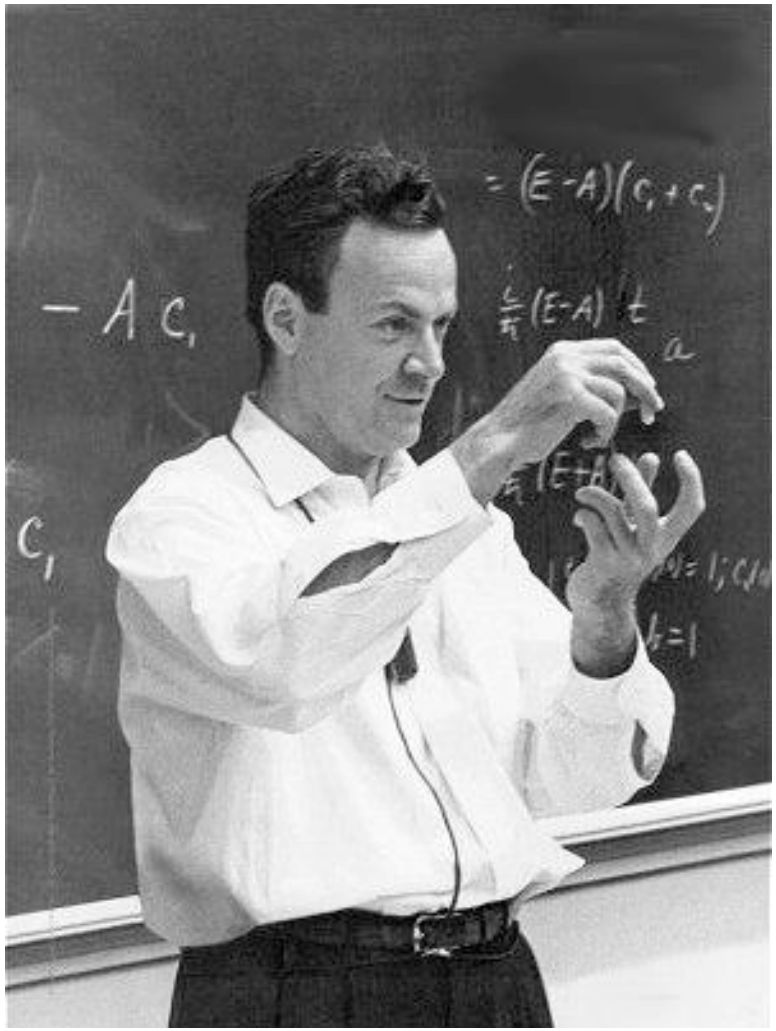
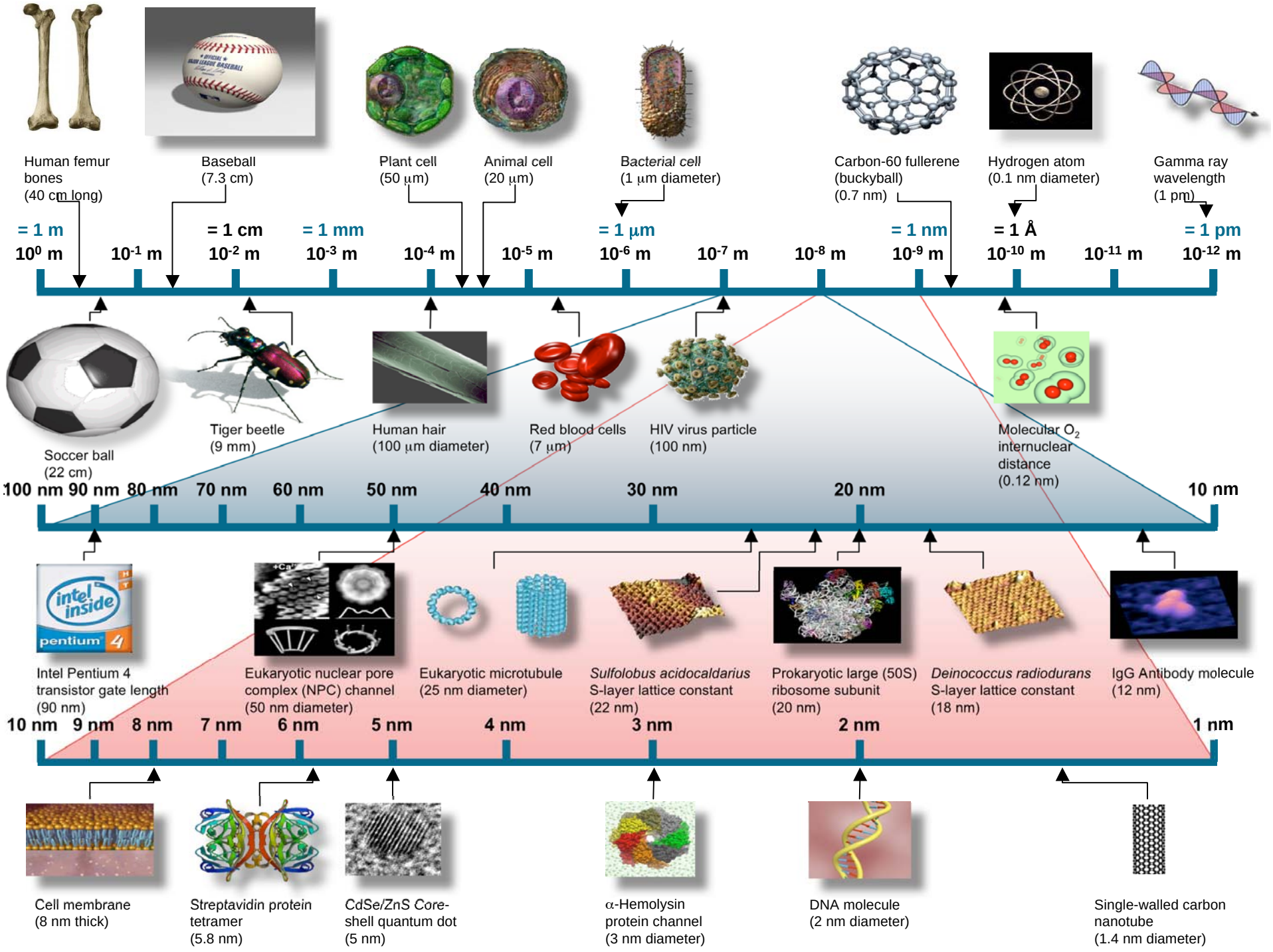
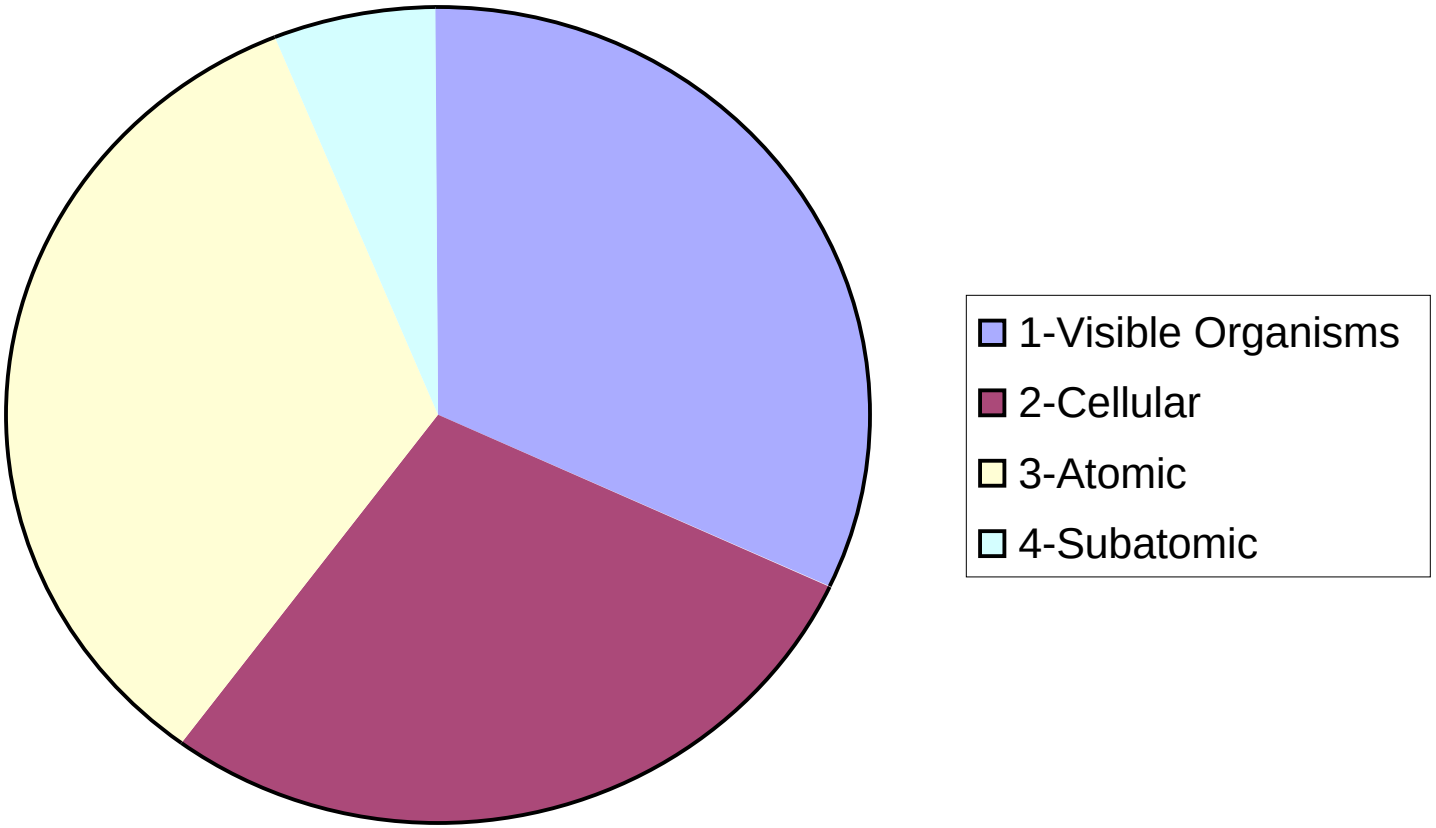
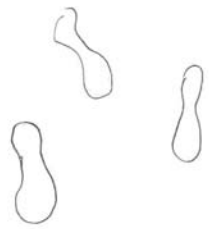
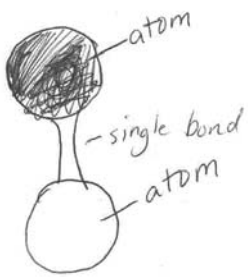
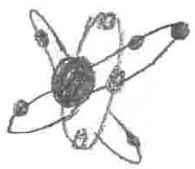
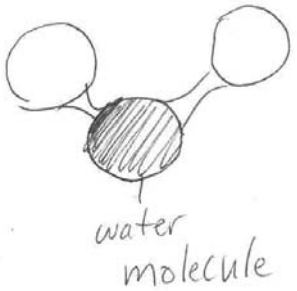

= (E-A)(C, + C,)
− A C,
C,

- All things are made of atoms.
- At the nanometer scale, atoms are in constant motion.
- Molecules have size and shape.
- Molecules and their environment make the properties at the nanometer scale unique

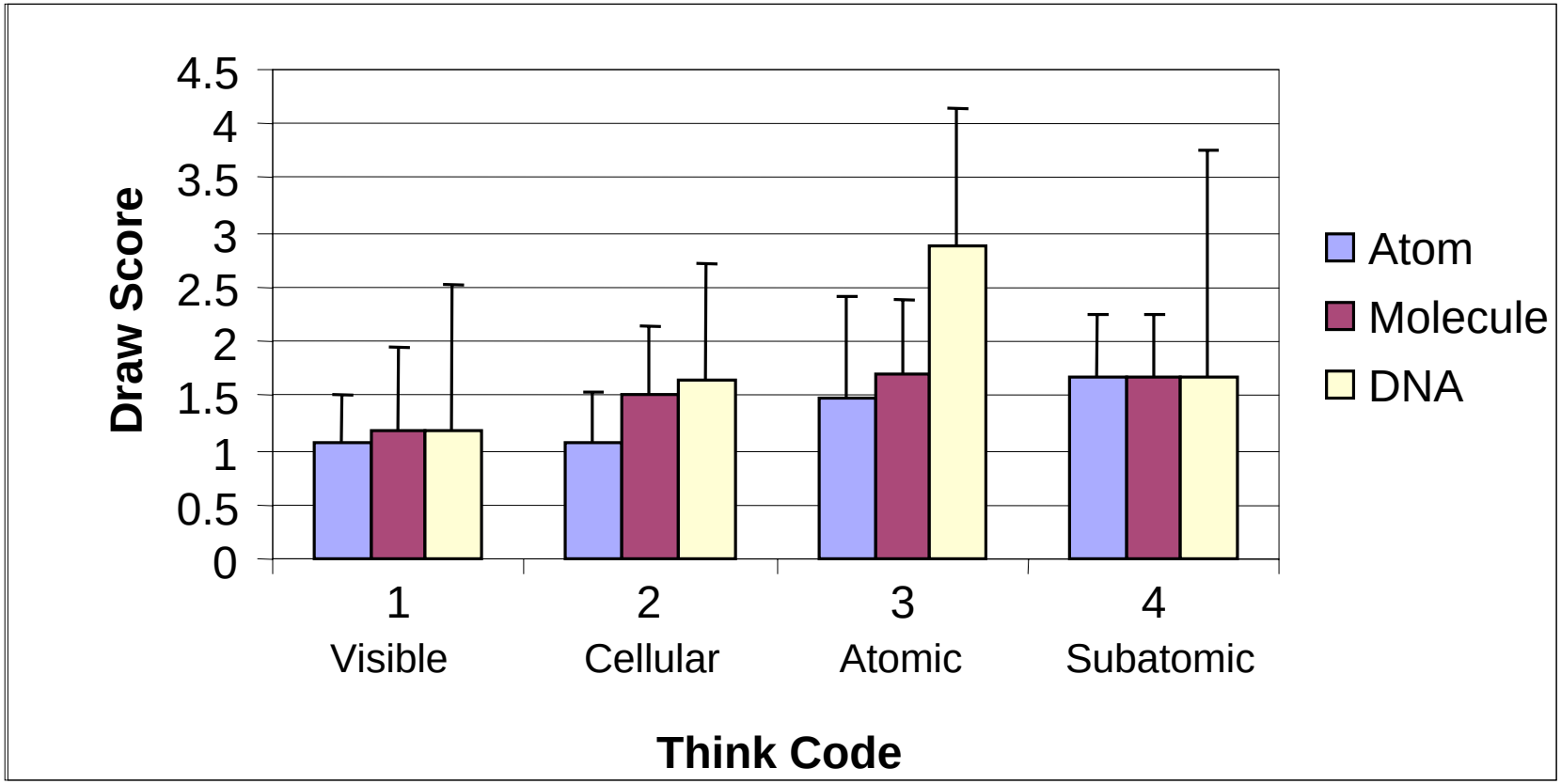

Human femur bones (40 cm long)
Baseball (7.3 cm)
Plant cell (50 μm)
Animal cell (20 μm)
Bacterial cell (1 μm diameter)
Carbon-60 fullerene (buckyball) (0.7 nm)
Hydrogen atom (0.1 nm diameter)
Gamma ray wavelength (1 pm)
= 1 m
10^0 m
10^-1 m
= 1 cm
10^-2 m
= 1 mm
10^-3 m
10^-4 m
10^-5 m
= 1 μm
10^-6 m
10^-7 m
10^-8 m
= 1 nm
10^-9 m
= 1 Å
10^-10 m
10^-11 m
= 1 pm
10^-12 m
Soccer ball (22 cm)
Tiger beetle (9 mm)
Human hair (100 μm diameter)
Red blood cells (7 μm)
HIV virus particle (100 nm)
Molecular O2 internuclear distance (0.12 nm)
100 nm
90 nm
80 nm
70 nm
60 nm
50 nm
40 nm
30 nm
20 nm
10 nm
Intel Pentium 4 transistor gate length (90 nm)
Eukaryotic nuclear pore complex (NPC) channel (50 nm diameter)
Eukaryotic microtubule (25 nm diameter)
Sulfolobus acidocaldarius S-layer lattice constant (22 nm)
Prokaryotic large (50S) ribosome subunit (20 nm)
Deinococcus radiodurans S-layer lattice constant (18 nm)
IgG Antibody molecule (12 nm)
10 nm
9 nm
8 nm
7 nm
6 nm
5 nm
4 nm
3 nm
2 nm
1 nm
Cell membrane (8 nm thick)
Streptavidin protein tetramer (5.8 nm)
CdSe/ZnS Core-shell quantum dot (5 nm)
α-Hemolysin protein channel (3 nm diameter)
DNA molecule (2 nm diameter)
Single-walled carbon nanotube (1.4 nm diameter)

What is the smallest thing you can think of?



	Gianinna, Age 10	Cliva, Age 11	Kelly, Age 12	Anthony, Age 13
Draw an atom:				
Draw a molecule:				
Draw DNA:				

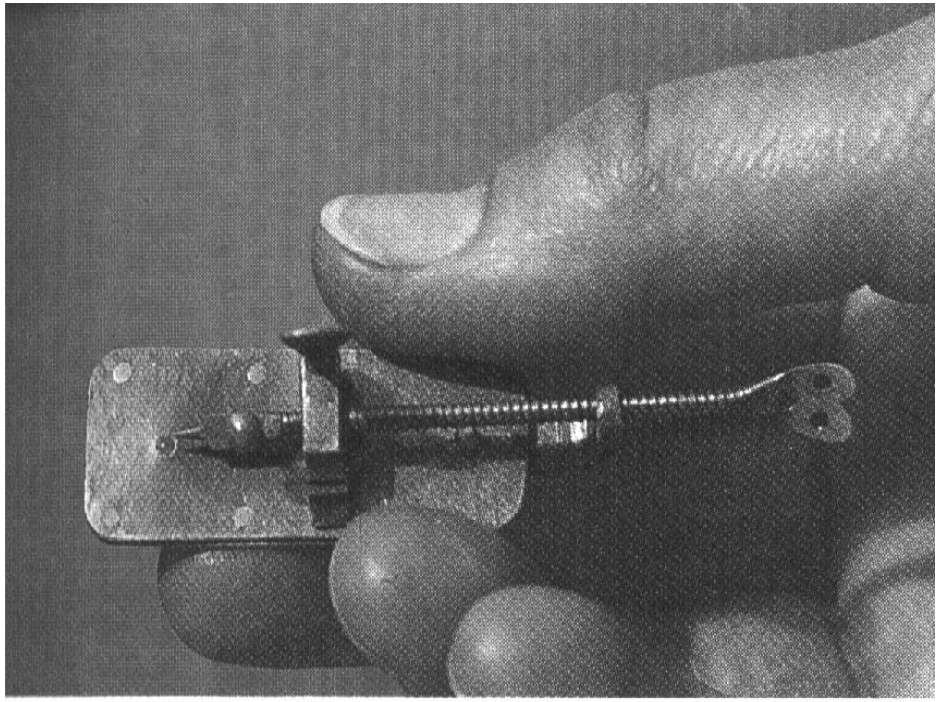
What is the smallest thing you can think of vs. Drawing Atom, Molecule & DNA

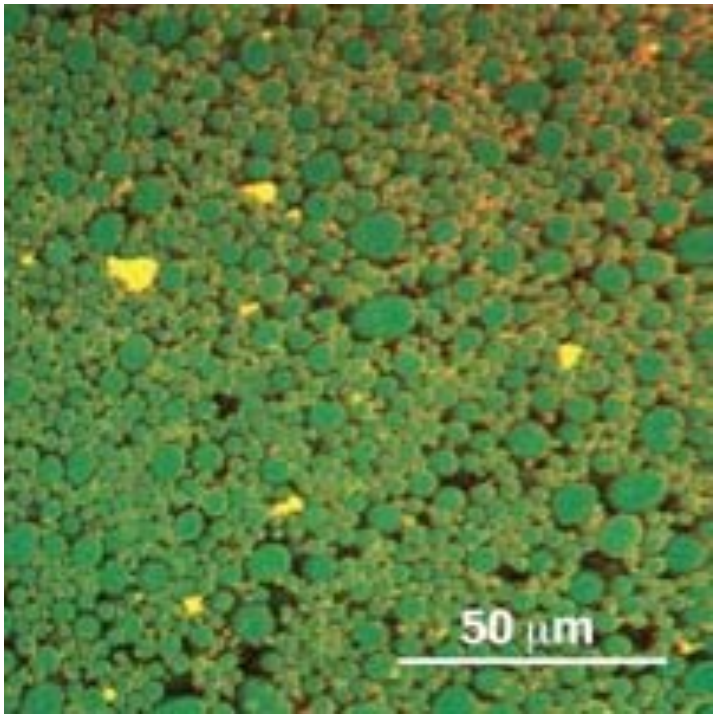


Too Small to See

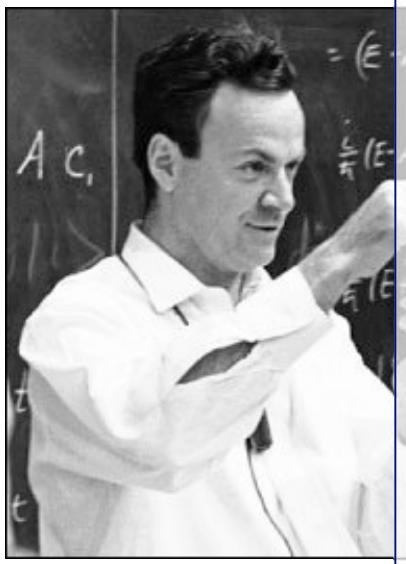
- How do we *see* things too small to see?
- How do we *make* things too small to see?

