LECTURE 1 : INTRODUCTION TO NANOMECHANICS

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Objectives: To establish the terminology, history, broad concepts, and motivation for course

Readings: Course Reader Documents 1-5

Multimedia : Listen to "*Tiny Machines*" by Richard Feynman, plus Introduction mp3 by Prof. Ortiz

NANOTECHNOLOGY / NANOMECHANICS DEFINITIONS

Nanotechnology : "Νανο" derives from the Greek word for dwarf. Technologies dealing with characteristic length scales 1-100 nanometer (1 nm) = $1*10^{-9}$ m (one billionth of a meter) →atoms molecules, cells.

Less than a nanometer : individual atoms are up to a few angstroms or up to a few tenths of a nanometer in diameter

One nanometer : Ten shoulder-to-shoulder hydrogen atoms (blue balls) span 1 nanometer. DNA molecules are ~ 2.5

Thousands of nanometers : Biological cells, like red blood cells, have diameters in this range

Billions of nanometers : A two meter tall male

A Million nanometers : The pinhead sized patch of this thumb (circled in black)

Adapted from a Report by the National Science and Technology Council (NSTC) Committee on Technology, The Interagency Working Group on Nanoscience, Engineering and Technology (IWGN) (1999)

Prefix	Symbol	Factor
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Molecular Manufacturing / Nanofabrication *:* Fabrication / modification of structures with nm-scale precision

Nanomechanics*:* Subset of the field of nanotechnology involving nN-scale forces or nm-scale displacements

Nanostructured Materials : materials where fundamental constituents are nm-sized

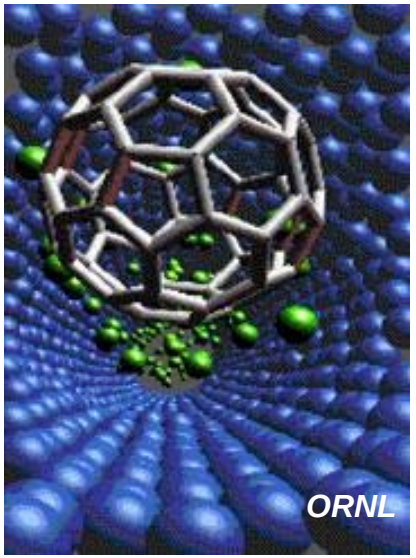
WHY IS NANO INTERESTING?

1) Design scale of nature → atoms, proteins, molecules; origins of disease
"bio-nano" - can interface with biology

2) Size-dependent nonscalable properties

3) Unique properties

HISTORY OF NANOTECHNOLOGY/NANOMECHANICS : TIME LINE



• Democritus in ancient Greece: concept of atom
• **1900** : Rutherford : discovery of atomic nucleus
• **1959** : Richard Feynman : speech at Caltech *"There is plenty of room at the bottom"*
• **1969** : Invention of Surface Forces Apparatus (SFA)
• **1981** : Invention of the Scanning Tunneling Microscope (STM) by Rohrer and Binnig at IBM Zurich (Nobel Prize 1986)
• **1982** : First STM atomic resolution by Binnig on Si 7x7
• **1985** : Fullerene " buckyballs" discovered at Rice University (Nobel prize awarded in 1996)
• **1986** : Invention of Atomic Force Microscope (AFM) by Binnig, Gerber, and Quate,measurement of 10^{-12} N forces, K. Eric Drexler "Engines of Creation"- Molecular manufacturing; bottom up & self-assembly and self-replicate, "grey-goo"
• **1989** : Invention of Optical Tweezers, first commercially available microfabricated cantilevers for AFMs
• **1990** : First commercially available AFMs, Eigler, et al. spells out "IBM" with Xenon atoms
• **1992** : First single molecule force spectroscopy experiments (DNA, Bustamante)
• **2000** : President Clinton mentions Nanotechnology in his state of the Union address : US National Nanotechnology Initiative since 2000 (14 federal agencies)
    -$422 M in '01 (federal), $604 M in '02, $774 M in '03, $847 M in '04 21 Federal agencies
• **2004** : Journals: Nanotechnology, Nano Letters, Journal of Nanoscience and Nanotechnology, IEEE Transactions on Nanotechnology, IEEE Transactions on Nanobioscience

THE FIRST TALK ON NANOTECHNOLOGY : "There's Plenty of Room at the Bottom" (1959)

Richard P. Feynman December 29th 1959 (41 y.o.)
American Physical Society Meeting (CalTech) : theoretical physicist

"Nanotech Prophet"

