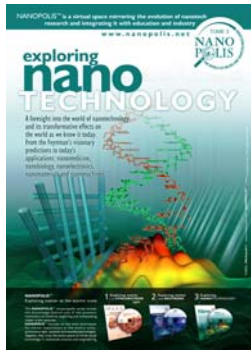


## EE 428/528 BioMEMS & Lab-on-a-chip

### Lecture 03: What is Nanotechnology & NanoBioSensors?



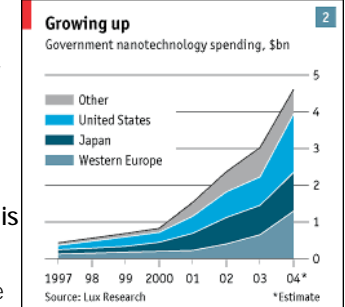
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### [Nano Tech] Nanotechnology Milestone (1)

- ◆ **1905:** Albert Einstein publishes a paper that estimates the diameter of a sugar molecule as about one nanometer
- ◆ **1931:** Max Knoll and Ernst Ruska develop the electron microscope that enabled sub-nanometer imaging
- ◆ **1959:** Richard Feynman gives his famed talk "There's plenty of room at the bottom"
- ◆ **1968:** Alfred Y. Cho and John Arthur of Bell Laboratories and their colleagues invent molecular-beam epitaxy, a technique that can deposit single atomic layers on a surface
- ◆ **1981:** Gerd Binnig and Heinrich Rohrer create the scanning tunneling microscope, which can image individual atoms Nobel prize in physics, 1986
- ◆ **1985:** Robert F. Curl Jr., Harold W. Kroto, Richard E. Smalley discovered the Fullerene (C60, also called buckyball) Nobel prize in Chemistry, 1995
- ◆ **1989:** Donald M. Eigler of IBM writes the letters of his company's name using individual xenon atoms

### [Nano Tech] What is Nanotechnology?

- ◆ Nanotechnology is the understanding and control of matter at dimensions roughly 1 to 100 nanometers, where unique phenomena enable novel applications.
- ◆ Nanotechnology 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 research is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties
- ◆ One area of nanotechnology R&D is medicine.
  - ◆ Medical researchers work at the micro- and nano-scales to develop new drug delivery methods, therapeutics and pharmaceuticals.
- ◆ A nanometer is one-billionth of a meter; a sheet of paper is about 100,000 nanometers thick.
  - ◆ For a bit of perspective, the diameter of DNA, our genetic material, is in the 2.5 nanometer range, while red blood cells are approximately 2.5 micrometers.



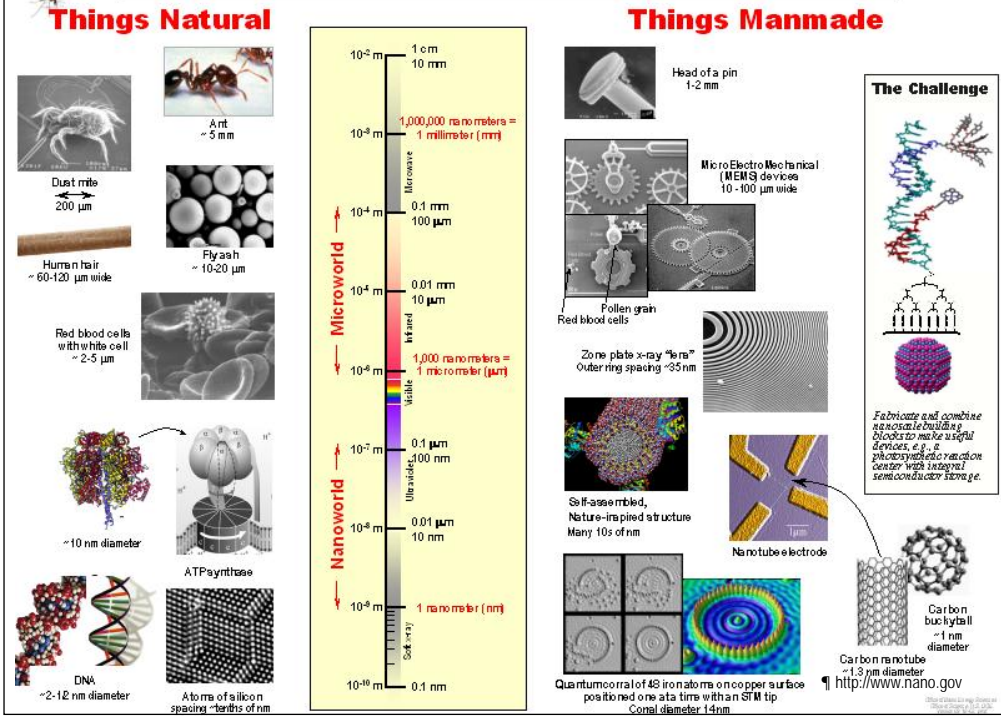
### [Nano Tech] Nanotechnology Milestone (2)