Seeing and making



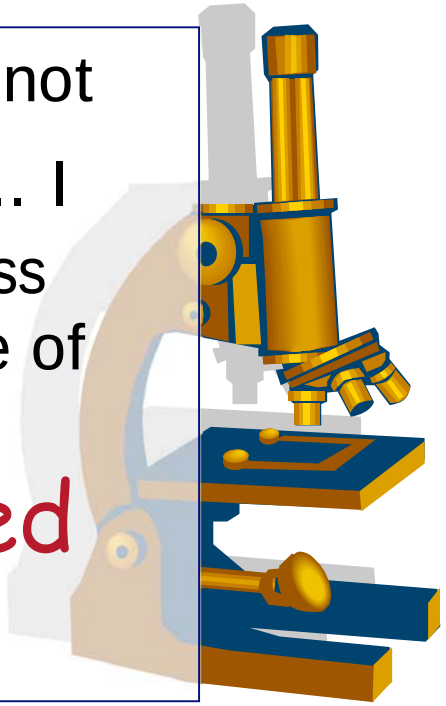


How do we see things?

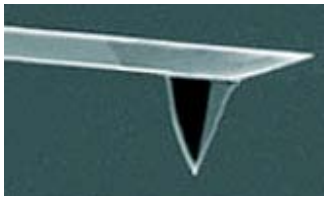


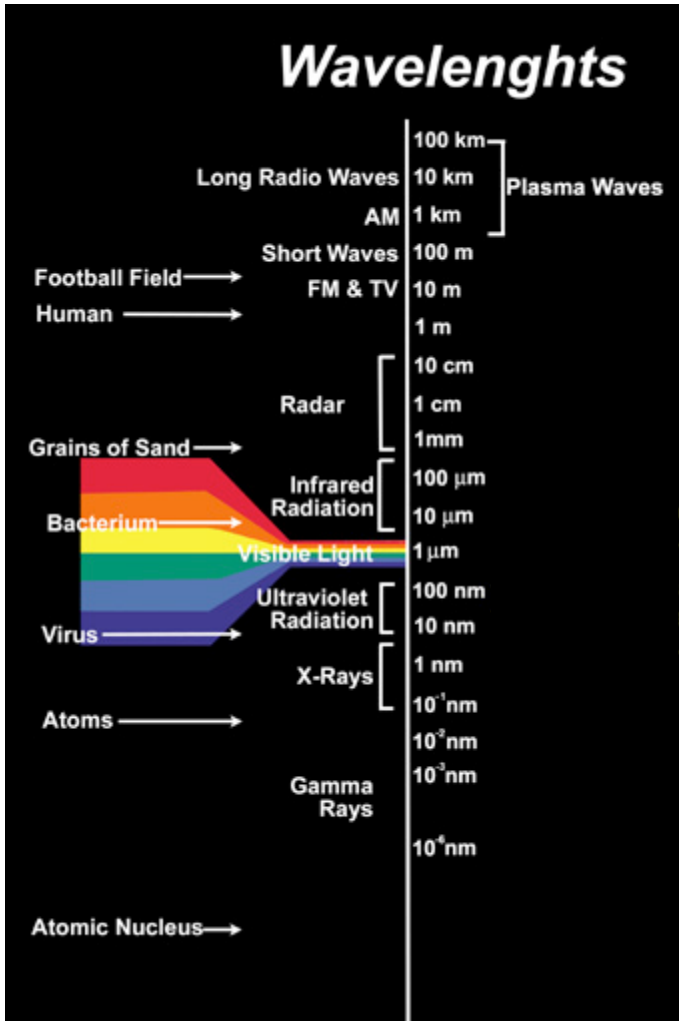
Richard Feynman
1959….

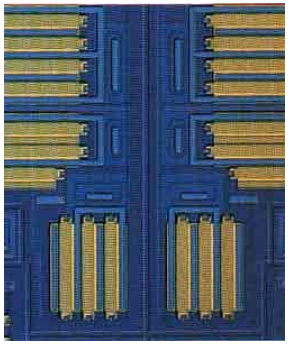
The electron microscope is not quite good enough….. I would like to try and impress upon you ... the importance of improving the electron microscope by a hundred times.

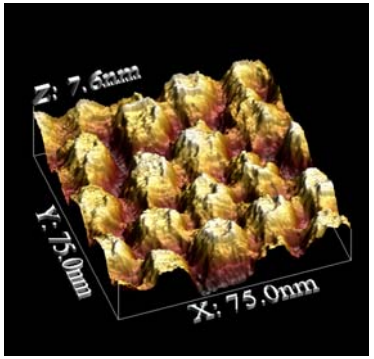


Seeing the world too small to

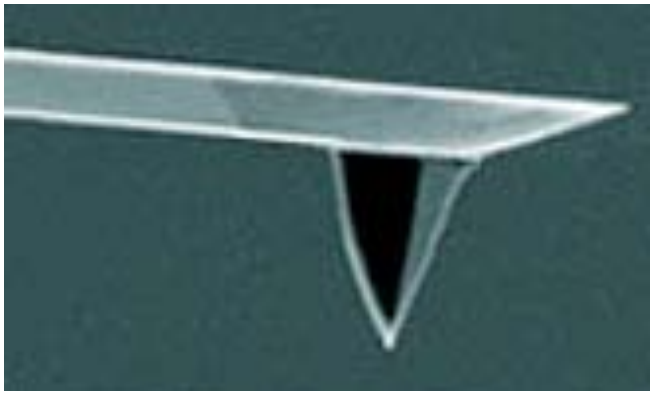


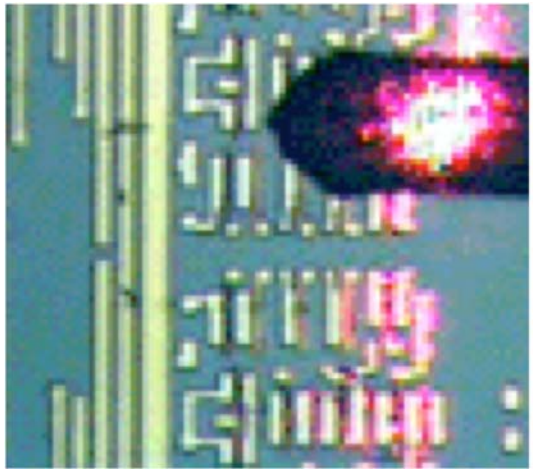




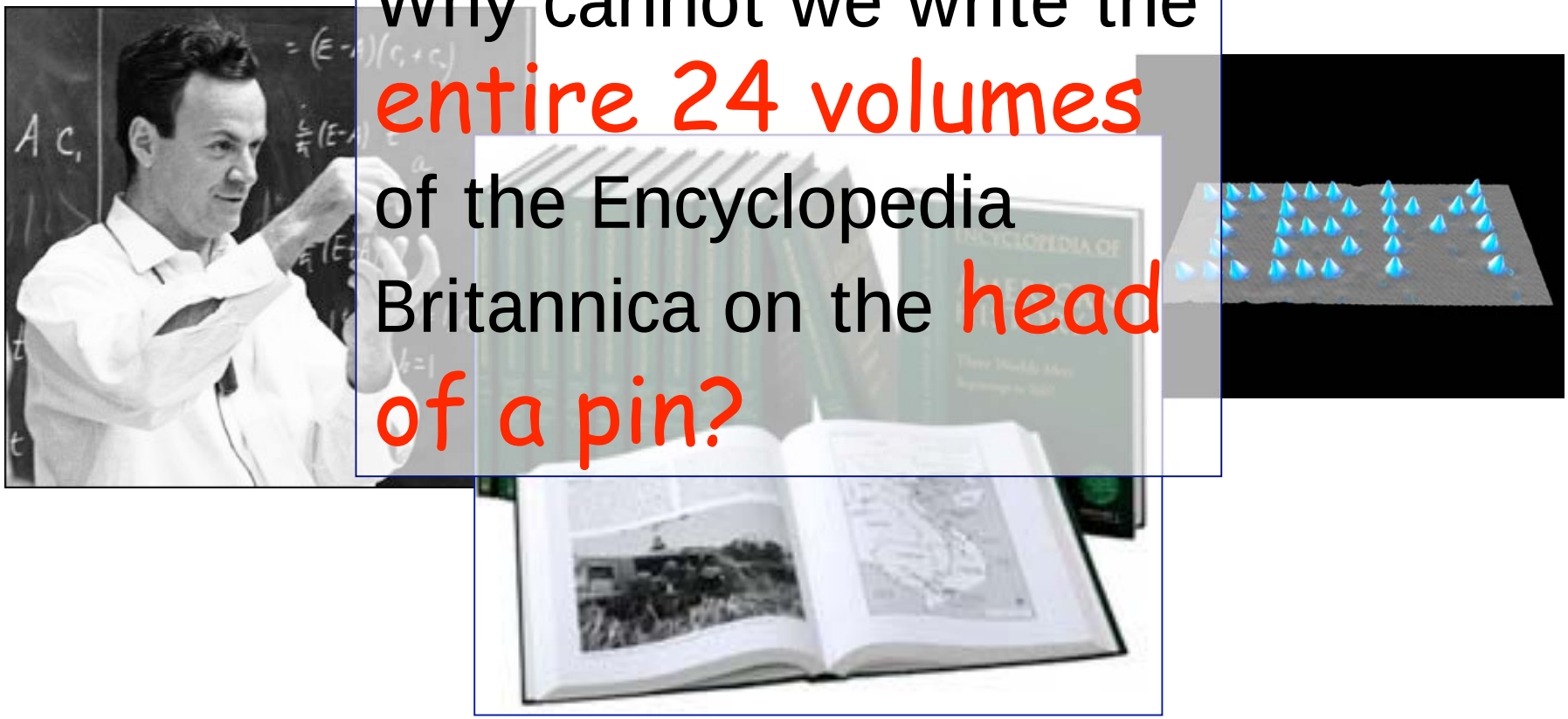


Even more powerful microscopes



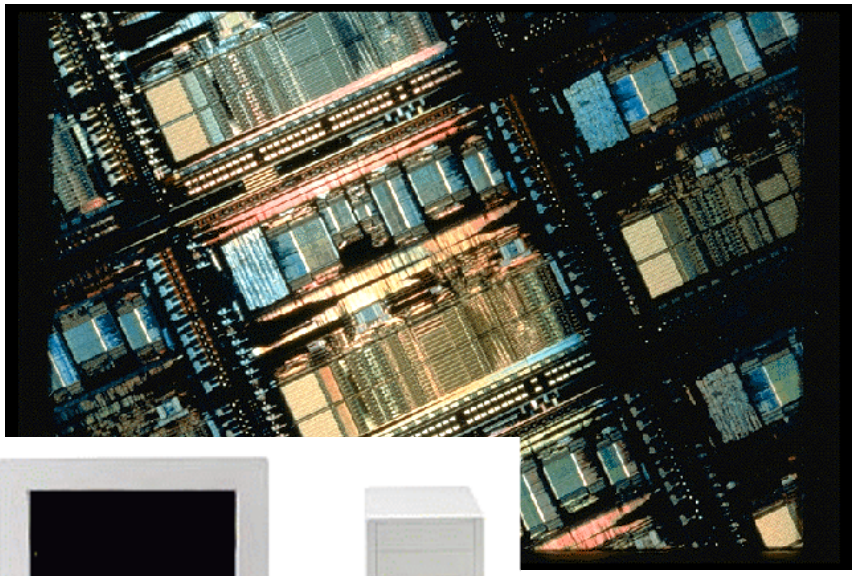


How do we make things?

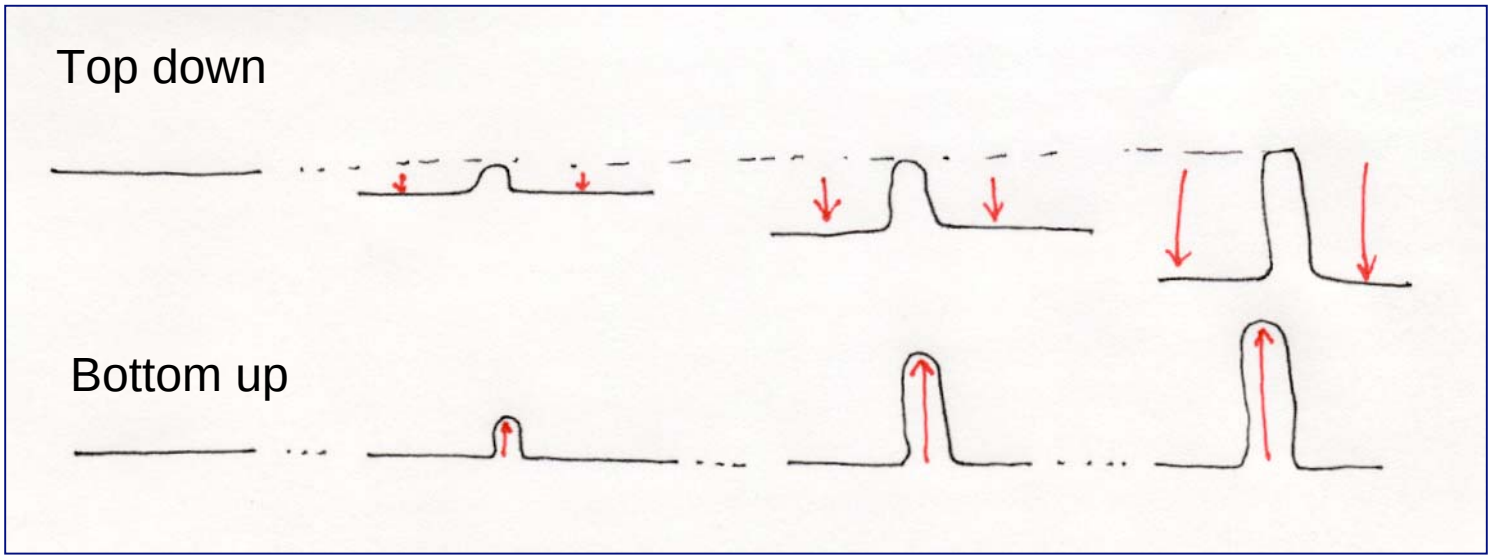


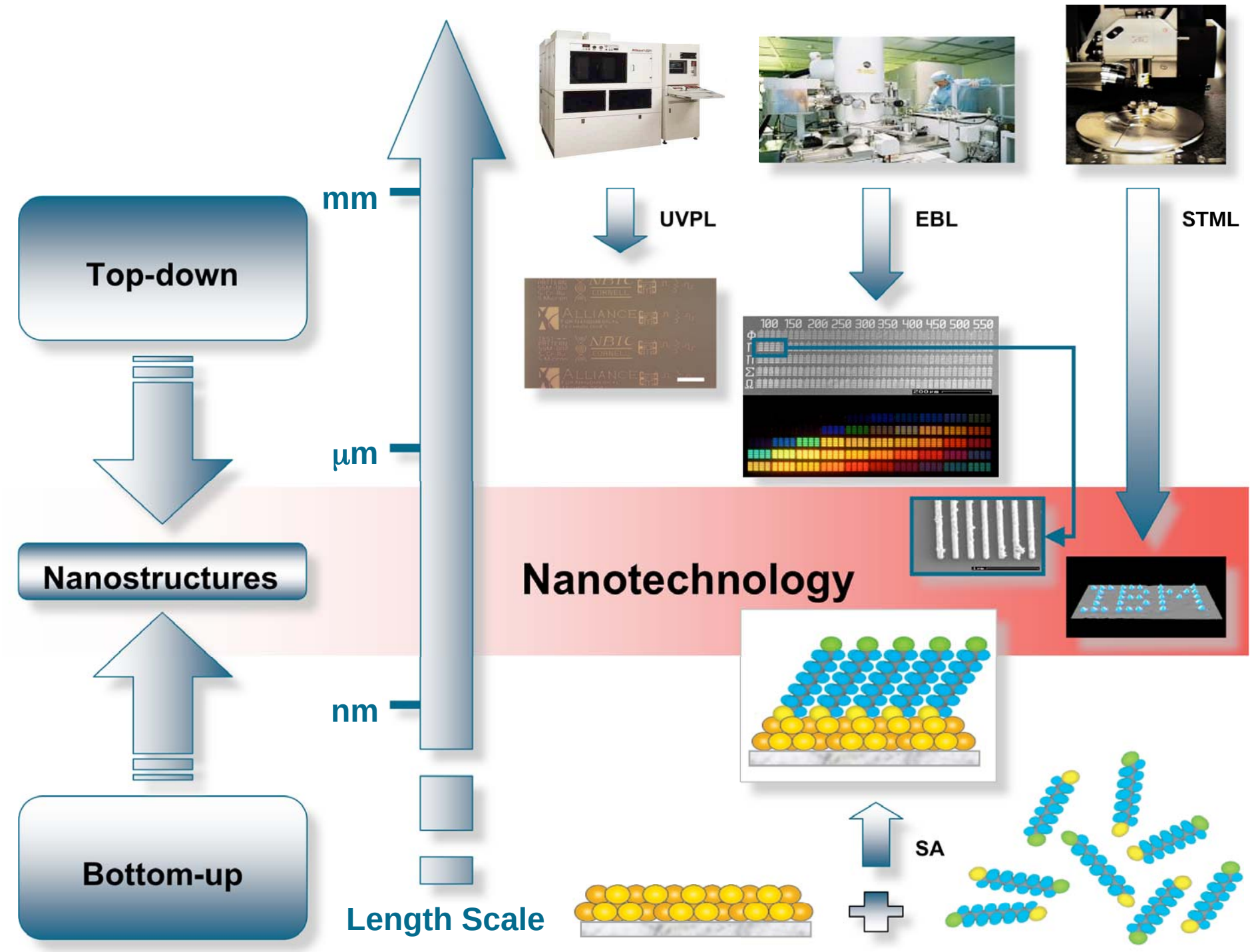
Why cannot we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?