-**enormous amounts of information** can be carried in an exceedingly small space

-**scaling down devices requires new designs** and does not violate any fundamental laws of physics; look at biology

- **army of "slave hands" :** nanomanipulators

-**"physical synthesis"** as opposed to "chemical synthesis"

Challenges : miniaturization of the computer, direct visualization at the nanoscale, Encyclopedia Brittanica on the head of a pin, construct a 1/64 cubic inch motor

Multimedia : *Watch the movie "Tiny Machines" by Richard Feynman (1988)*

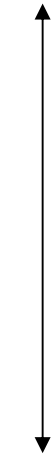
Cool book to read "Surely You're Joking Mr. Feynman"

Image removed due to copyright restrictions.
Portrait photo of Richard Feynman playing bongo drums.

MOVING INDIVIDUAL ATOMS WITH THE SCANNING TUNNELING MICROSCOPE (STM)- 30 Years after Feynaman (1990)

D. M. Eigler & E. K. Schweizer IBM Almaden (NATURE VOL 344 5 APRIL 1990)

5 nm



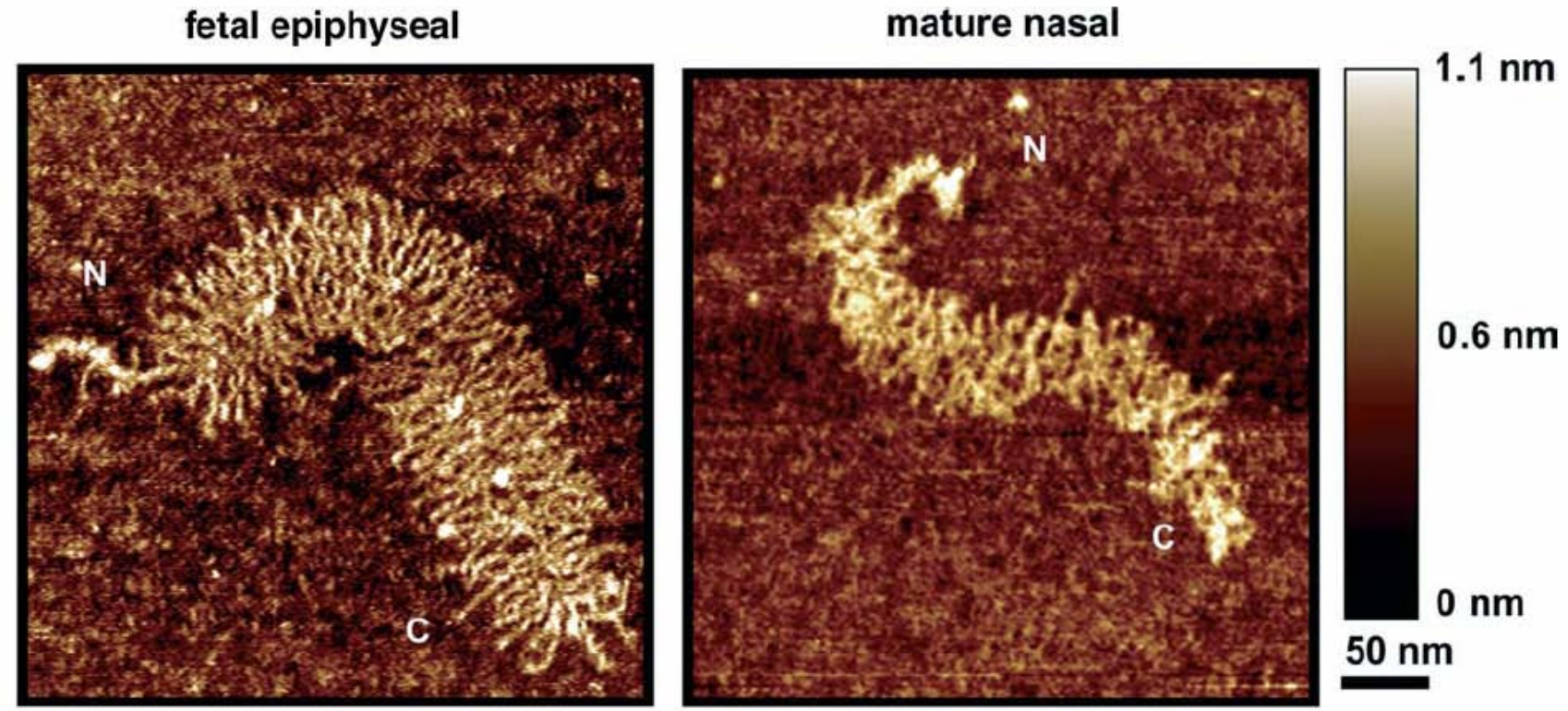
Images removed due to copyright restrictions.
1) 3-D image of letters "IBM" produced by a series of points.
2) Photo of the STM tip.