- ◆ **1991:** Sumio Iijima of NEC discovers carbon nanotubes
- ◆ **1997:** Steven Chou and coworkers at Princeton unveils a single-electron transistor that operates at room temperature
- ◆ **1997:** James Tour, now at Rice University and Mark Reed of Yale University measure the resistance of a single molecule placed between two electrodes
- ◆ **1998:** Cees Dekker's group at the Delft University of Technology creates a transistor from a single molecule (carbon nanotube)
- ◆ **2000:** The Clinton administration announces the National Nanotechnology Initiative (NNI), providing a big boost in funding (\$700M/yr)
- ◆ **2002:** IBM announces the Millipede, a data storage device based on the atomic force microscope that can write, read, and erase 10nm holes in a plastic film (50GB/square inch)

## [Nano Tech] The National Nanotechnology Initiative (NNI)

- An American federal nanoscale science, engineering, and technology research and development program.
- Vision
  - ◆ A future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry.
- Goals
  - ◆ Maintain a world-class research and development (R&D) program;
  - ◆ Facilitate technology transfer;
  - ◆ Develop educational resources, a skilled workforce, and supporting research infrastructure and tools; and
  - ◆ Support responsible development of nanotechnology.
- History
  - ◆ In a 21 January 2000 speech at the California Institute of Technology, President Clinton said, "Some of our research goals may take twenty or more years to achieve, but that is precisely why there is an important role for the federal government."
  - ◆ In 2003 President Bush signed into law the 21st Century Nanotechnology Research and Development Act (Public Law 108-153), which authorizes expenditures for five of the participating agencies totalling \$3.63 billion over four years.
  - ◆ Federal funding for nanotechnology R&D has increased substantially since inception of the NNI, from \$464 million in 2001 to an estimated \$1,081 million in 2005.

## The Scale of Things – Nanometers and More



## [Nano Tech] Examples of Nanotechnology Applications

- ◆ Giant magnetoresistance in nanocrystalline materials
- ◆ Nanolayers with selective optical barriers, hard coatings
- ◆ Dispersions with optoelectronic properties, high reactivity
- ◆ Chemical and bio-detectors
- ◆ Advanced drug delivery systems
- ◆ Chemical-mechanical polishing with nanoparticle slurries
- ◆ New generation of lasers
- ◆ Nanostructured catalysts
- ◆ Systems on a chip
- ◆ Carbon nanotube products
- ◆ Nanoparticle reinforced materials
- ◆ Thermal barrier
- ◆ Ink jet systems
- ◆ Information recording layers
- ◆ Molecular sieves
- ◆ High hardness cutting tools