Reduction in size



Fabrication schemes

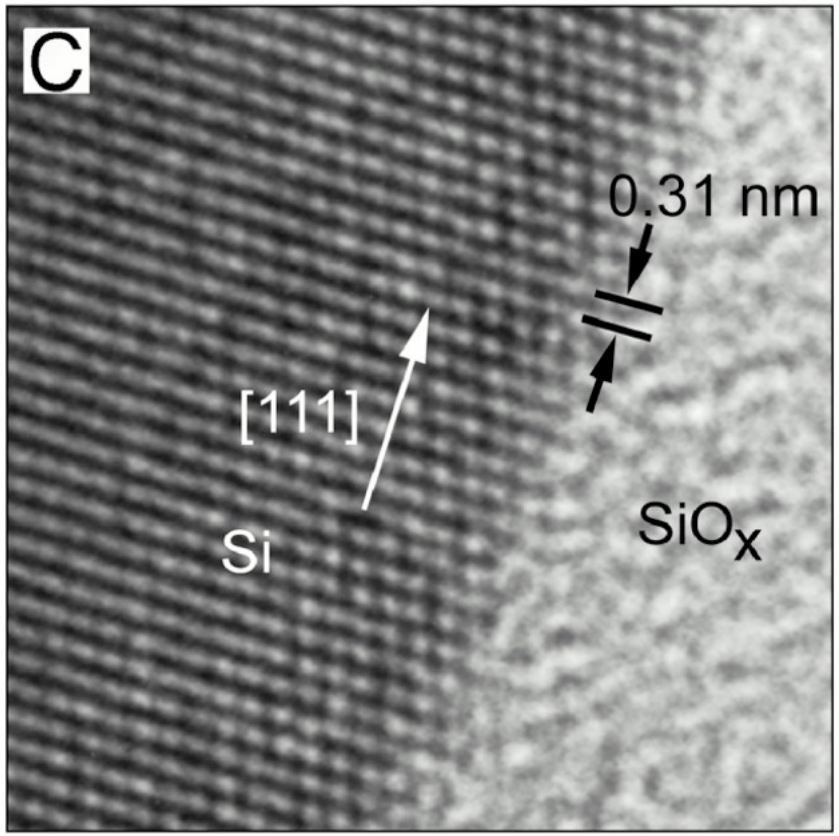


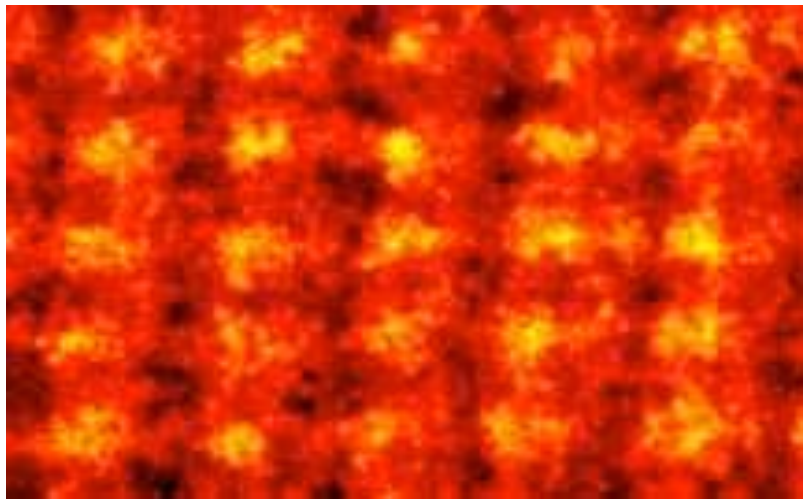

Top-down
Nanostructures
Bottom-up
mm
μm
nm
Length Scale
UVPL
EBL
STML
Nanotechnology
SA

A silicon wafer is the substrate

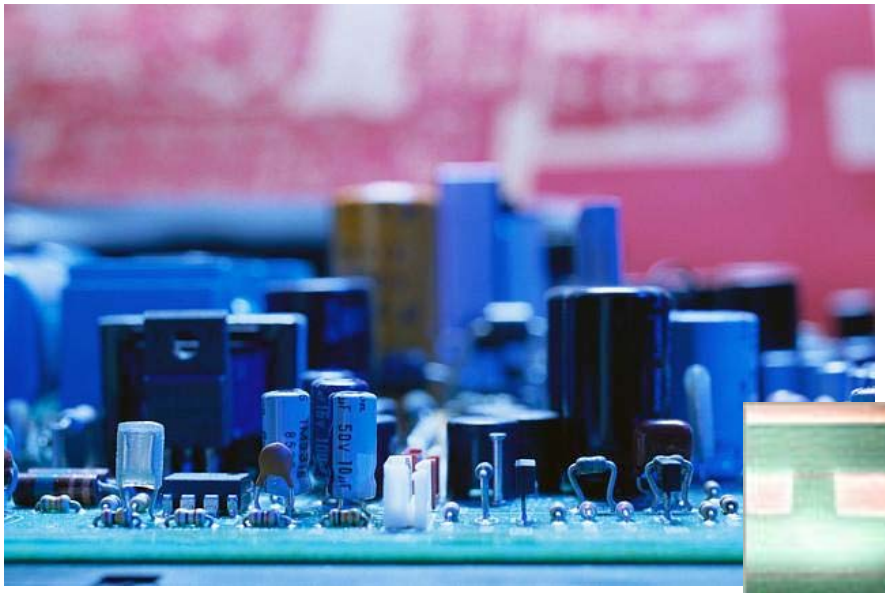
- Silicon is a very smooth material and can be used to make very fine structures

Silicon crystals

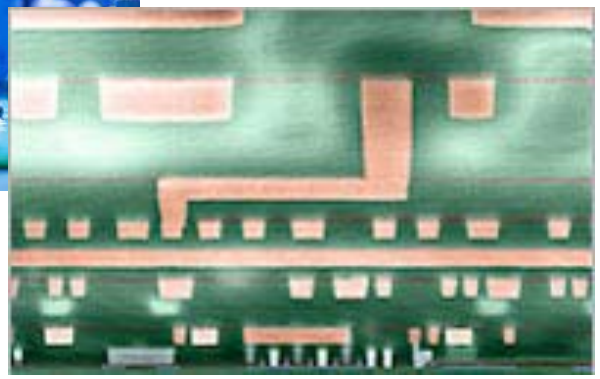




You are on a desert island

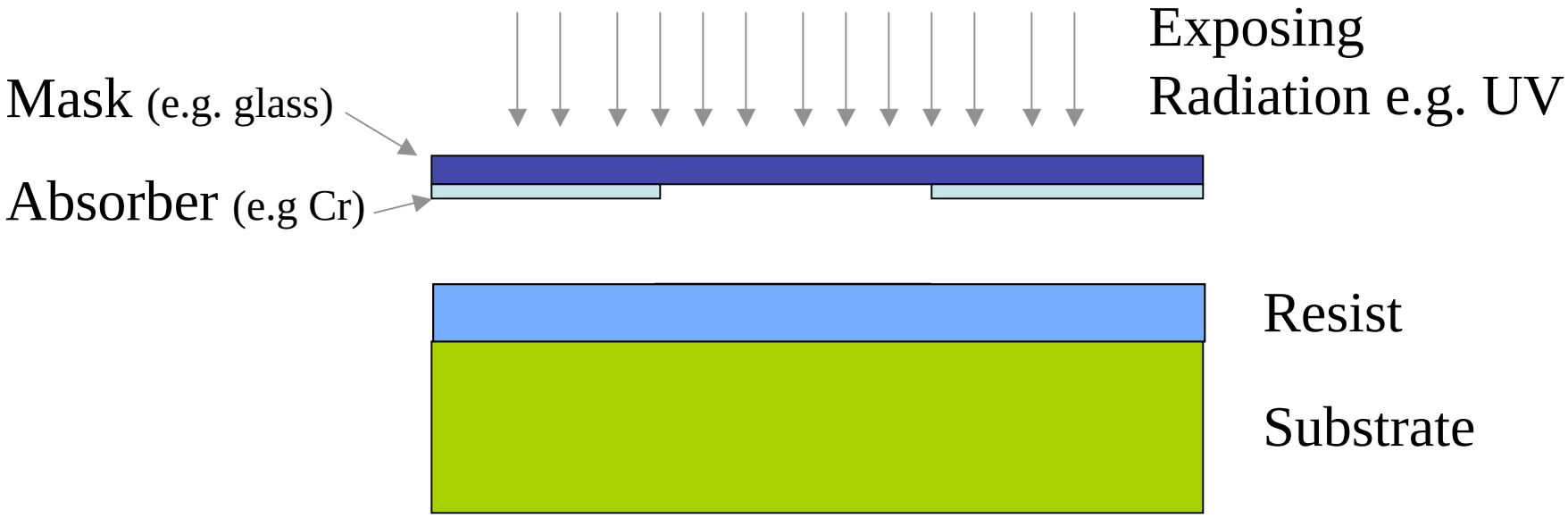


- Silicon wafer
- Make a channel 1/10 the width of your hair.
- How would you do this?

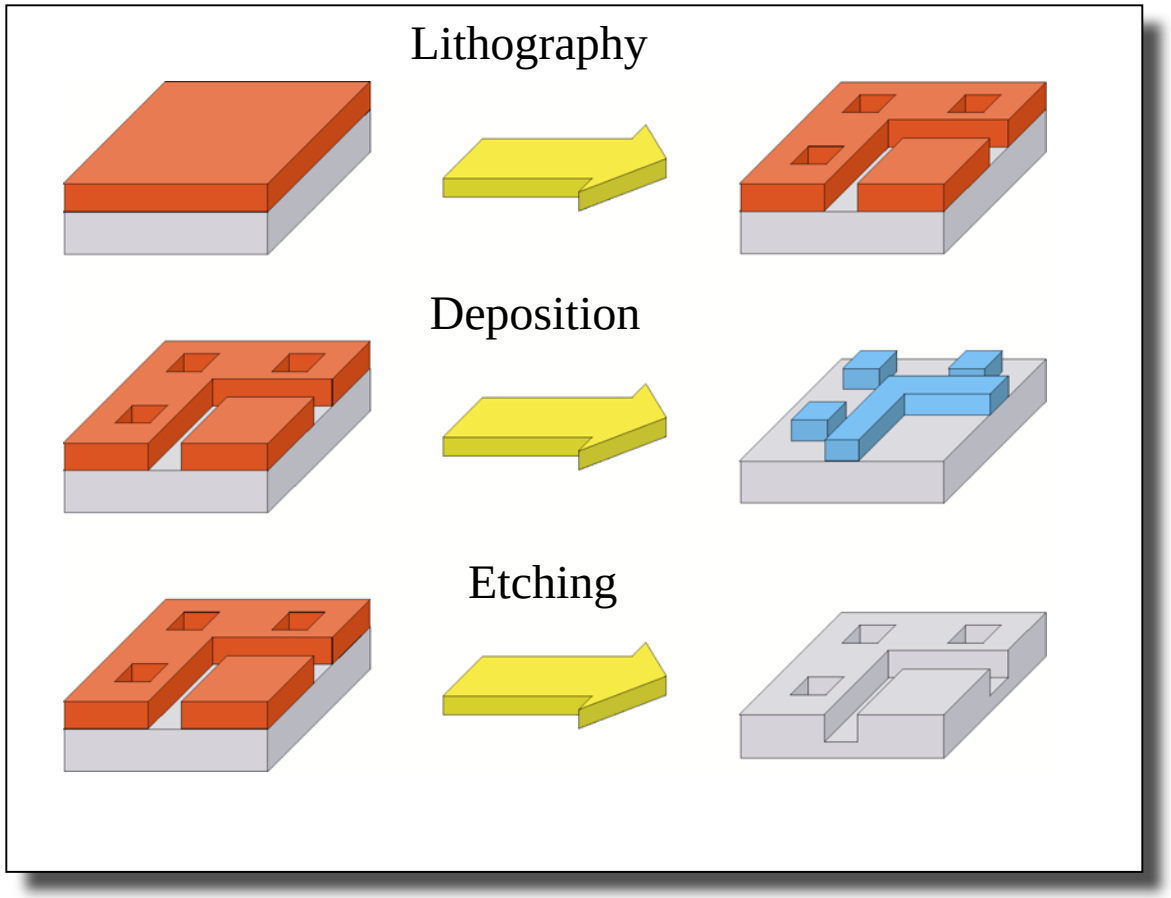


Carving stone

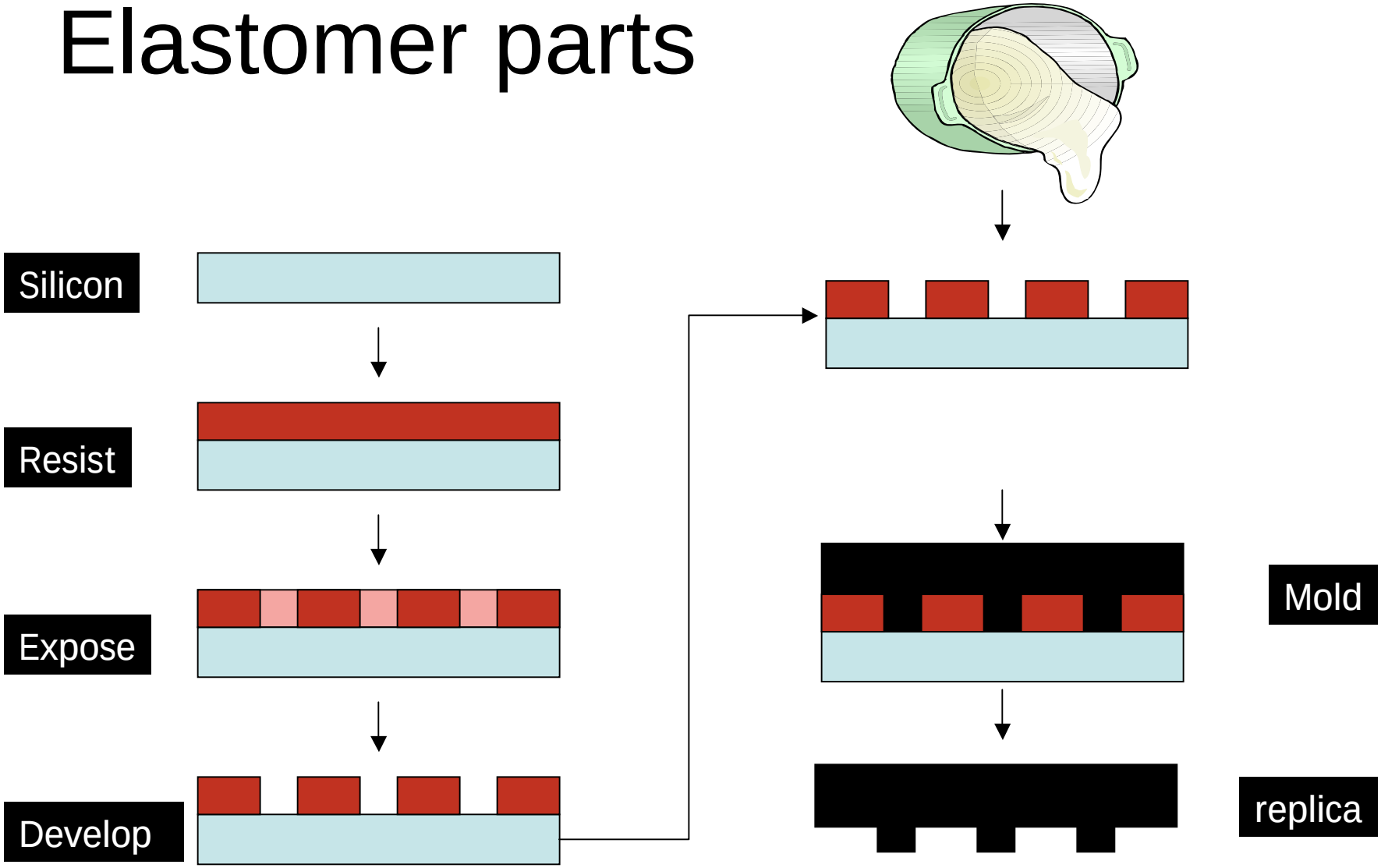
Basic Lithographic Process



Postlithographic processes



Elastomer parts



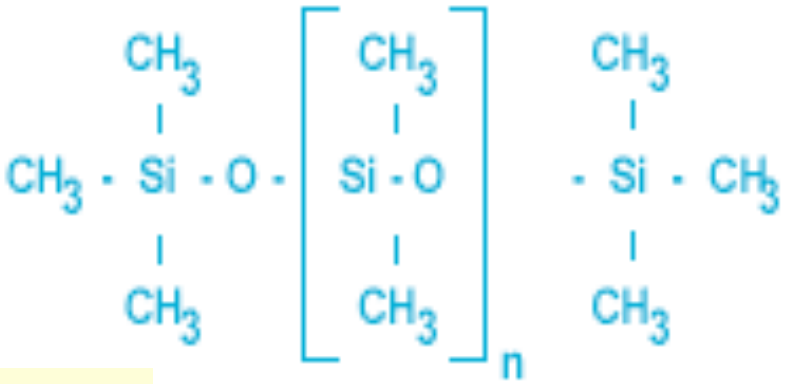
Soft lithography

- *Near-Field Phase Shift Lithography*. (Rogers et al. n.d.).
- *Replica Molding*. (Xia et al. 1997).
- *Micromolding in Capillaries (MIMIC)*. (Kim, Xia and Whitesides 1995; Xia, Kim, and Whitesides 1996).
- *Microtransfer Molding (TM)*. (Zhao, Xia, and Whitesides 1996).
- *Solvent-assisted Microcontact Molding (SAMIM)*. (Kim et al. n.d.).
- *Microcontact Printing (CP)*. (Kumar and Whitesides 1993).