Move and position individual atoms on a metal surface using a scanning tunneling microscope tip. Writing one atom at a time with Xe atoms on a Ni (110) surface, IBM scientists could actually fit the Encyclopedia Brittanica on a space the size of a pin head. The STM microscope was cooled to 4 K, in an ultra-high -vacuum system, and the STM tip speed was 0.4 nm/sec. At that speed they could have completed the job in about 87,000 years.

- **The challenge is how to build macroscopic structures in a reasonable time frame and how to make functional structures.**

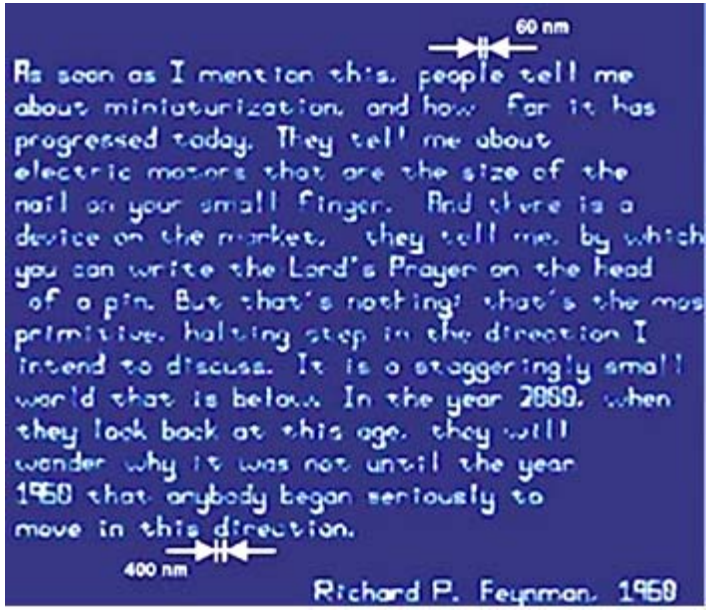
IMAGING INDIVIDUAL BIOMACROMOLECULES WITH THE ATOMIC FORCE MICROSCOPE (2003)

Ng, Ortiz et al. 143 Journal of Structural Biology 2003 242- individual cartilage aggrecan macromolecules



-Relevance to disease (e.g. osteoarthritis), diagnostics, and tissue engineering

DIP PEN NANOLITHOGRAPHY: "There's Plenty of Room at the Bottom" - 40 years later (1999)



Mirkin Research Group (Northwestern)

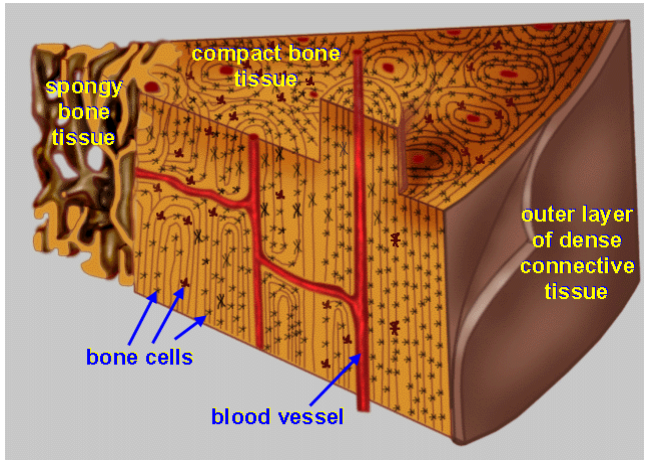
Schematic diagram of "Dip-Pen Nanolithography" removed due to copyright restrictions.