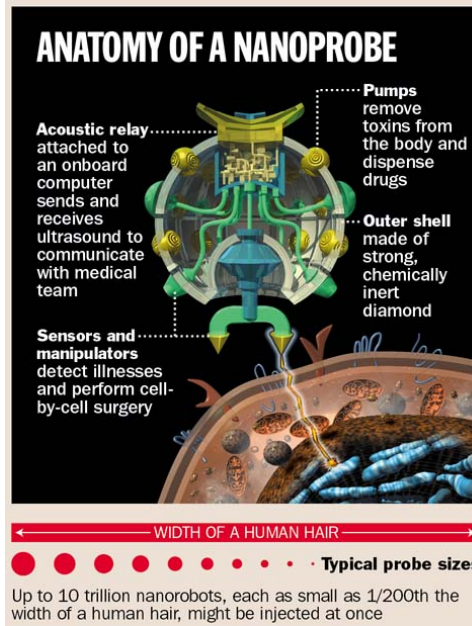
## [Nano Tech] What products will be available in the next few years?

- Prototype tires exist today that provide improved skid resistance, reduced abrasion and resulting longer wear, although a date for market introduction has yet to be announced.
  - ◆ The nanocomposites being used in tires can be used in other consumer products as well, according to experts, including high performance footwear, exercise equipment, and car parts such as belts, wiper blades and seals.
- The pharmaceutical and chemical industries are being impacted greatly by nanotechnology, as well.
- New commercial applications of nanotechnology that are expected in two to five years in these industries include:
  - ◆ Advanced drug delivery systems, including implantable devices that automatically administer drugs and sensor drug levels;
  - ◆ Medical diagnostic tools, such as cancer tagging mechanisms and lab-on-a-chip, real time diagnostics for physicians;
  - ◆ Cooling chips or wafers to replace compressors in cars, refrigerators, air conditioners and multiple other devices, utilizing no chemicals or moving parts;
  - ◆ Sensors for airborne chemicals or other toxins;
  - ◆ Photovoltaics (solar cells), fuel cells and portable power to provide inexpensive, clean energy, and
  - ◆ New high-performance materials.

## [Nano Tech] Next 10-20 years?

- ❖ It's hard to predict what products will move from the laboratory to the marketplace over such a long period, but today's predictions center on pervasive computing applications.
  - ◆ It is believed that nanotechnology will facilitate the production of ever-smaller computers that store vastly greater amounts of information and process data much more quickly than those available today. Computing elements are expected to be so inexpensive that they can be in fabrics (for smoke detection, for instance) and other materials.
- ❖ Advances in the field of defense are also expected through work in nanoscience.
- ❖ Nanomedicine
  - ◆ To create the *conceptual and literal interface* between biology and medical devices *at the scale* of biomolecular processes.
  - ◆ Bio is Nano

Time Magazine, 11/08/1999, <http://www.nano.gov>



## [NanoBiosensor] What is NanoBiotechnology?

- ❖ The application of nanotechnology to the life sciences is relatively new.
- ❖ Academic projects far outnumber marketed products in the field. Nanomaterials such as carbon Buckyballs, dendrimers, and metal nanoparticles have begun to reach the market for pharmaceutical and diagnostic use both in vitro and in vivo.
- ❖ Currently available products fall into three major segments of nanobiotechnology:
  - ◆ Drug delivery
  - ◆ Imaging agents, and
  - ◆ Biosensors
- ❖ The market for nanobiotechnology has only existed for a few years, but is expected to grow rapidly to reach over \$3B in 2008, reflecting growth at an annual rate of 28% worldwide. The current estimated worldwide market breakdown is: U.S. at 65%, Europe at 20%, Japan at 10%, and the rest of the world at 5%.