G. Whitesides

Polydimethylsiloxane

- Silicone rubber
- Highly viscoelastic
- Virtually transparent



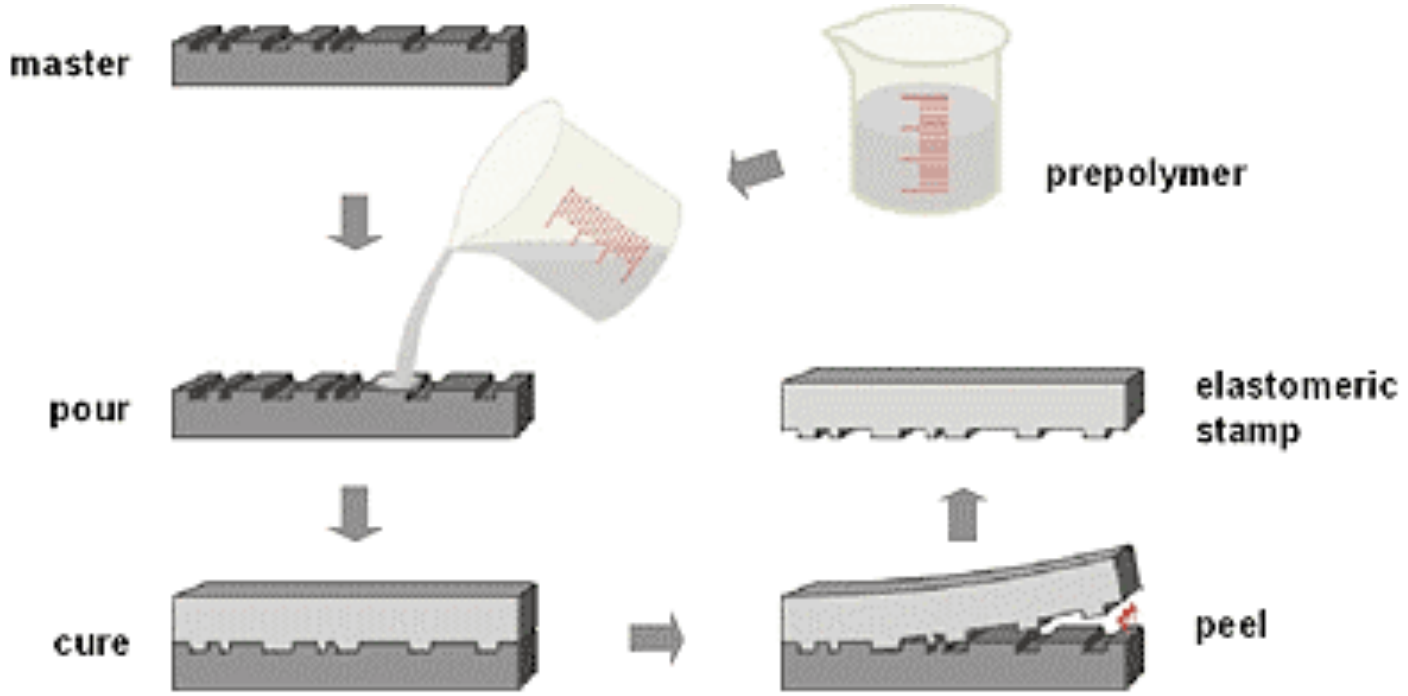
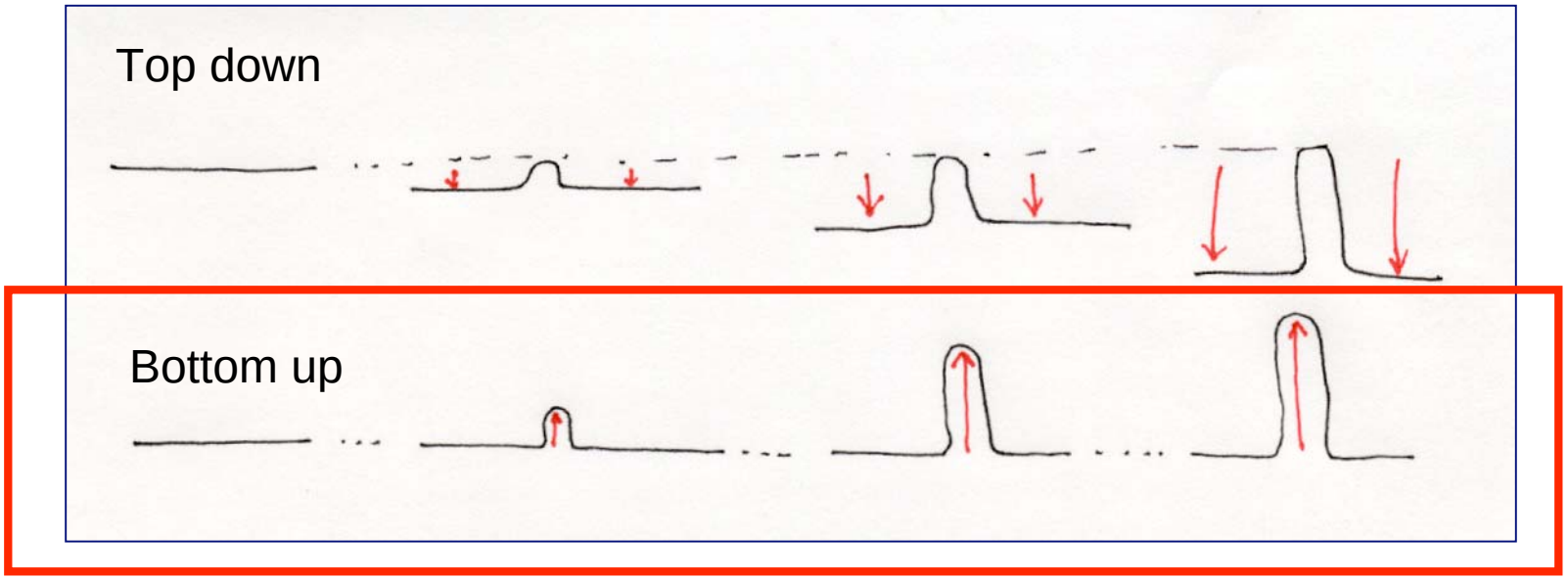


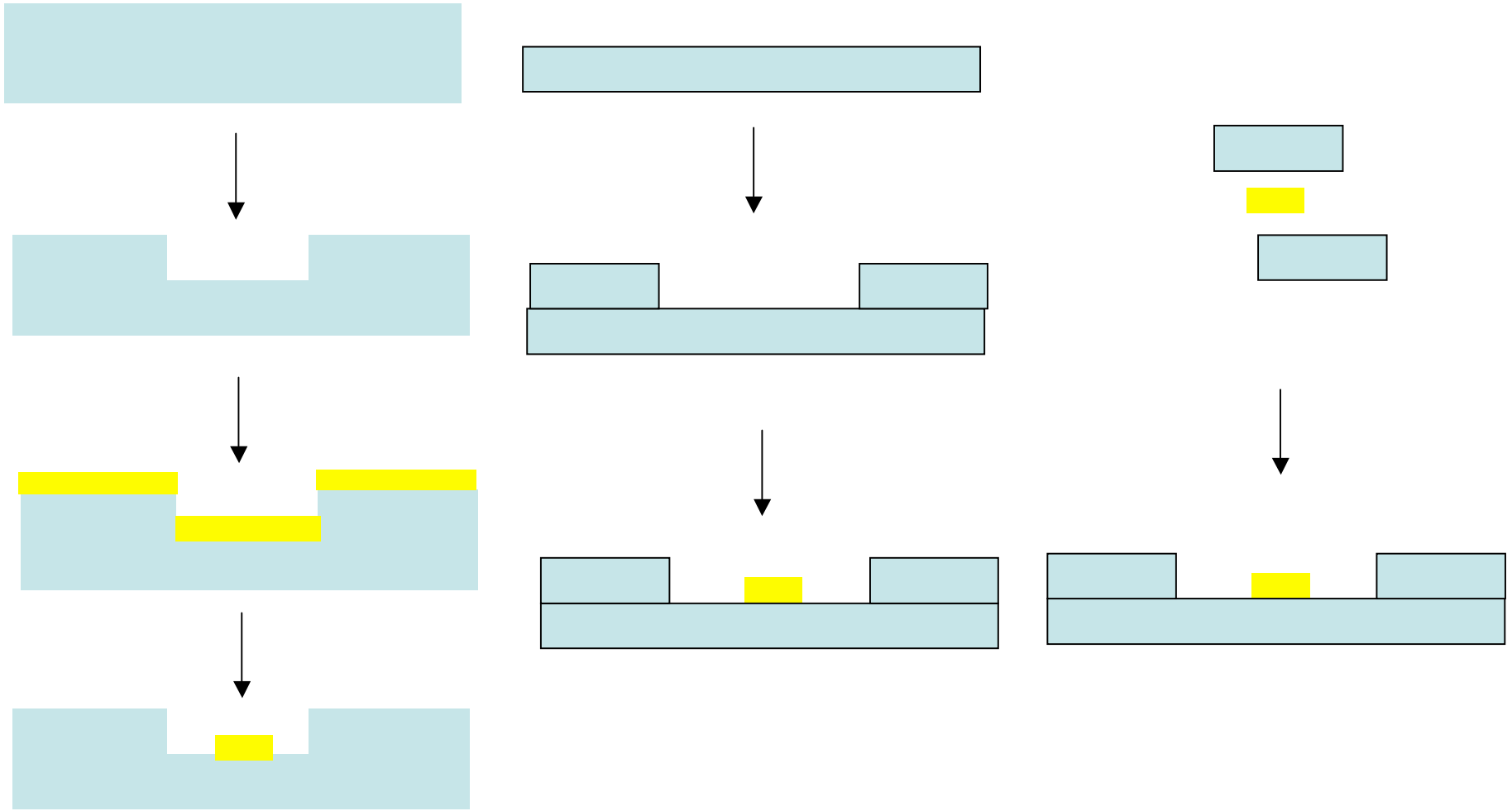
Fig.2 The stamp replication process: A master with a negative of the desired pattern is cast with a pre-polymer. After curing the polymer, the elastomeric stamp is peeled off the master and ready for microcontact printing.

