OUR BIOTECH FUTURE - NANOTECHNOLOGY MEETS BIOTECHNOLOGY: SCIENCE FICTION OR REALITY?

- CHEMICAL SENSORS GROUP -

CSG

NANOMATERIALS - NUCLEIC ACIDS - DETECTION

UNIVERSITY OF TORONTO AT MISSISSAUGA

UNIVERSITY of TORONTO

MISSISSAUGA

DISCOVERY → KNOWLEDGE

KNOWLEDGE ←→ TECHNOLOGY

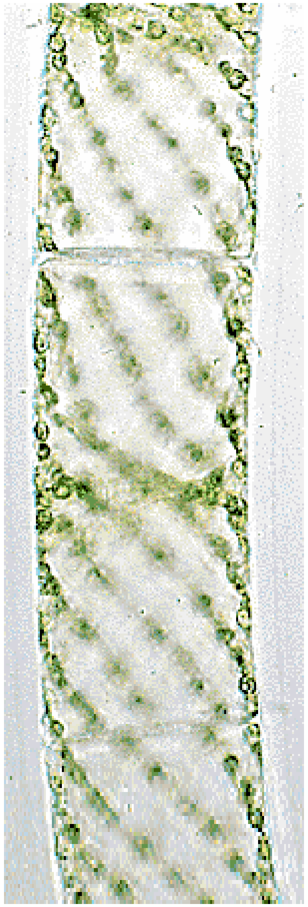
TECHNOLOGY ←→ SOCIETY

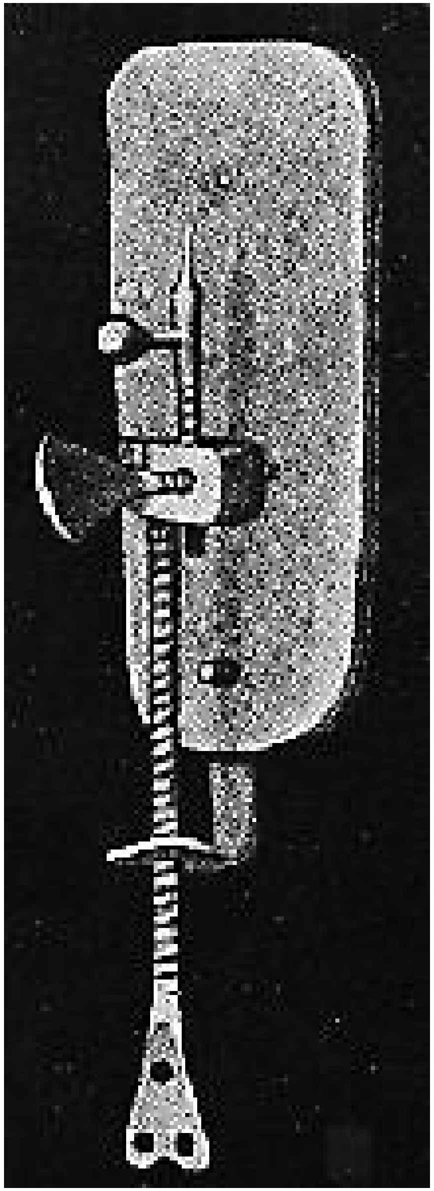
SOCIETY → DISCOVERY??

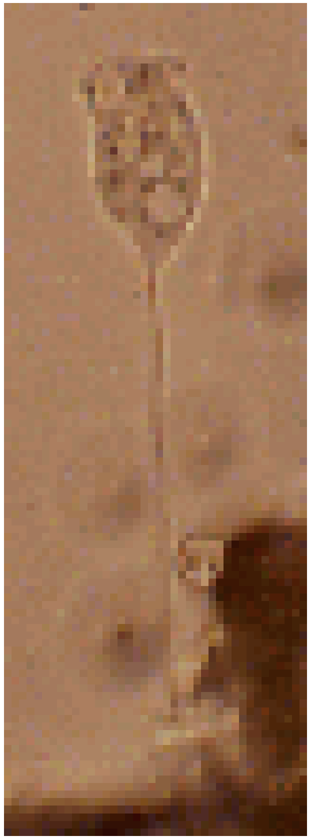
A cycle driven by curiosity and exploration, tempered by need and prejudice