## [NanoBiosensor] What is NanoBiosensors?

- ❖ Biosensors
  - ◆ Natural sensors that are part of life
  - ◆ A device generally for sensing and measuring particular chemicals of biological components
    - Sensors for biological entities including proteins, drugs, and even specific viruses
  - ◆ A device incorporating a biological sensing element connected to a transducer
- ❖ Best Biosensors will be made from Nanostructures
  - ◆ The scale of Bio is about small (nano and/or micro)
- ❖ Nano + Bio + Sensors
  - ◆ Nano-scale (nanoscience & nanotechnology)
  - ◆ Bio (bio/medical/chemical) applications
  - ◆ Sensors
    - Structures that indicate the presence of particular molecules or biological structures, as well as the amounts that are present

## [NanoBiosensor] Challenges in NanoBiosensor

- ❖ Attain a fundamental understanding of nanoscale biosensing phenomena.
- ❖ Design and fabricate biologically active sensing interfaces
  - ◆ DNA, proteins, cells, tissues, other.
- ❖ Novel theoretical and experimental tools for a rapid development of the NanoBiosensor technology.
- ❖ Novel detection
  - ◆ Label-free detection (optics-free, cheap)
  - ◆ Selective detection (specificity)
  - ◆ High resolution and sensitivity (how small amount)
  - ◆ In-situ detection (real-time)
  - ◆ In-vivo detection (in a living cell, organism, or even human body)
- ❖ Integration of biological, physical (mechanical, optical, acoustic) and electronic components into multifunctional biosensor systems
  - ◆ Novel immobilization techniques
  - ◆ Solid-state transducer nano/microfabrication technologies
  - ◆ Microfluidic systems
  - ◆ IC circuits for signal conditioning and processing
  - ◆ Smart biosensors and biosensor systems.

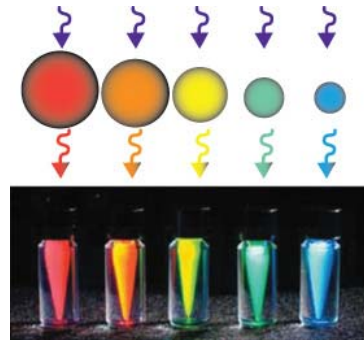
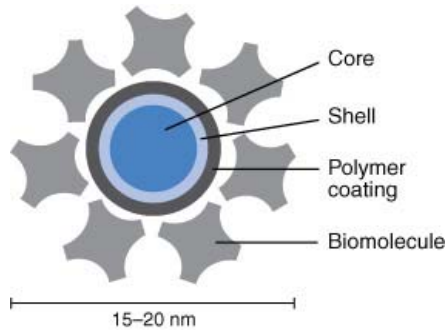
## [NanoBiosensor] Example of NanoBiosensors

### Gold Nanoparticles

- The research of DNA functioning and detection of proteins involved in cancers.

### Quantum Dots

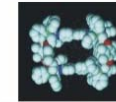
- Structure of Qdot™ by Invitrogen and schematic of difference in color due to core size difference.



## [NanoBiosensor] Example of NanoBiosensors

### Mirkin Group Research Controlling Architecture on the 1-100 nm Length Scale

#### Supramolecular Assembly



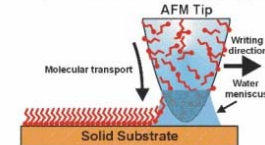
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J. Am. Chem. Soc., 2003, 125, 10508-10509  
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J. Am. Chem. Soc., 2005, 127, 1644-1645

#### Biomolecule Directed Assembly



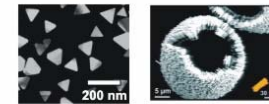
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J. Am. Chem. Soc., 2004, 126, 5932-5933  
Proc. Natl. Acad. Sci., 2005, 102, 2273-2276

#### Dip-Pen Nanolithography



Science, 2000, 288, 1808-1811  
Angew. Chem., Int. Ed., 2004, 43, 30-45  
J. Am. Chem. Soc., 2004, 126, 16653-16658  
Small, 2005, 1, 445-451  
Science, 2005, 307, 1763-1766

#### Anisotropic Nanostructures



Science, 2004, 303, 348-351  
Angew. Chem., Int. Ed., 2004, 43, 3048-3050  
Adv. Mater., 2005, 17, 412-415