http://www.research.philips.com/technologies/light_dev_microsys/softlitho/

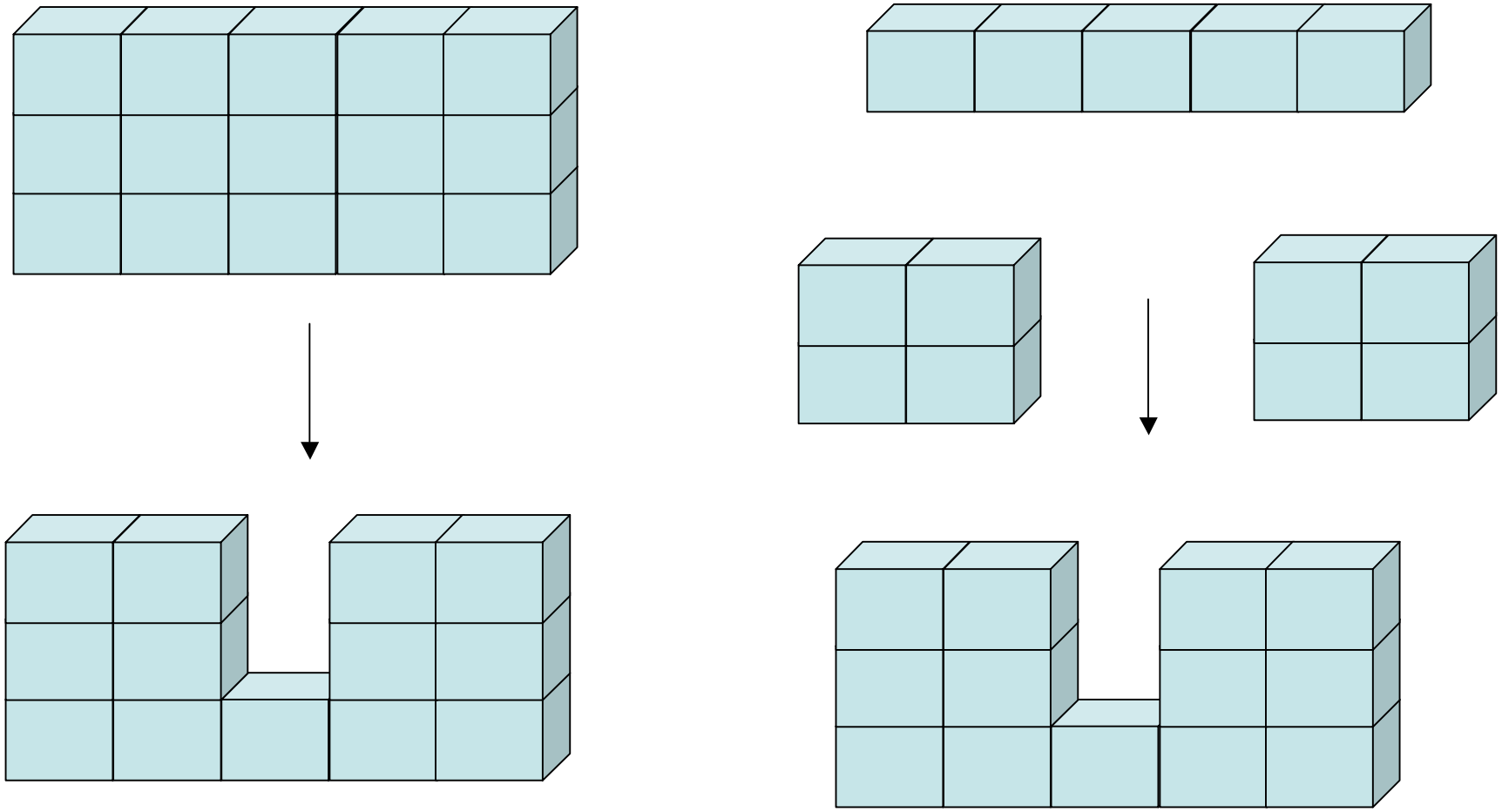
Fabrication schemes



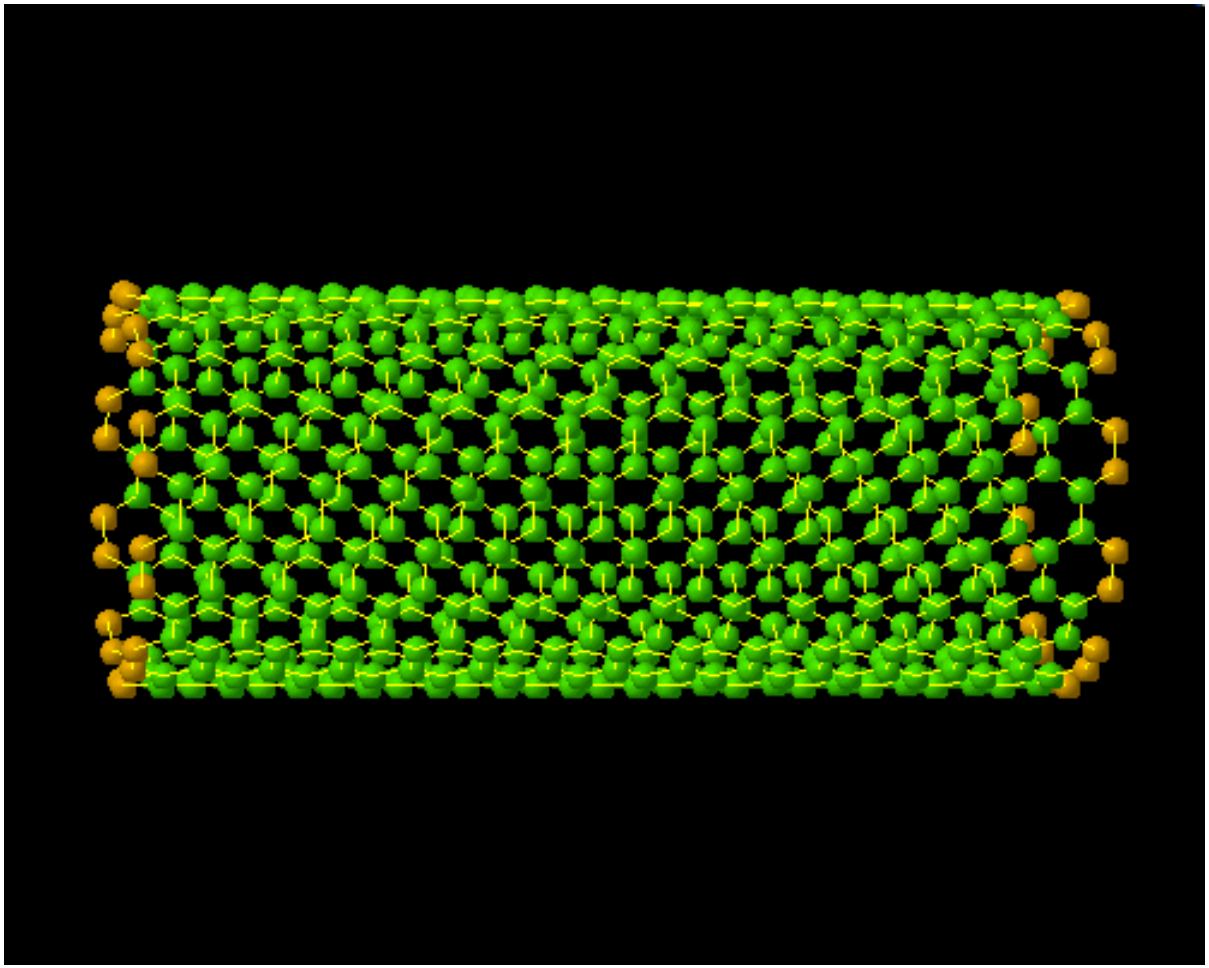
Top down vs. bottom up



Top down vs. directed assembly

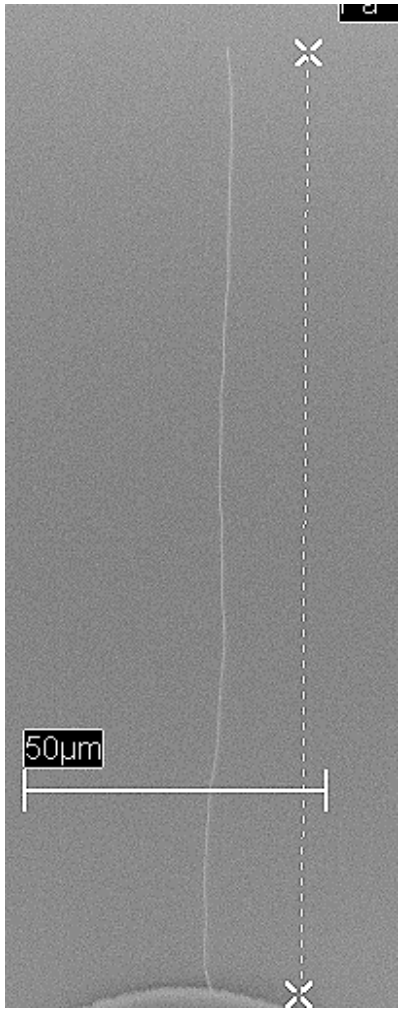


Carbon nanotubes



http://www.photon.t.u-tokyo.ac.jp/~maruyama/nanotube/nanotube.html

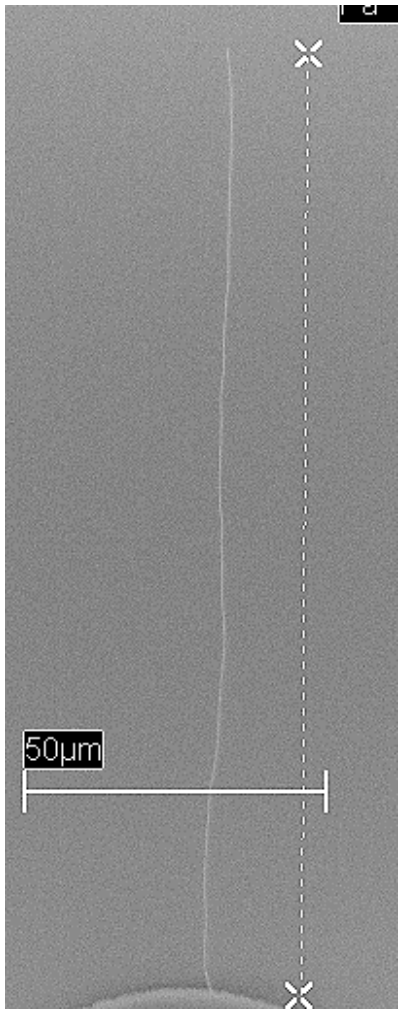
Carbon nanotubes

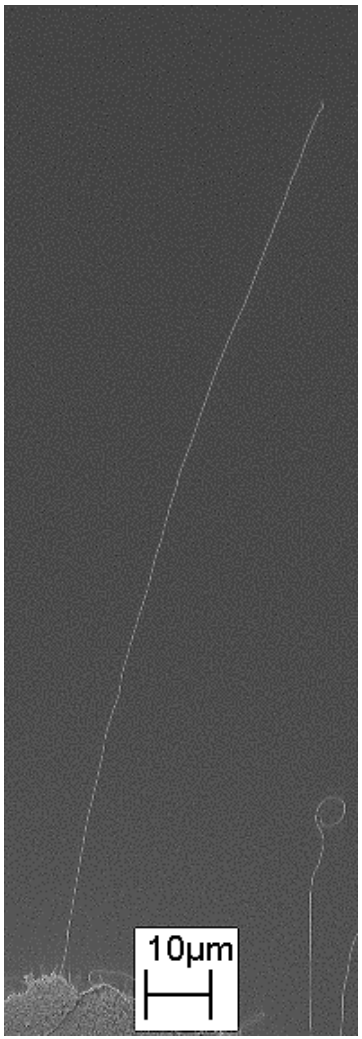


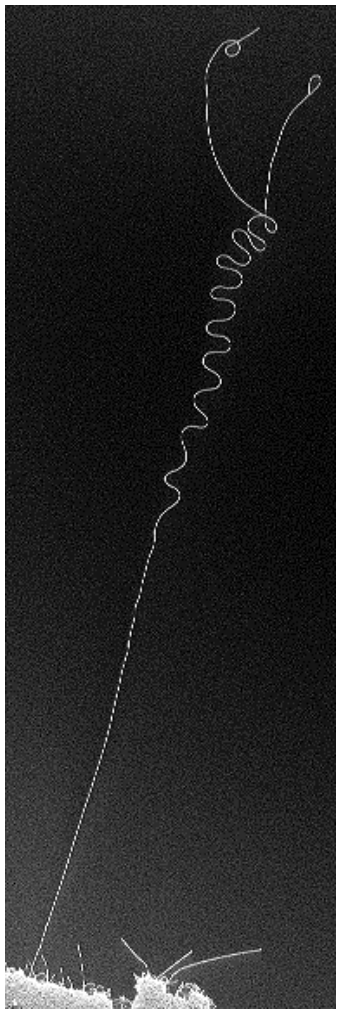
~150 µm

~150 µm

Growing Single walled carbon nanotubes

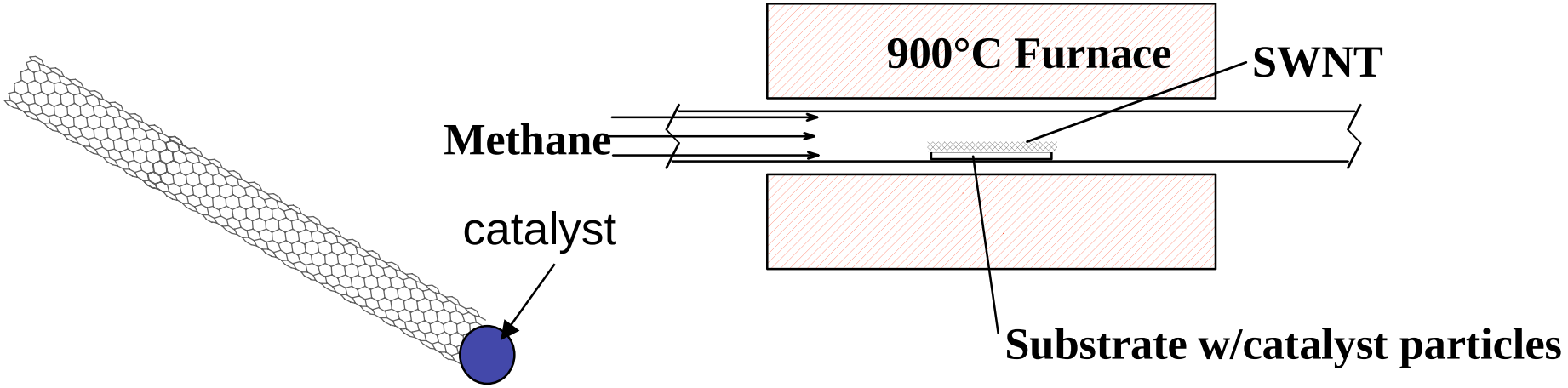


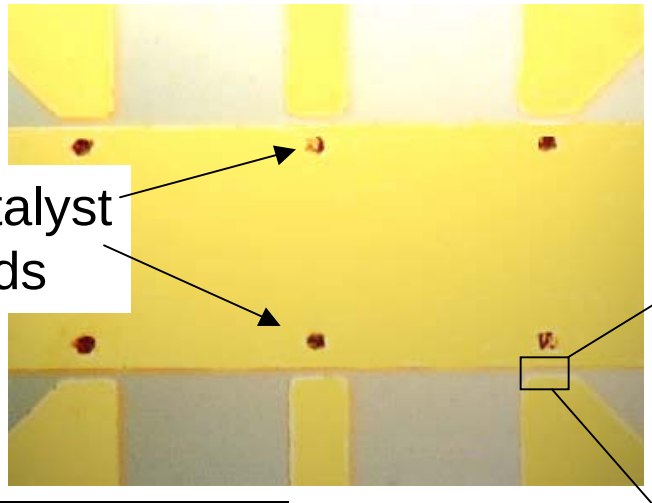




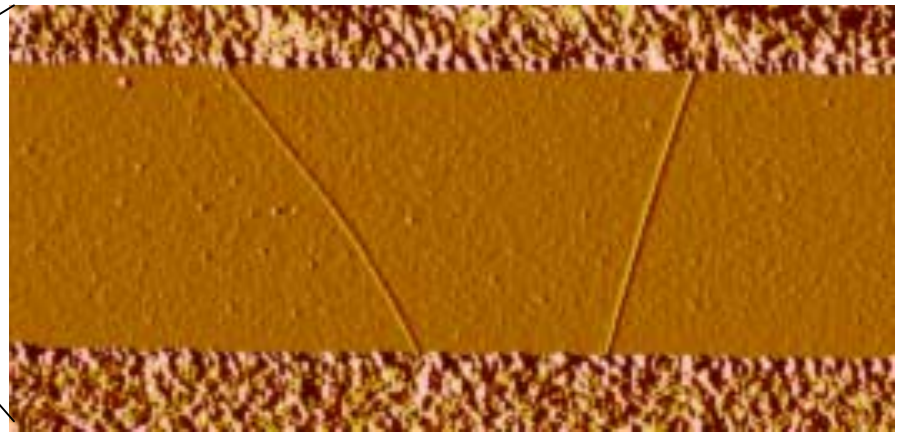
~150 µm

~150 µm





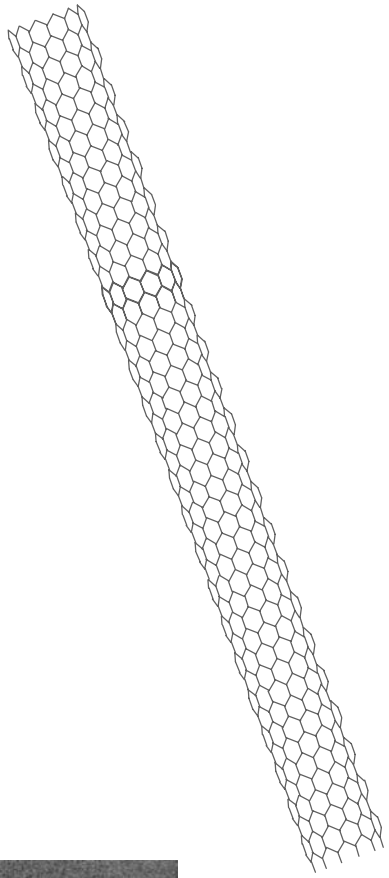
Following Kong et al.
*Nature **395**, 878 (98)*

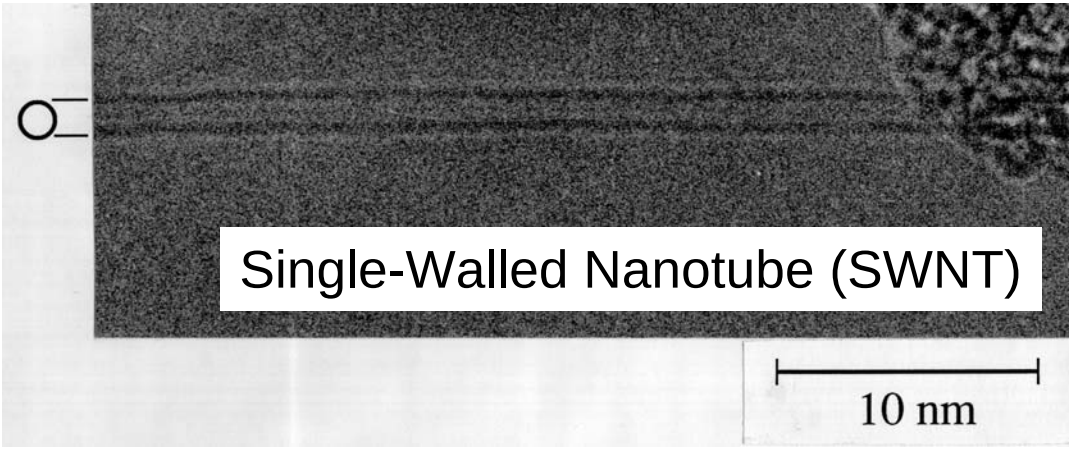


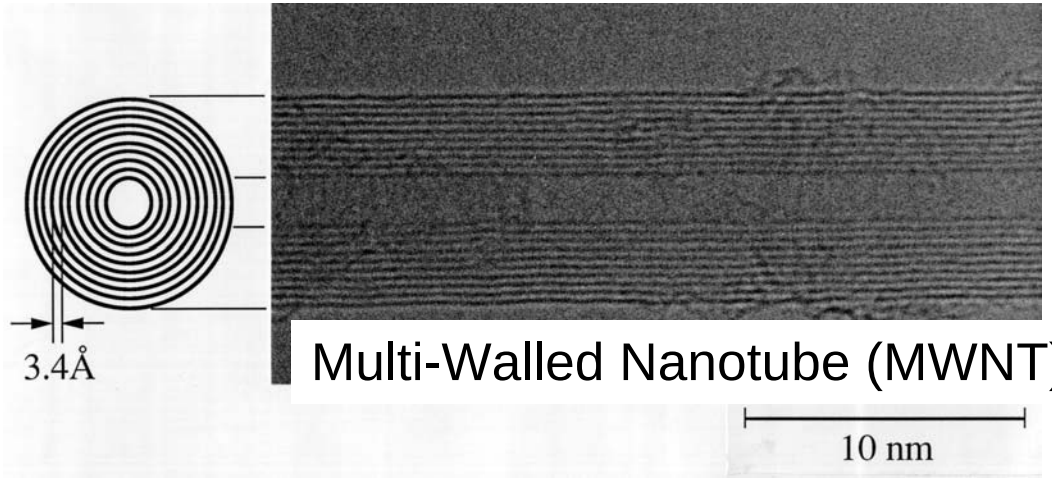
P. McEuen, Cornell

CNF Cornell Nanofabrication Facility

Carbon Nanotubes

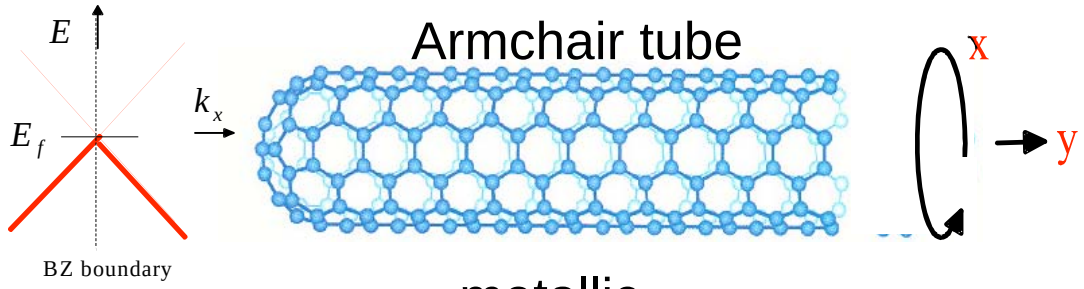




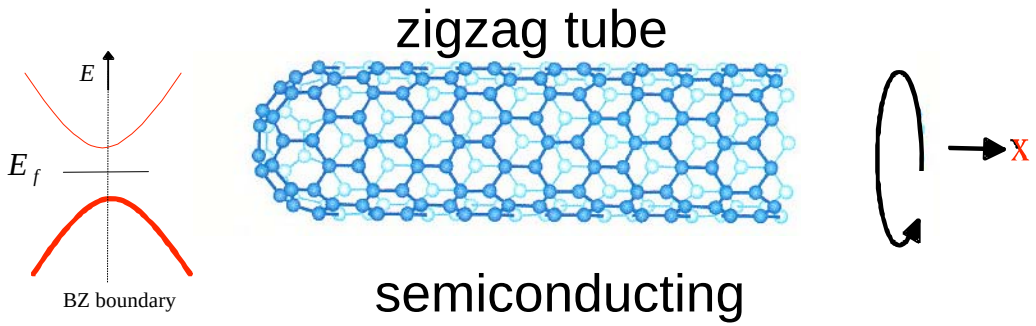


P. McEuen, Cornell

Nanotube Electronic Properties



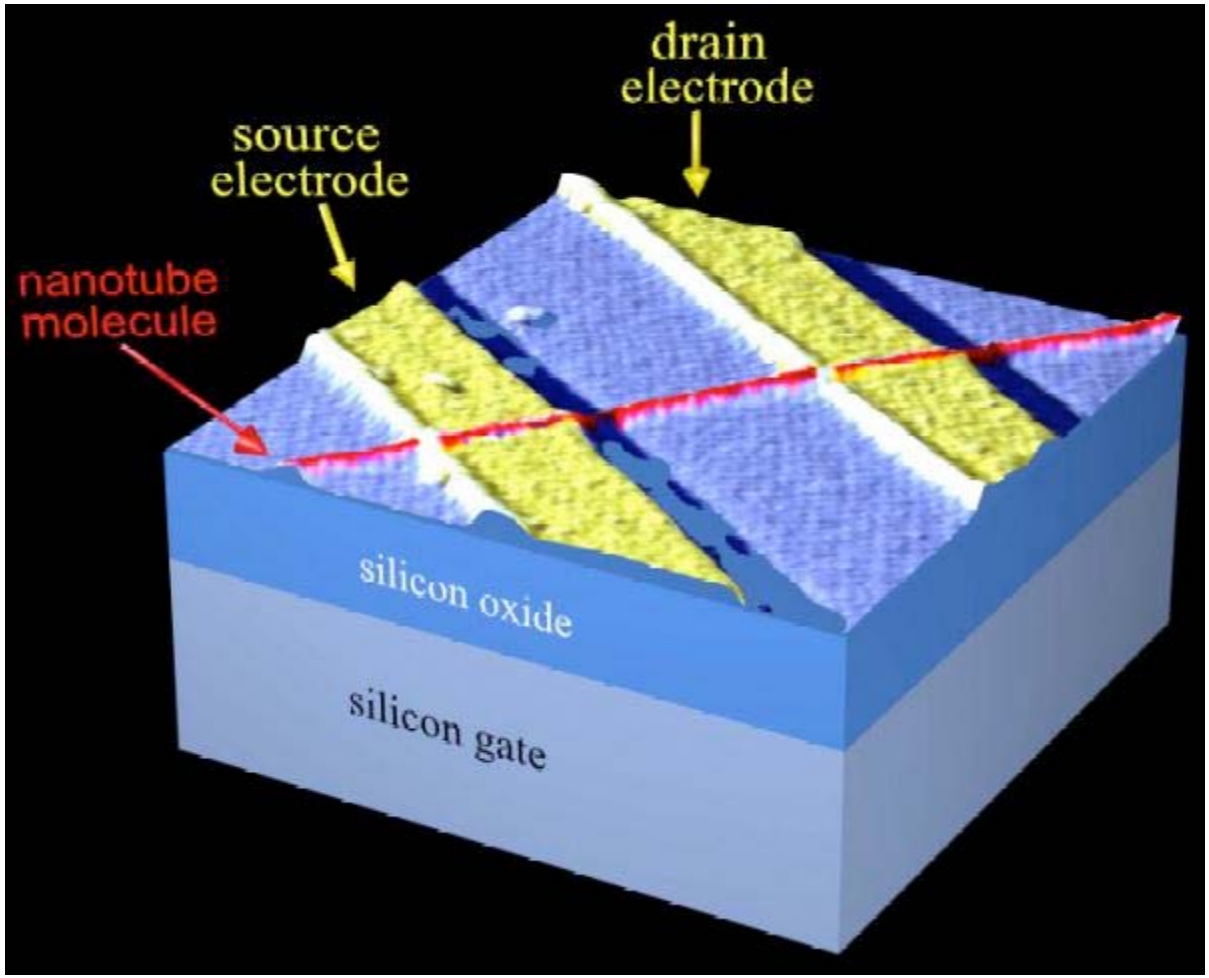
metallic



semiconducting

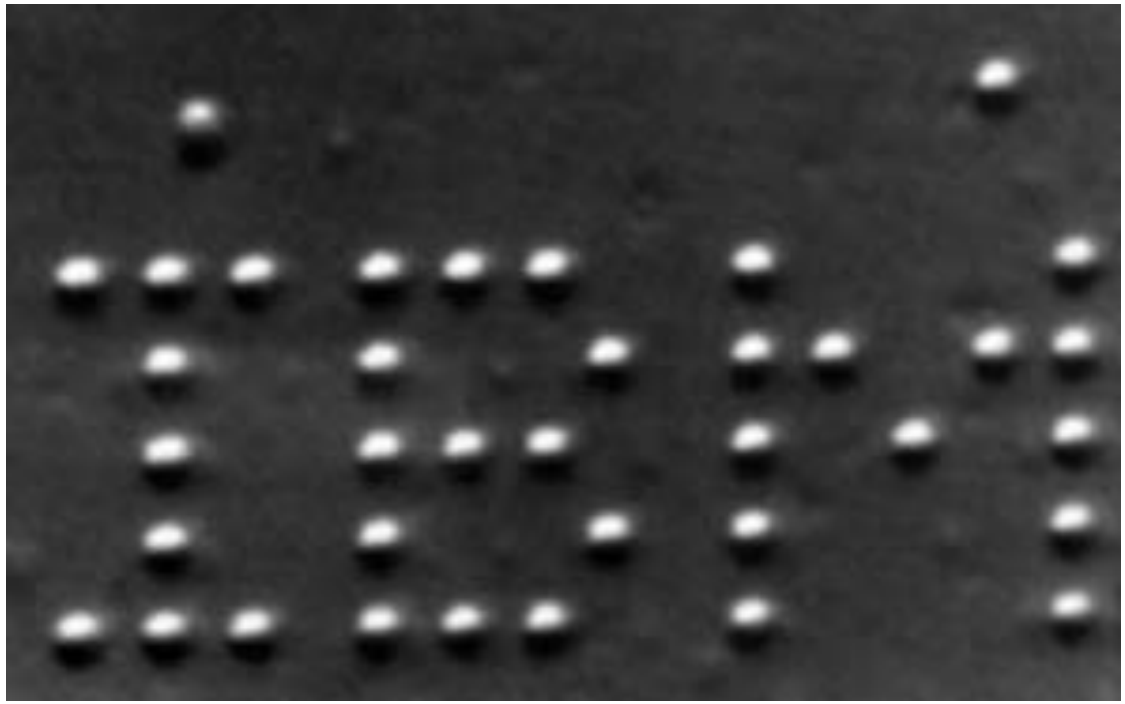
Electrical properties of nanotubes rival (or beat) the best materials known !