Antony van Leeuwenhoek (1632-1723)

http://www.ucmp.berkeley.edu/history/leeuwenhoek.html



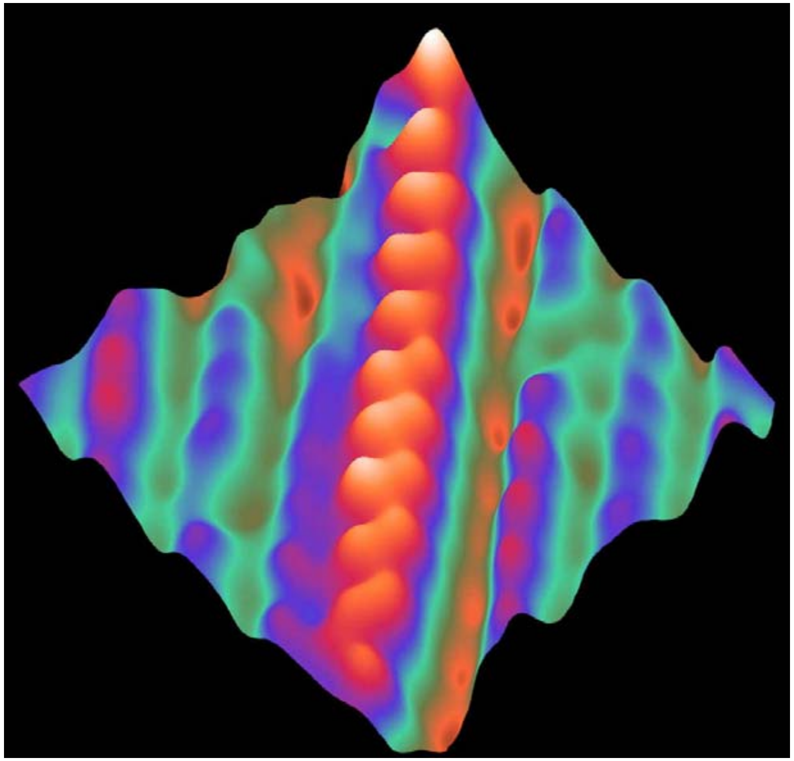




http://www.ucmp.berkeley.edu/history/leeuwenhoek.html

NANOSCALE CONCEPTS

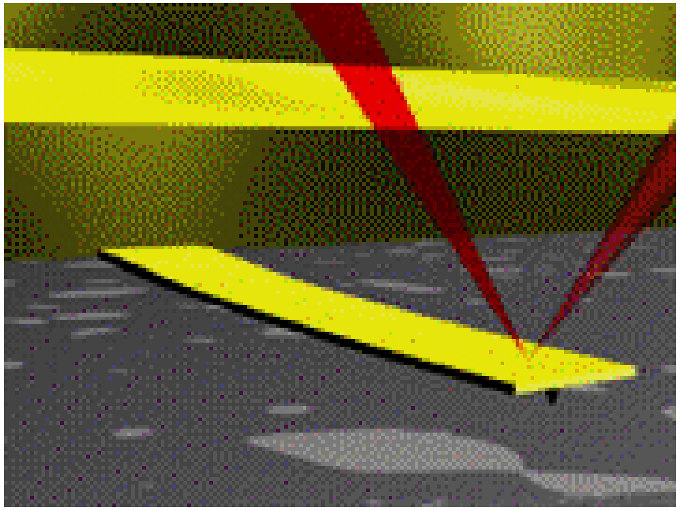
What is Nanotechnology?