Richard P. Feynman, “There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics,” - *http://www.its.caltech.edu/~feynman/plenty.html*
Feynman’s speech written with organic molecular ink on a gold surface via dip pen nanolithography in 1999. - *http://www.physics.fsu.edu/PhysicsNewsletter/Fall01/Default.htm*

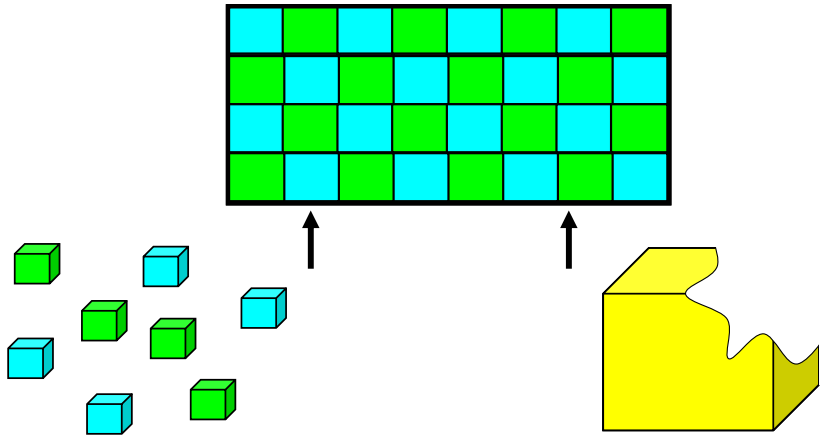
NanoInk Nanoencryption Pharmaceutical Brand Protection *(www.Nanoink.net)*

Photo courtesy of andrew_mrt1976.

NANOFABRICATION /NANOSTRUCTURED MATERIALS: "BOTTOM UP" vs. "TOP DOWN"

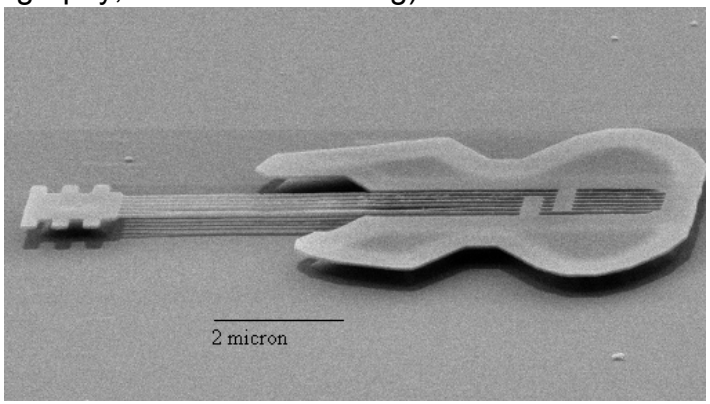


(Chemistry-Biology) Self-assembly : molecules aggregate in well-defined manner creating a supramolecular structure



(*Engineering*)- start with larger, bulk structure sculpt away to create smaller nm-size structures (e.g. mechanical milling electron beam lithography, reactive ion etching)

Electron microscope image of the world's smallest guitar. Its length is 10 μm- approximately the size of a red blood cell and about 1/20th the width of a single human hair. Its strings have a width of about 50 nm (the size of approximately 100 atoms). Plucking the tiny strings would produce a high-pitched sound at the inaudible frequency of approximately 10 megahertz. Made by Cornell researchers with a single silicon crystal.
(*http://www.news.cornell.edu/science/July97/guitar.ltb.html*)



Courtesy of Prof. Harold G. Craighead. Used with permission.

NANOMECHANICS : CONCEPT OF A CONTINUUM

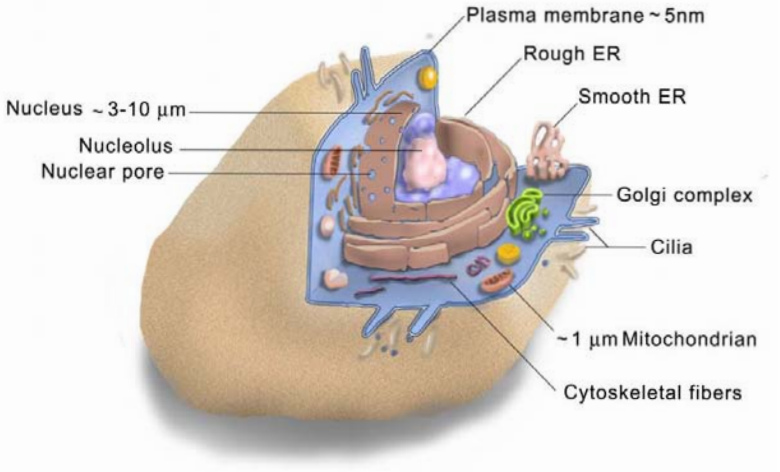
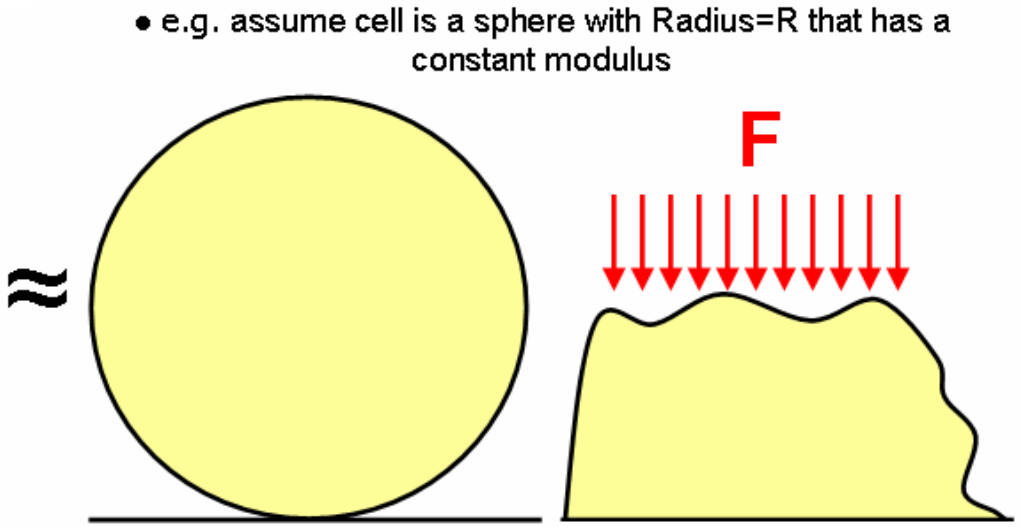