P. McEuen, Cornell

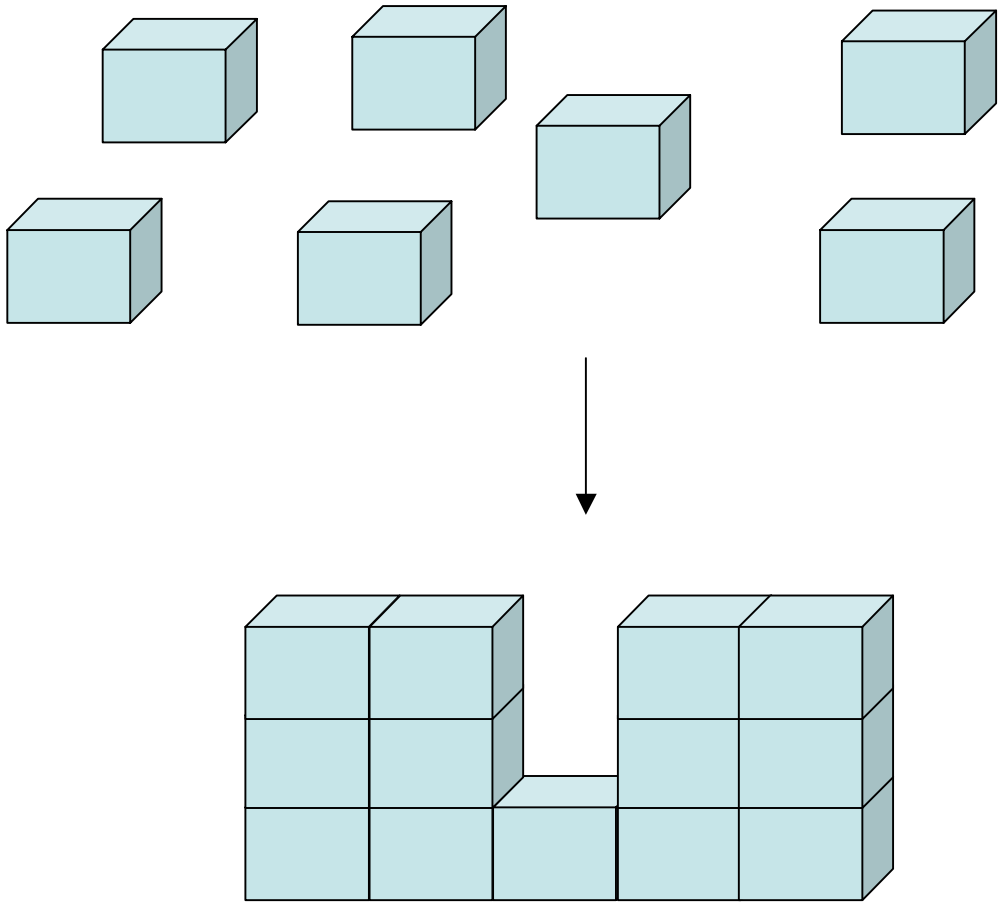

drain
electrode
source
electrode
nanotube
molecule
silicon oxide
silicon gate

Moving atoms one at a time

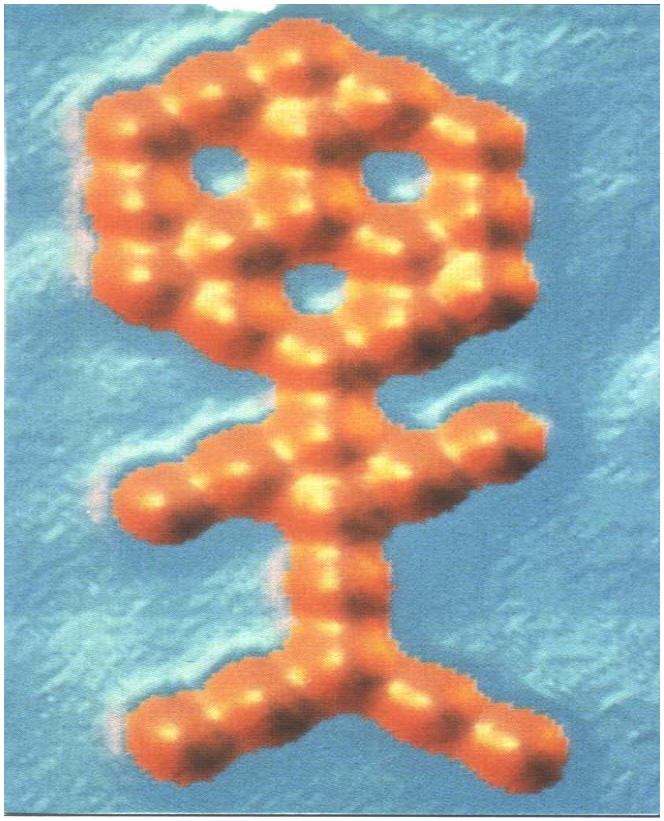
- 1989
- Xenon
- On nickel
- Absolute zero



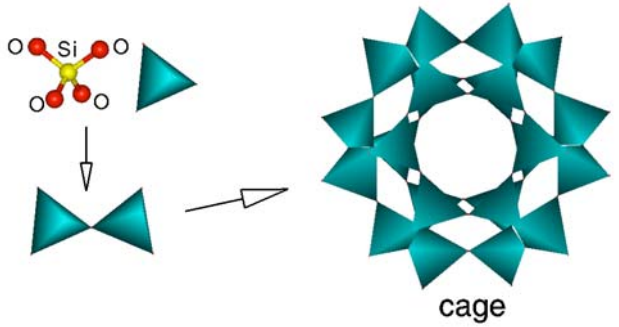
Self-assembly

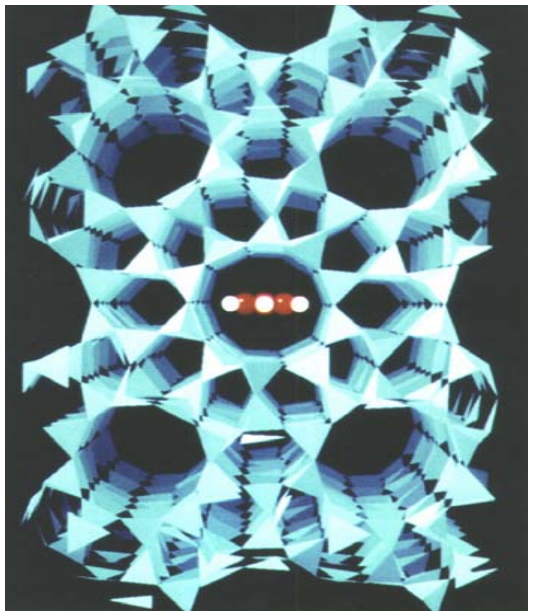


Assembly vs. self-assembly



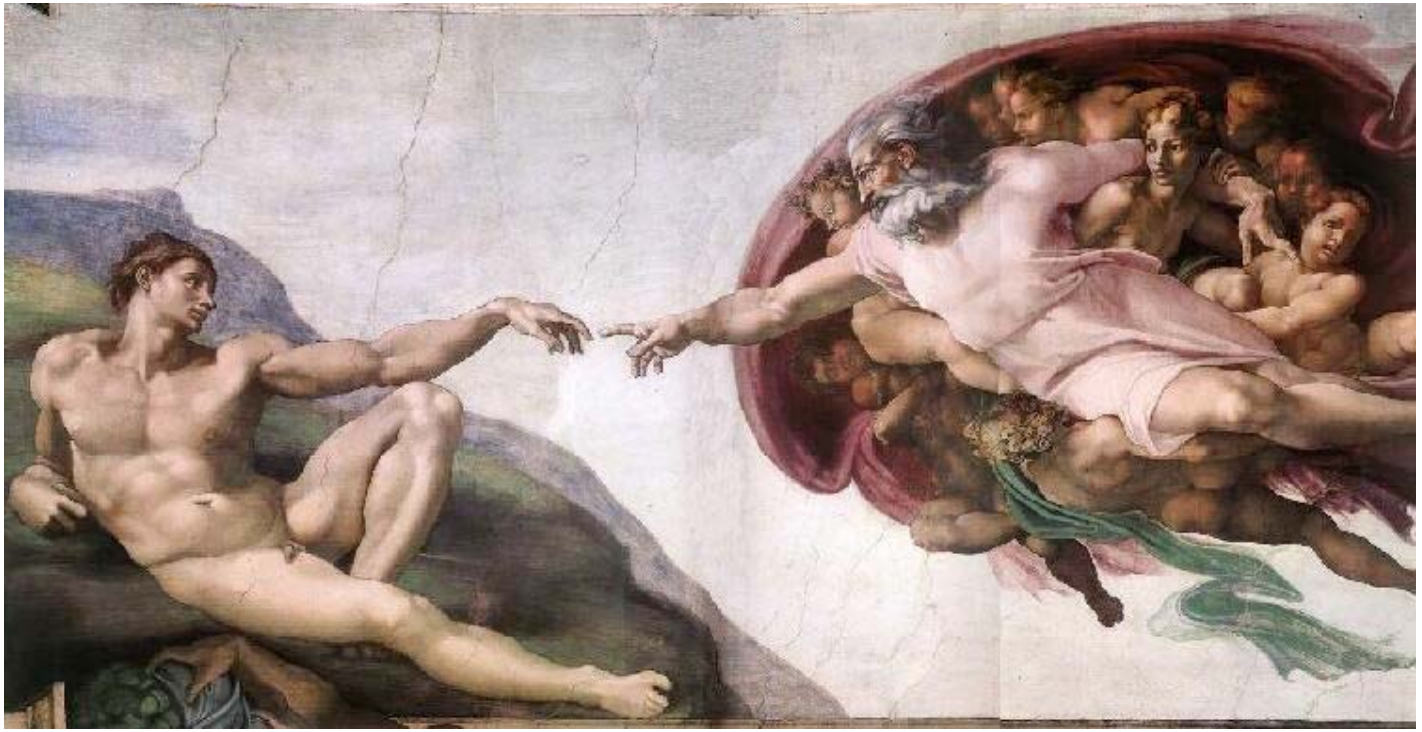
“molecular human”





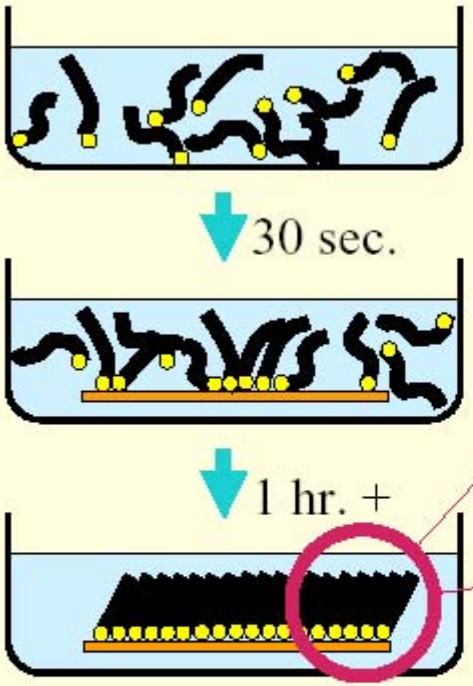
zeolites

Man vs. nature

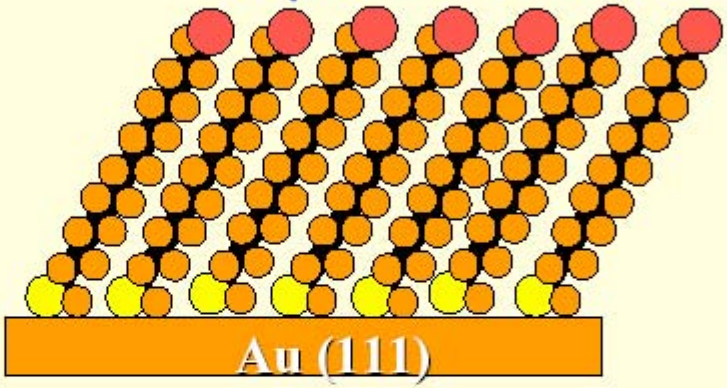


entropy

Self-assembled monolayers



A perfect molecular material.

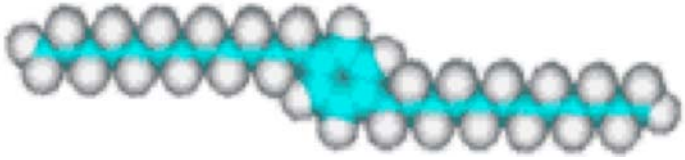


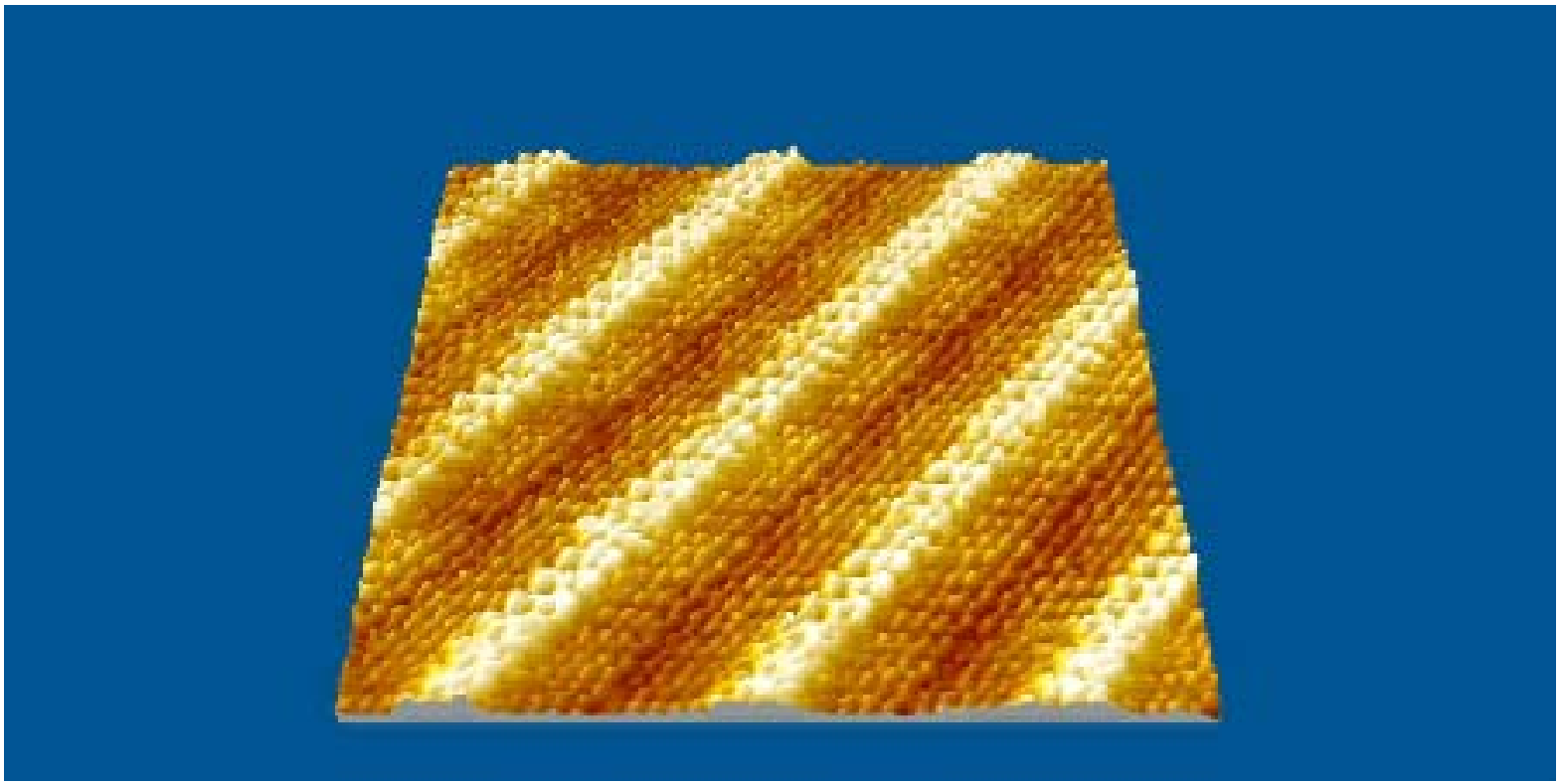
Thiol anchoring group
Head group

Major discovery -- 1983

Nuzzo,RG; Allara,DL (1983): Adsorption of bifunctional organic disulfides on gold surfaces. J. Am. Chem. Soc. 105(13), 4481-4483.

