Web of Science (literature search engine):**
<http://portal.isiknowledge.com/?DestApp=WOS&Func=Frame>
- **Journals:**
 - ◆ Nano Letters
<http://pubs.acs.org/journals/nalefd/index.html>
 - ◆ Small
<http://www3.interscience.wiley.com/cgi-bin/jhome/107640323>
- **Websites:**
 - ◆ National Nano Initiative
<http://www.nano.gov/>
 - ◆ Nanotechnology on Zyvex:
<http://www.zyvex.com/nano/>