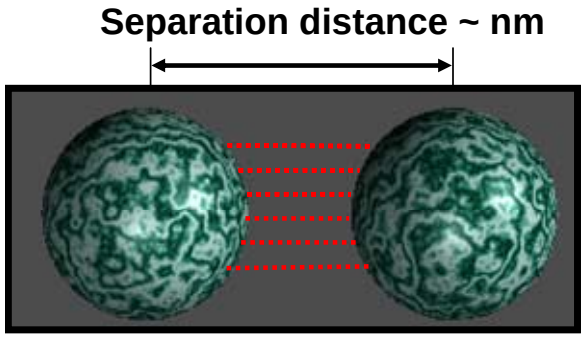
Figure by MIT OCW.



- A continuum is a region of space filled with continuous matter that has continuous properties→ ignore heterogeneities (e.g. pores)
- Approximation that breaks down at small enough length scales depending on the material structure.

NANOMECHANICS SUBCATEGORIES

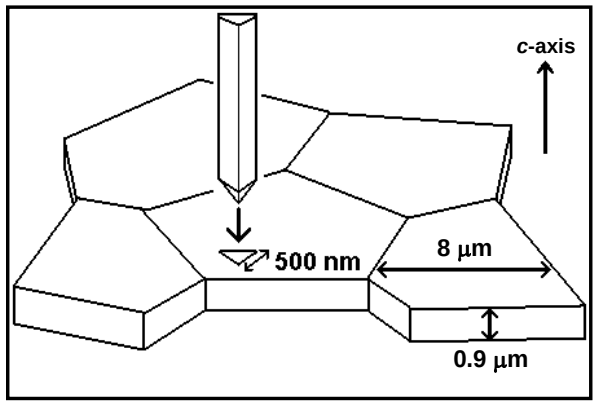
1. Noncontact : High Resolution Force Spectroscopy, surface forces measurement (e.g. electrostatics, van der Waals forces, etc.)

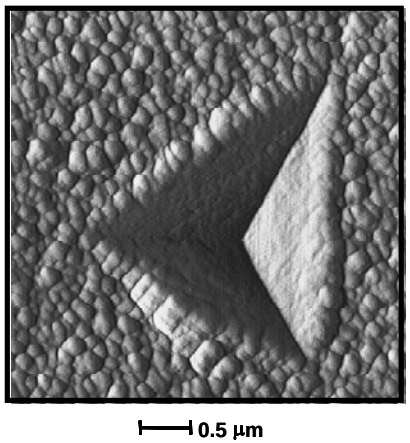


Sample topics covered in course :

- heparin biosensor
- single protein and DNA tensile testing
- sacrificial bonding in biological materials
- nanomechanics of cell surfaces -lipid bilayers
- molecular origins of biocompatibility
- electrostatic interactions in cartilage and the origins of osteoarthritis

2. Contact : Nanoindentation, single cell tensile testing (e.g. elasticity, plasticity, → dislocations) etc.





Sample topics covered in course :

- tensile testing of diseased cells-malaria
- nanogranular friction in bone
- nanomechanics of seashells