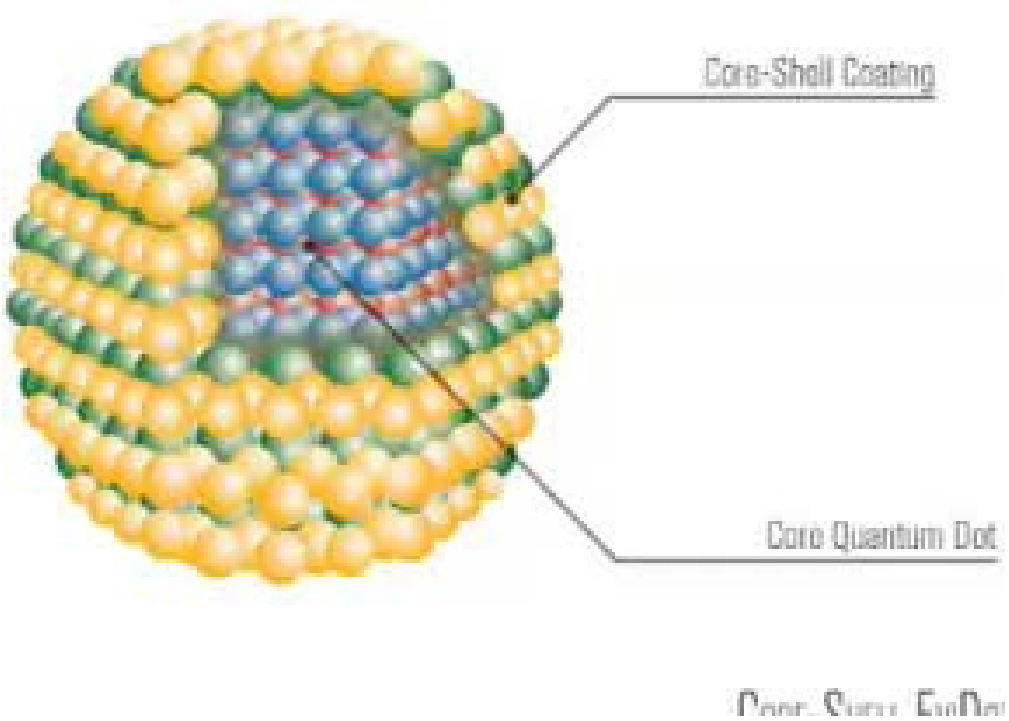
Self-assembly-2D





nanoScience Instruments

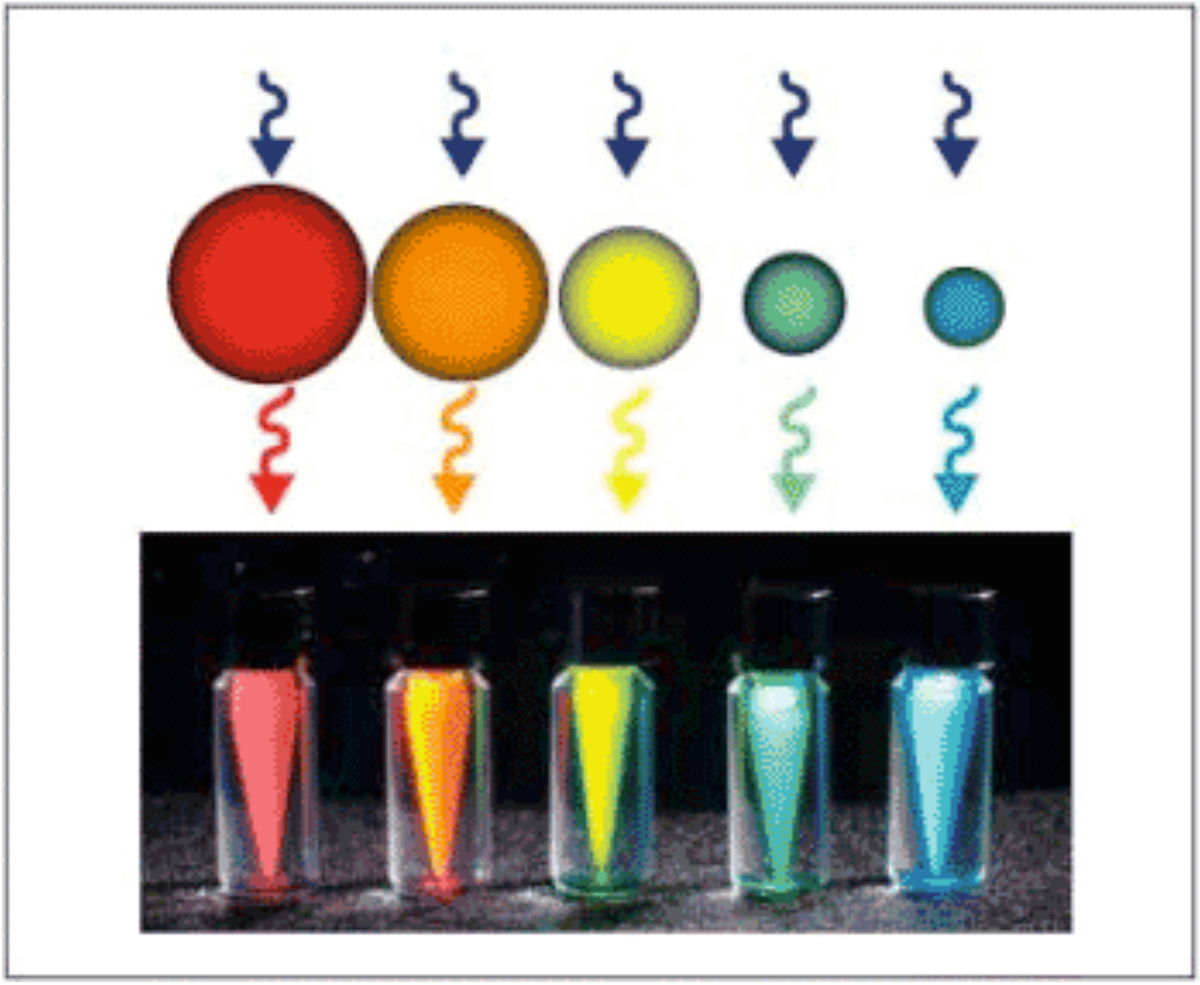
Quantum dots



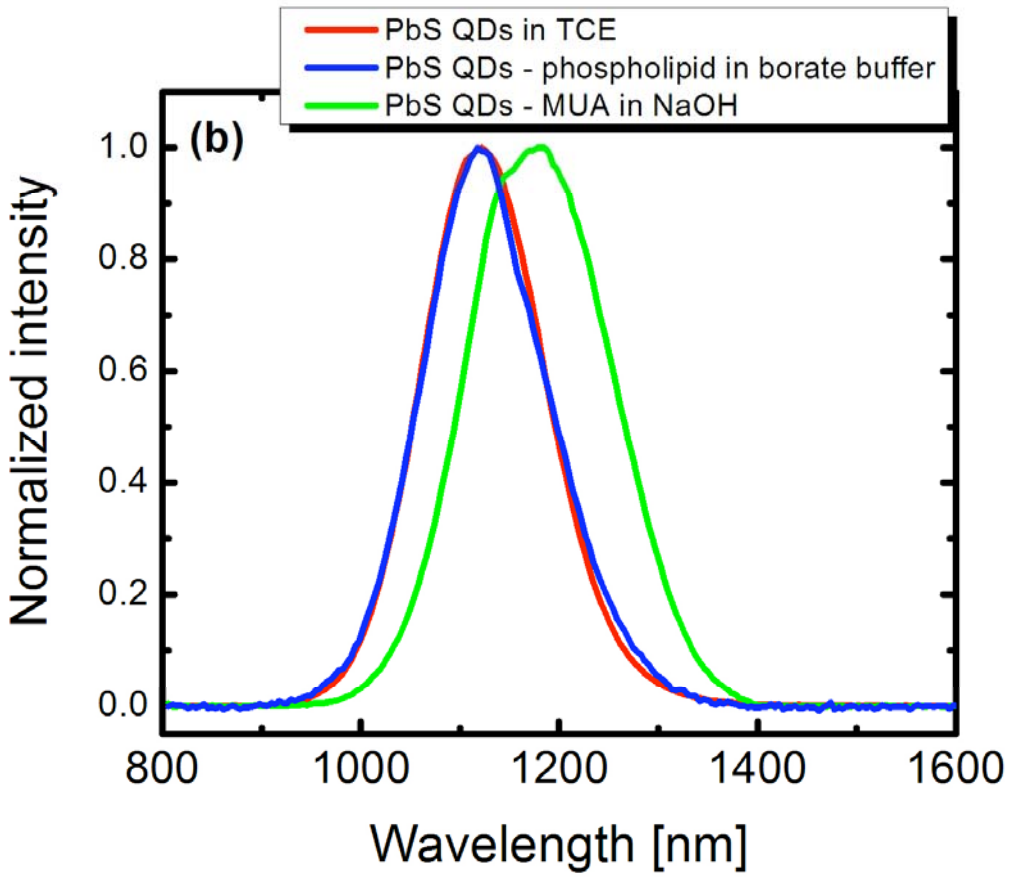
Shape control of CdSe nanocrystals

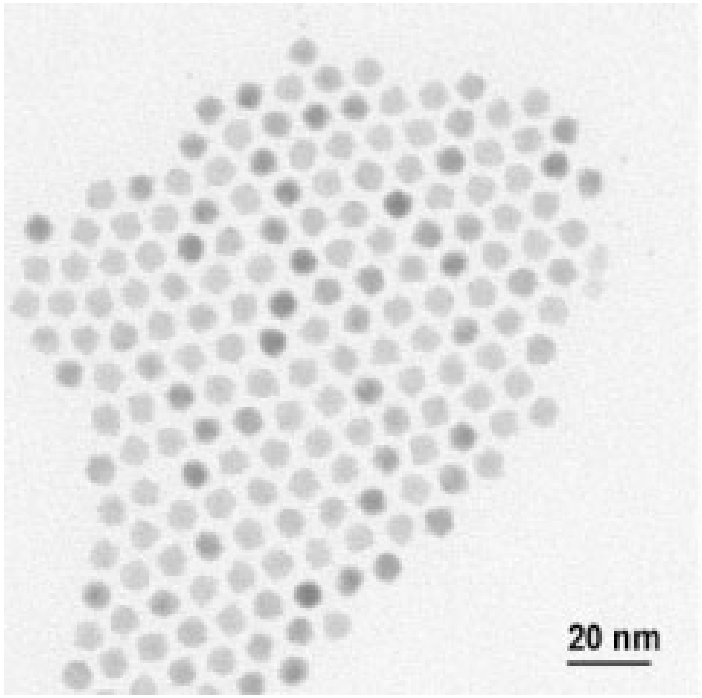
Xiaogang Peng*, Liberato Manna, Weidong Yang, Juanita Wickham,
Erik Scher, Andreas Kadavanich & A. P. Alivisatos
Department of Chemistry, University of California at Berkeley, and Lawrence
Berkeley National Laboratory, Berkeley, California 94720, USA

Quantum dots are often referred to as nanocrystals (although they have at least 10 other aliases, including artificial atoms, quantum crystallites and nanodots), and they can also be thought of as colloidal particles.

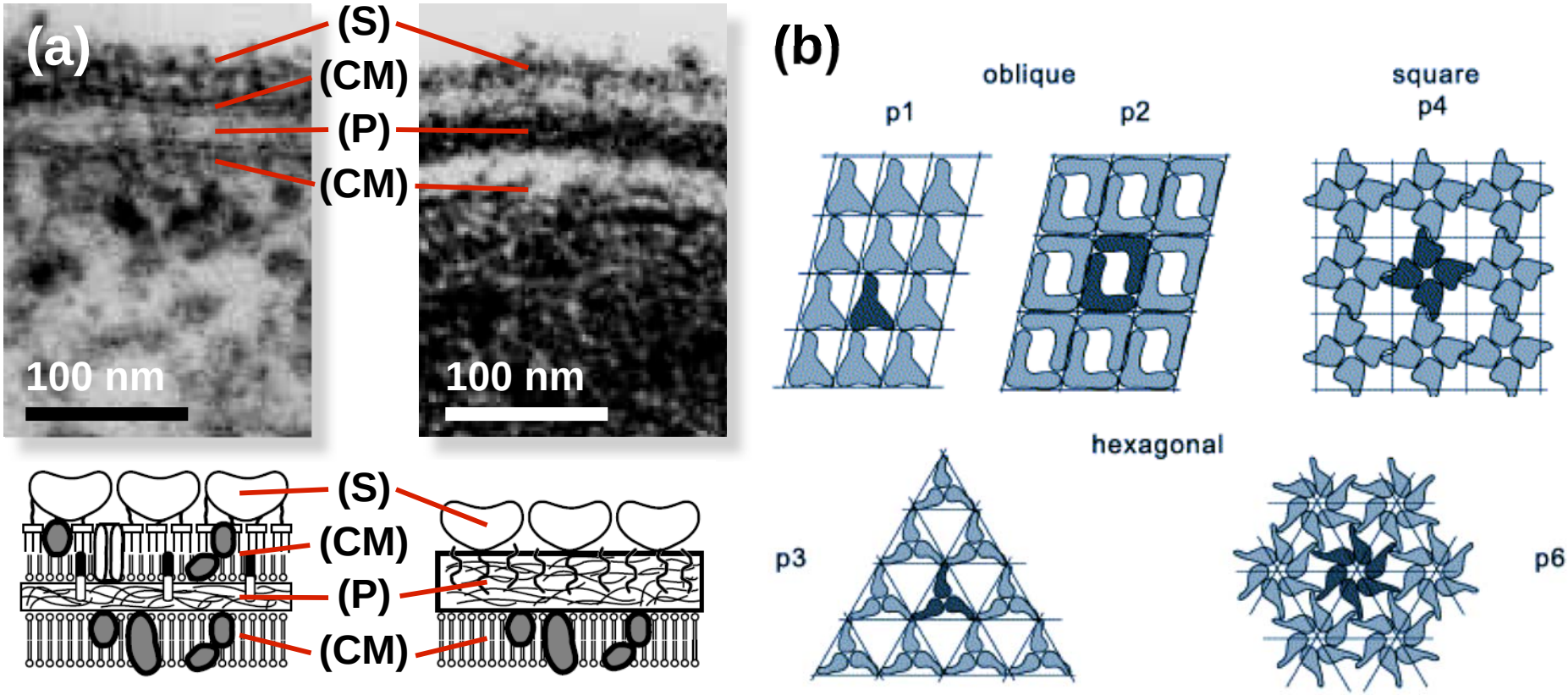


Imaging in tissue

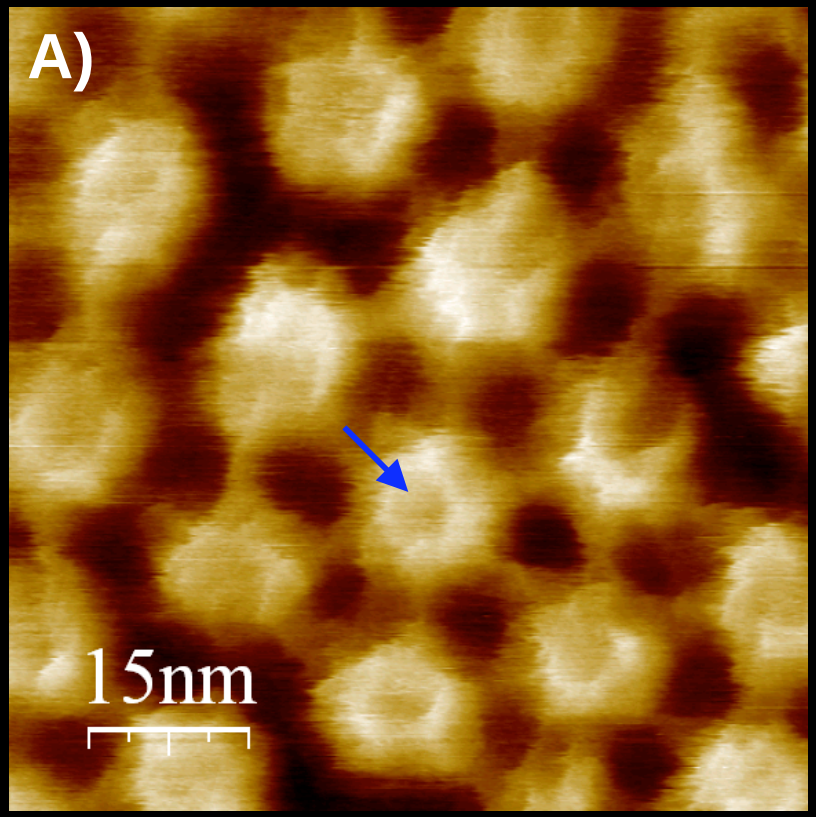


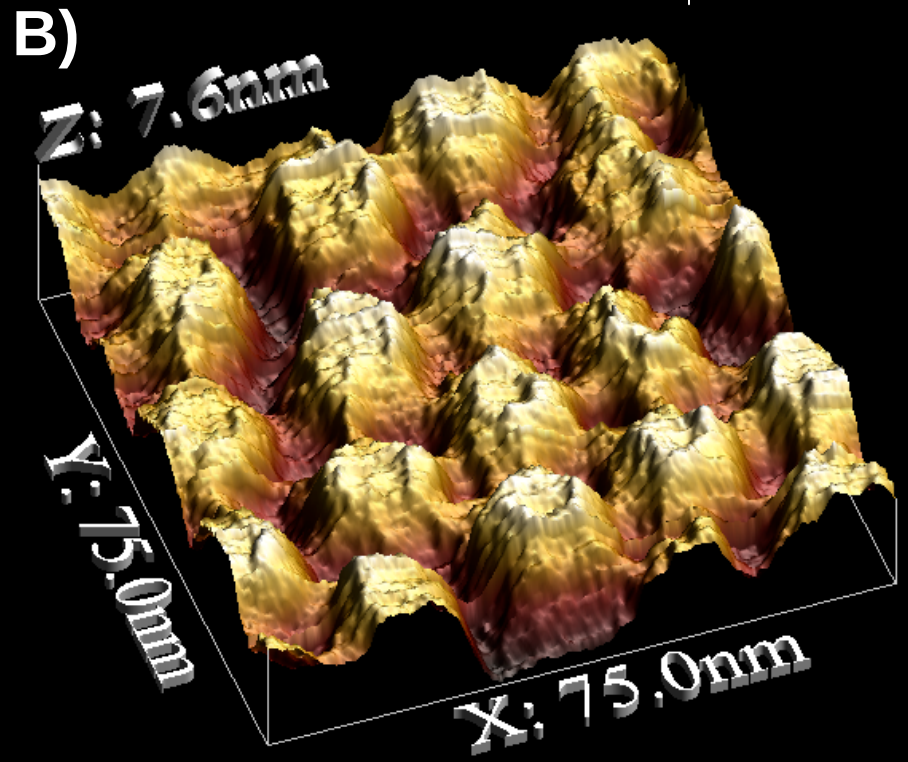


Location and Ultrastructure of Surface Layer (S-Layer) Proteins



(a) Comparison of Gram-negative (left) and Gram-positive (right) cell wall structures. **(S)**, S-layer; **(CM)**, cell membrane; **(P)**, peptidoglycan. **(b)** Types of S-layer morphologies

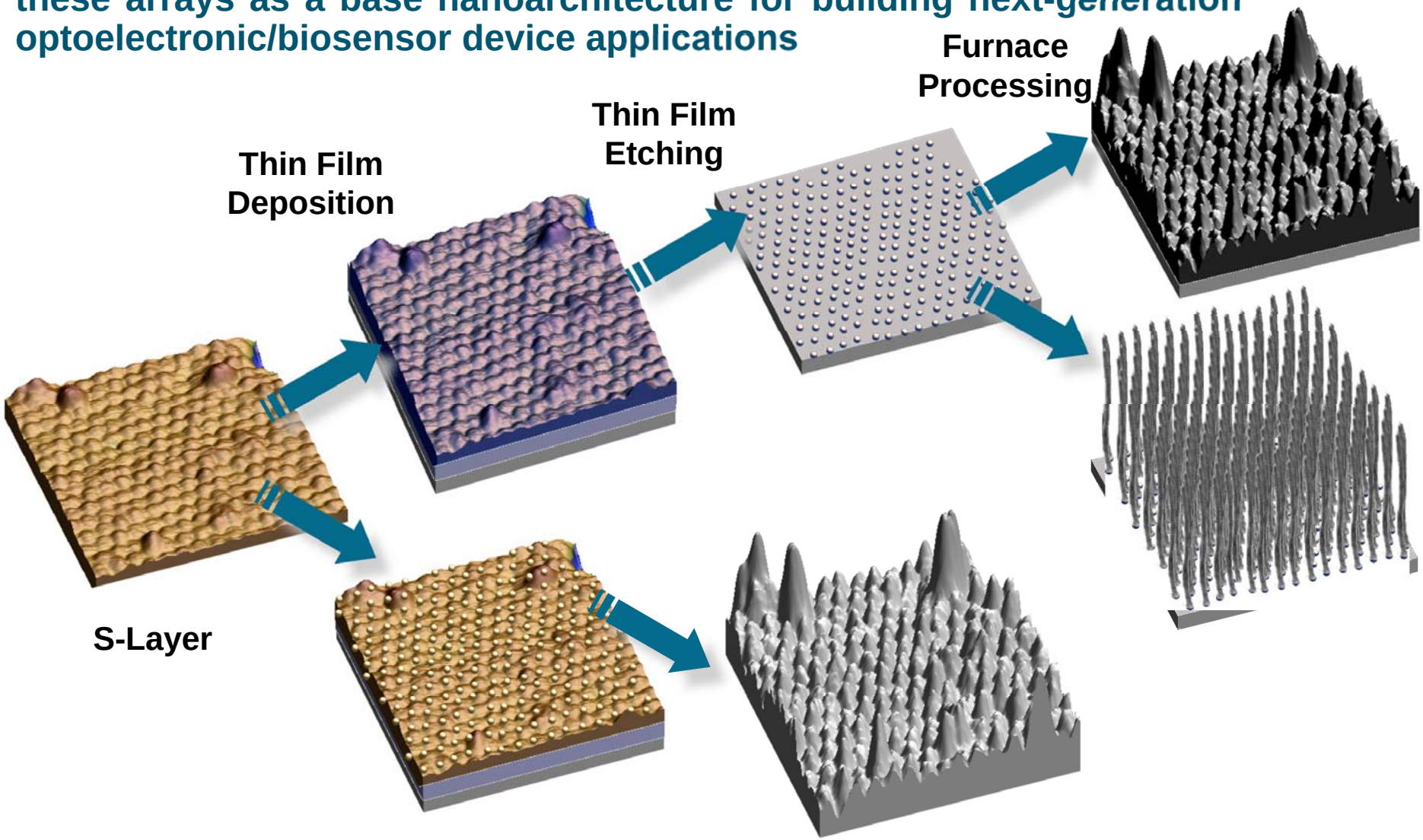




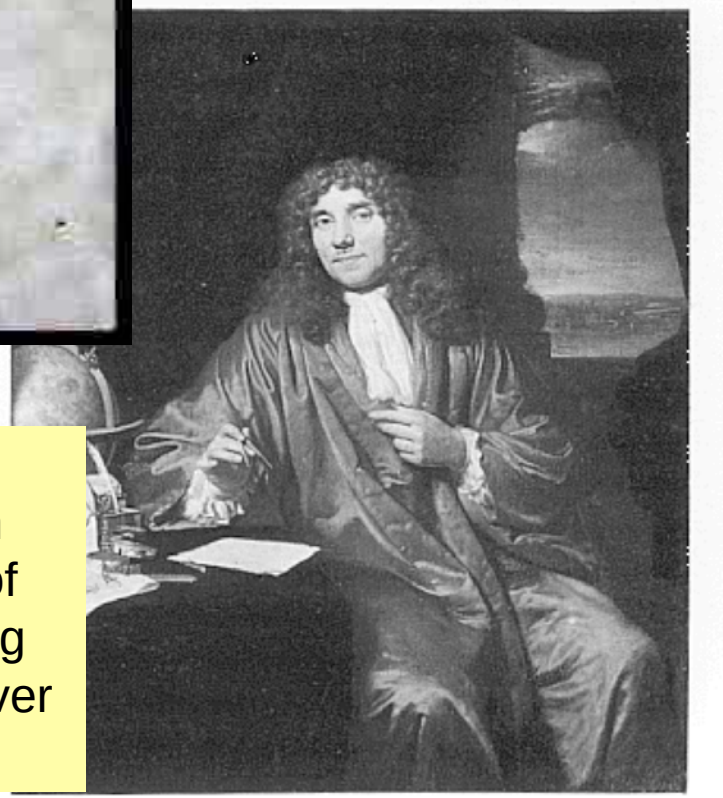
A) Top view of height image of intracellular face of HPI. Blue arrow indicates the pore within each S-layer hexameric unit. **B)** 3-D surface plot of height image of intracellular face of HPI. (Acknowledgement: Scott Bunch, McEuen LASSP Group)

Project Objectives

The major goal is to fabricate highly ordered arrays of organic/ inorganic nanostructures using S-layers as biotemplates and to use these arrays as a base nanoarchitecture for building next-generation optoelectronic/biosensor device applications