<http://www.chem.northwestern.edu/%7Emkngrp/Group%20Research.htm>

## [ Nano Tech] Confusion regarding the term "Nano-" ?

### Nanosatellite

- A 'volleyball-sized' satellite with an on-orbit mass of 1-10 kg
- [http://www.daviddarling.info/encyclopedia/S/satellite\\_mass\\_categories.html](http://www.daviddarling.info/encyclopedia/S/satellite_mass_categories.html)

### iPod Nano

- Just size of pencils



### Case-by-Case

- A continuation of "regular" science and technology, just done on the nano-scale?
- A completely new type of science and technology (or concept)?
- Reactions at the nano-scale?
- Free-floating particles measured on the nano-scale?
- Objects with fixed pieces that are designed and/or work only on the nano-scale?
- Small-scale (micro or nano is relatively small size)?
- All of the above?
- Some combination of the above?
- Something else altogether? (maybe for better business)

#### SI prefixes

Factor	Name	Symbol
10 <sup>24</sup>	yotta	Y
10 <sup>21</sup>	zetta	Z
10 <sup>18</sup>	exa	E
10 <sup>15</sup>	peta	P
10 <sup>12</sup>	tera	T
10 <sup>9</sup>	giga	G
10 <sup>6</sup>	mega	M
10 <sup>3</sup>	kilo	k
10 <sup>2</sup>	hecto	h
10 <sup>1</sup>	deka	da
10 <sup>-1</sup>	deci	d
10 <sup>-2</sup>	centi	c
10 <sup>-3</sup>	milli	m
10 <sup>-6</sup>	micro	μ
10 <sup>-9</sup>	nano	n
10 <sup>-12</sup>	pico	p
10 <sup>-15</sup>	femto	f
10 <sup>-18</sup>	atto	a
10 <sup>-21</sup>	zepto	z
10 <sup>-24</sup>	yocto	Y

## UB2020 A Plan for the Future

- Through the strong leadership of UB President John B. Simpson, the university community has undertaken an intensive self-evaluation and review of its mission, aspirations and goals.
- At the core of the strategic planning process — UB 2020 — is the goal of changing how we think about what we do.
- This paradigm shift will advance academic excellence, making our university one of the nation's leading public research universities during the next 15 years.
- UB is creating a comprehensive plan to support the university's academic programs and best position them to realize their potential.
- The plan will be a roadmap that the university will follow to realign resources, make strategic investments, develop partnerships and recruit new faculty.

## 10 “Strategic Strengths”

- ◆ Aging and Chronic Diseases
- ◆ Artistic Expression and Performing Arts
- ◆ [Bioinformatics and Health Sciences](#)
- ◆ Civic Engagement and Public Policy
- ◆ Clinical Sciences and Experimental Medicine
- ◆ Cultural, Historical and Literary/Textual Studies
- ◆ Extreme Events: Mitigation and Response
- ◆ [Information and Computing Technology](#)
- ◆ [Integrated Nanostructured Systems](#)
- ◆ [Molecular Recognition in Biological Systems](#)

## [EE 5xx] EE 5xx Nanobio Systems & Sensors

<u>Wk 01</u>	Introduction to Integrated Nanobiosystems
<u>Wk 02</u>	Biological problems
<u>Wk 03</u>	Assembly - Top Down
<u>Wk 04</u>	Growth - Bottom Up
<u>Wk 05</u>	Novel biomaterials through molecular self-assembly
<u>Wk 06</u>	Nanodevices / nanosystems
<u>Wk 07</u>	Integrated nanoliter systems / nanofluidics
<u>Wk 08</u>	Biosensors and bioelectronics
<u>Wk 09</u>	Electrochemical sensors / BioFET
<u>Wk 10</u>	Nanostructure-based biosensors
<u>Wk 11</u>	Nanoparticles for biosensing
<u>Wk 12</u>	Nanocrystals for biosensing
<u>Wk 13</u>	Magnetic biosensors
<u>Wk 14</u>	Small-scale systems for <i>in vivo</i> drug delivery
<u>Wk 15</u>	Commercializing nanobiotechnology
<u>Wk 16</u>	Recent and future trends in Integrated Nanobiosystems