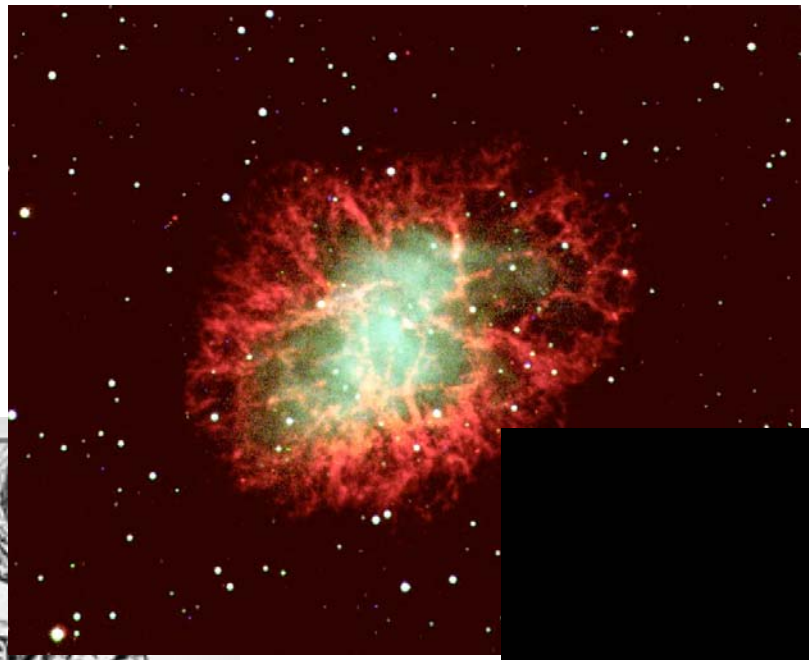


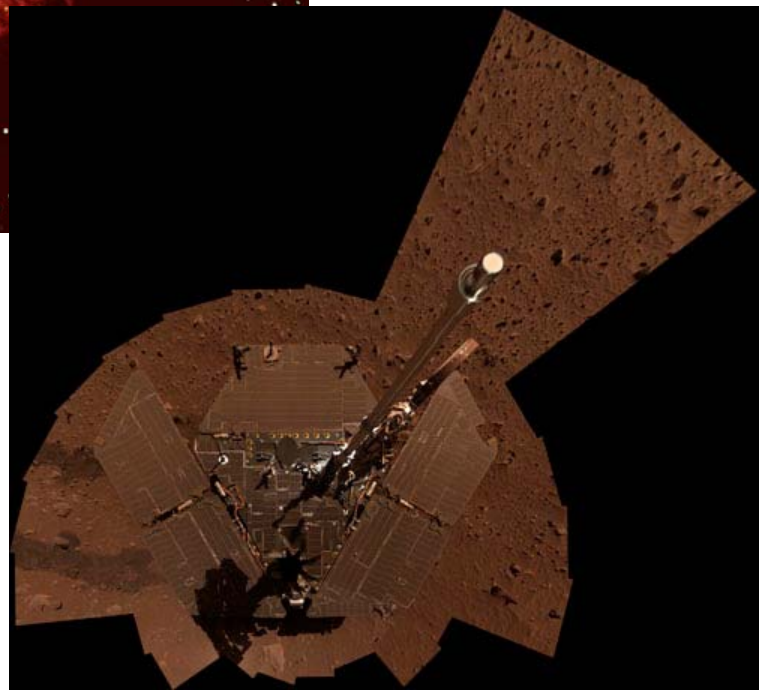
The world too small to see

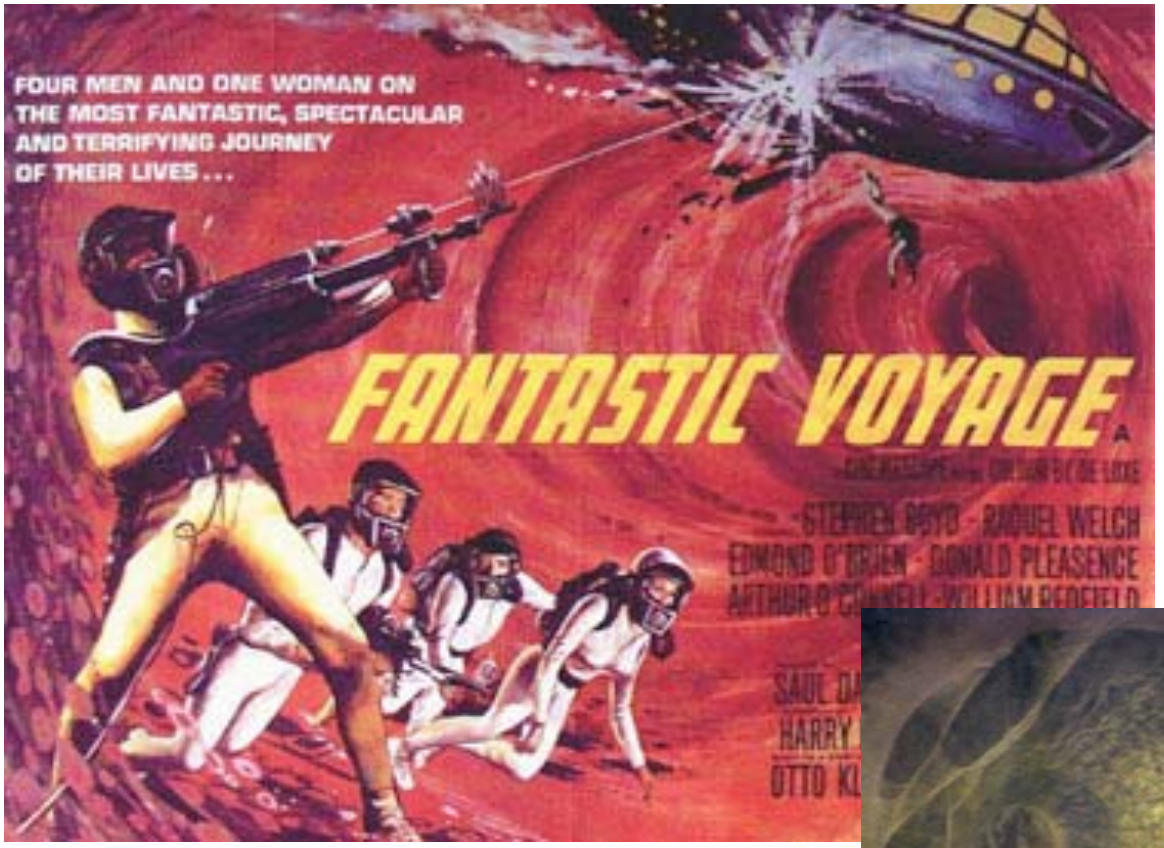


In the mouth of one of the old men, Leeuwenhoek found "an unbelievably great company of living animalcules, a-swimming more nimbly than any I had ever seen up to this time.

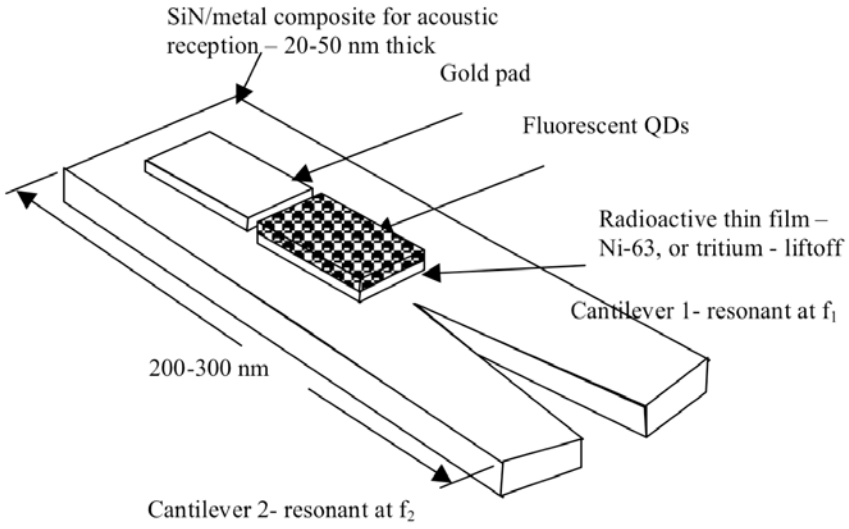
Inner space

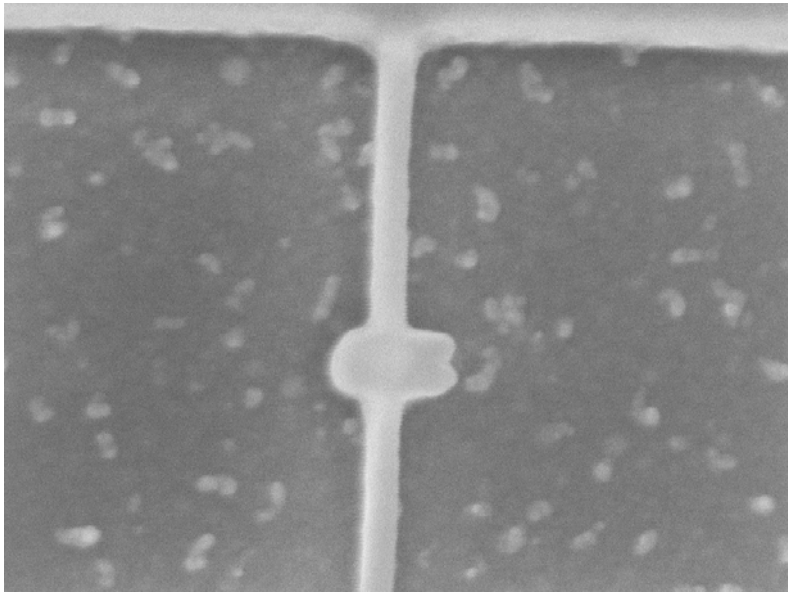


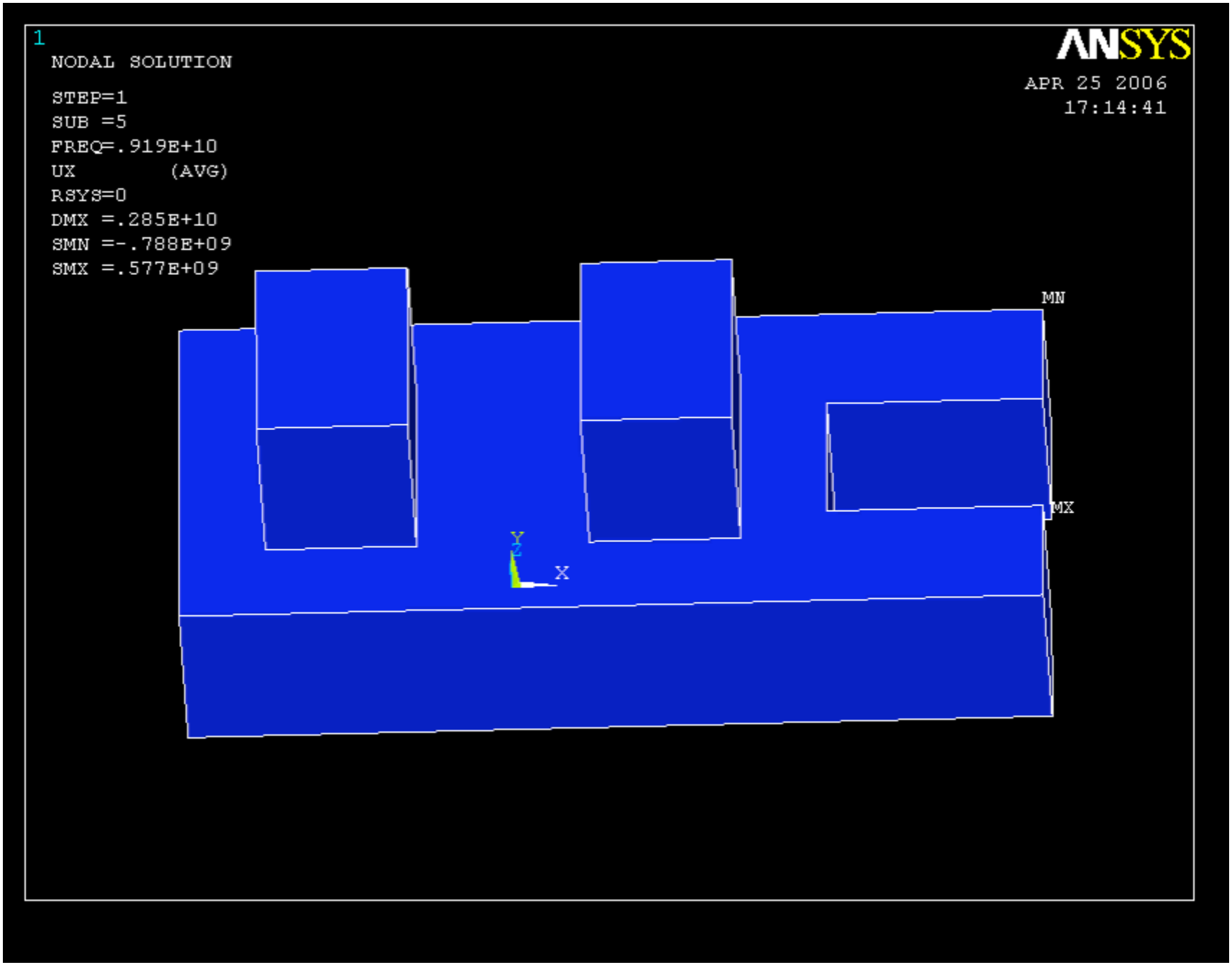



FOUR MEN AND ONE WOMAN ON
THE MOST FANTASTIC, SPECTACULAR
AND TERRIFYING JOURNEY
OF THEIR LIVES...
FANTASTIC VOYAGE
STEPHEN BOYD · RAQUEL WELCH
EDMOND O'BRIEN · DONALD PLEASENCE

Cellular space ship



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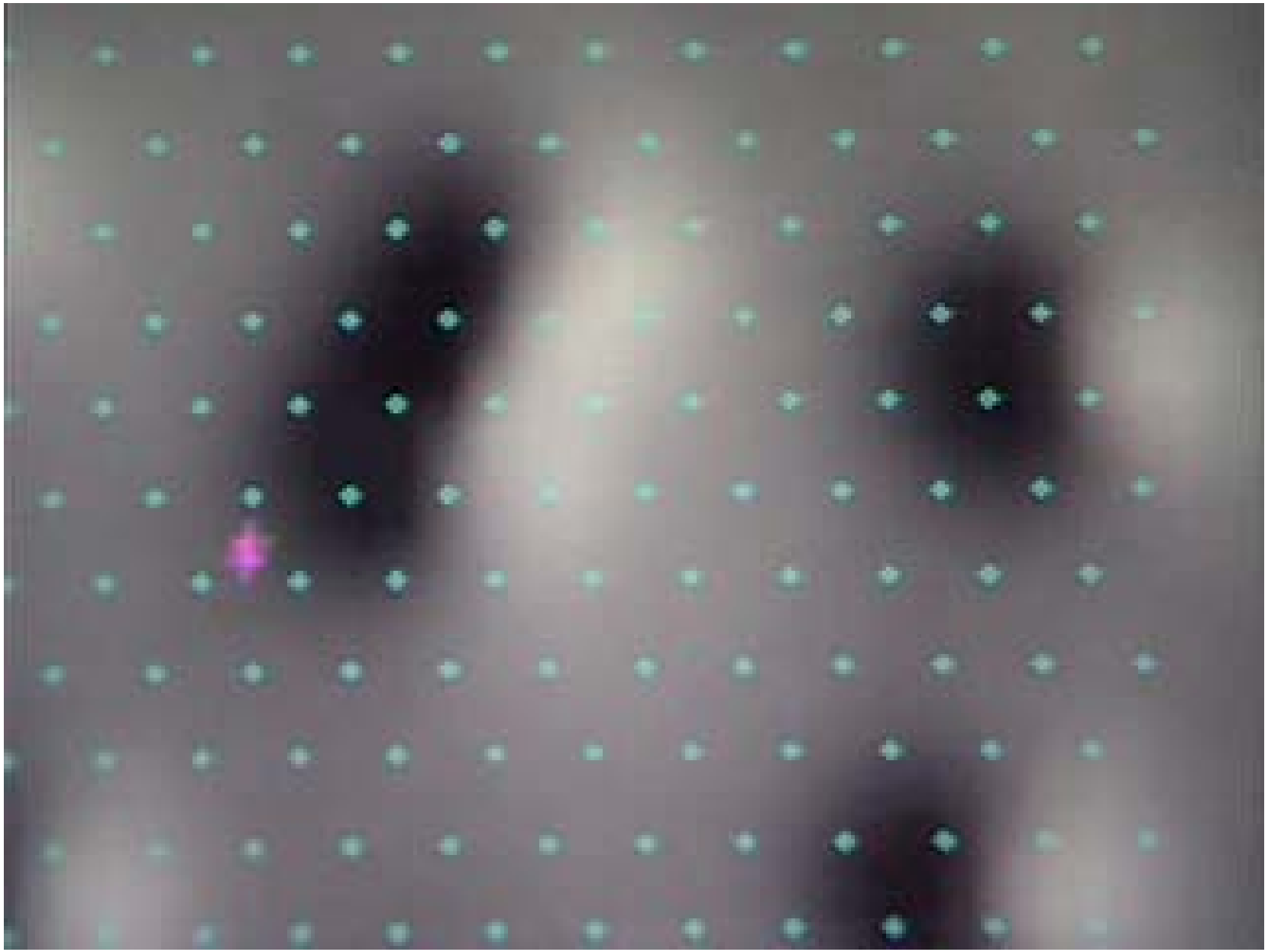
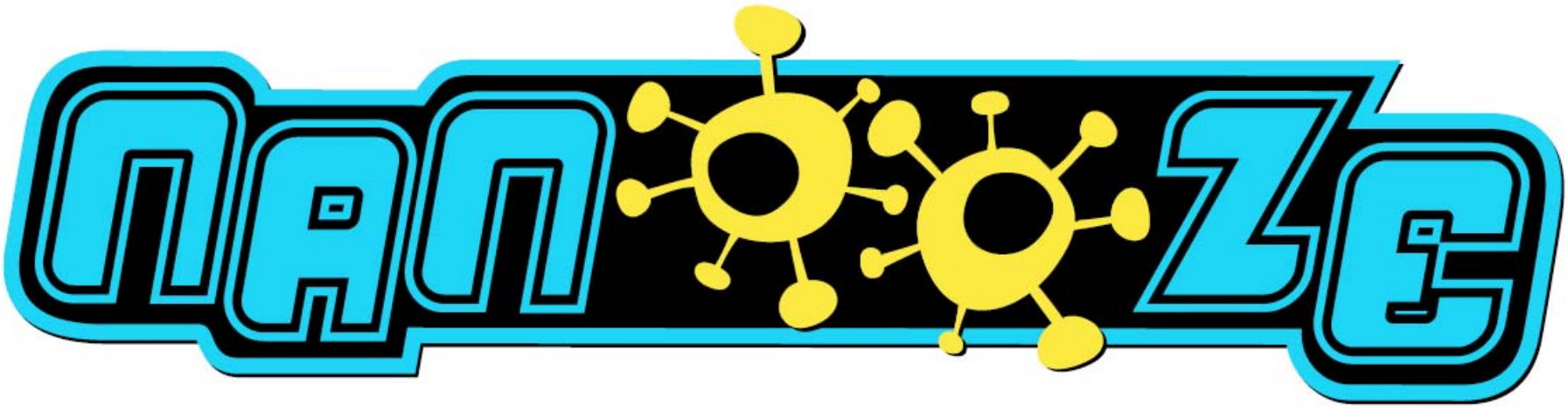
SMX =.577E+09
ANSYS
APR 25 2006
17:14:41
MN
MX
Y
Z
X

Life at the nanoscale

- All things are made of atoms.
- At the nanometer scale, atoms are in constant motion.
- Molecules have size and shape.
- Molecules and their environment make the properties at the nanometer scale, unique




NANOZC