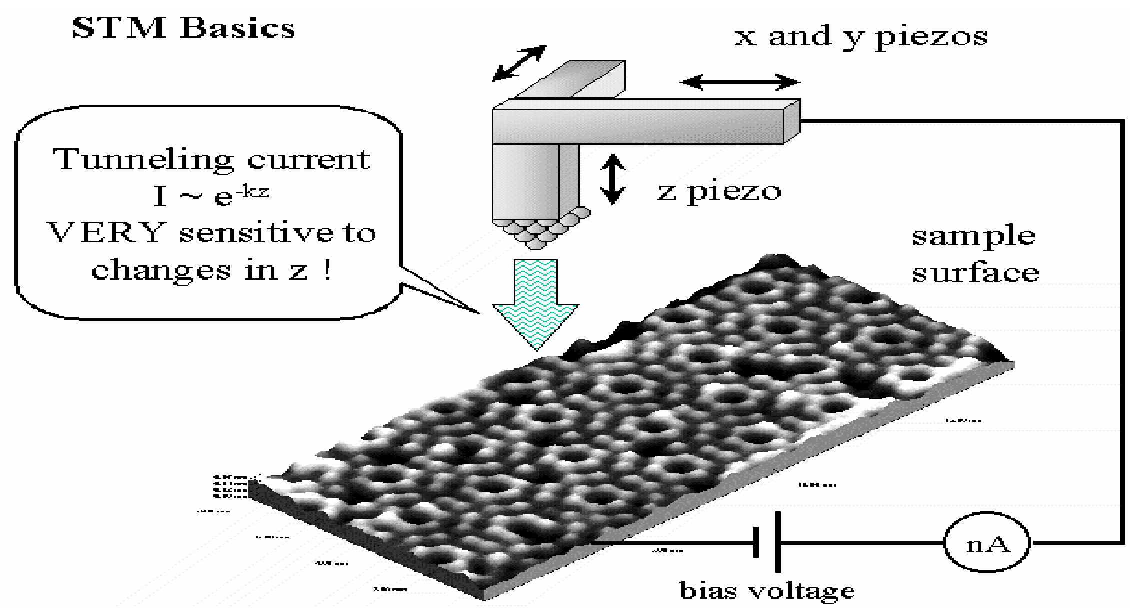
Nanotechnology is defined as the application of science to developing new materials and processes by manipulating molecular and atomic particles.

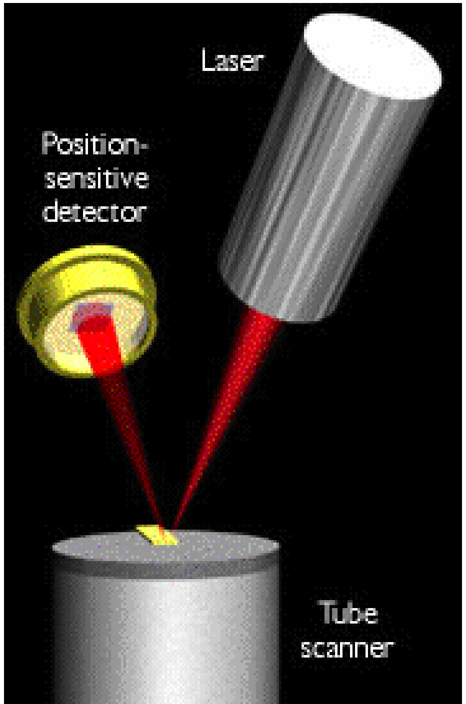
http://www.nint.ca/nav01.cfm?nav01=12988

Atomic Force Microscopy



AFM invented in 1986 by G. Binning.
STM in 1982 by H. Roher and G. Binning



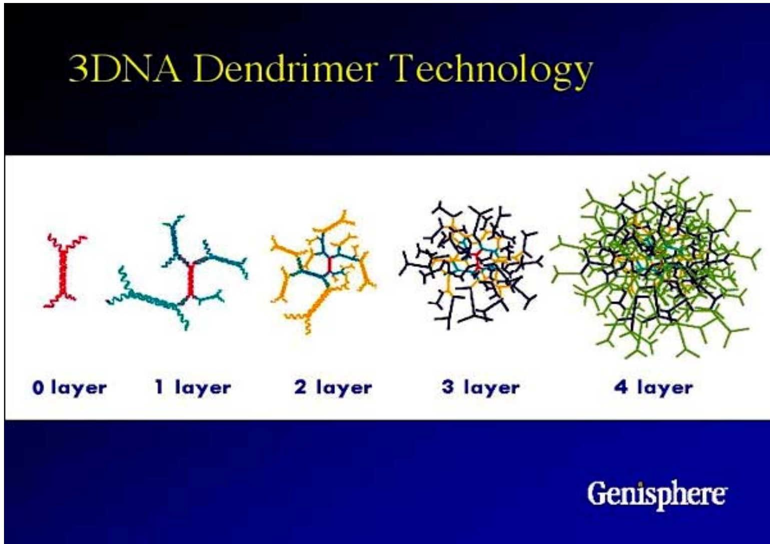


SMALL SCALE PROVIDES NEW OPPORTUNITIES, BUT WHAT IS NANOTECHNOLOGY?

Commercially hear about “nanosomes” for cosmetics; but these are lipid vesicles of 100 nm size and larger

“Stain Guard” is an example of an application of nanotechnology

Rolling water from a Lotus leaf is an example of natural nanotechnology



MULTI-DISCIPLINARY AND CREATIVITY

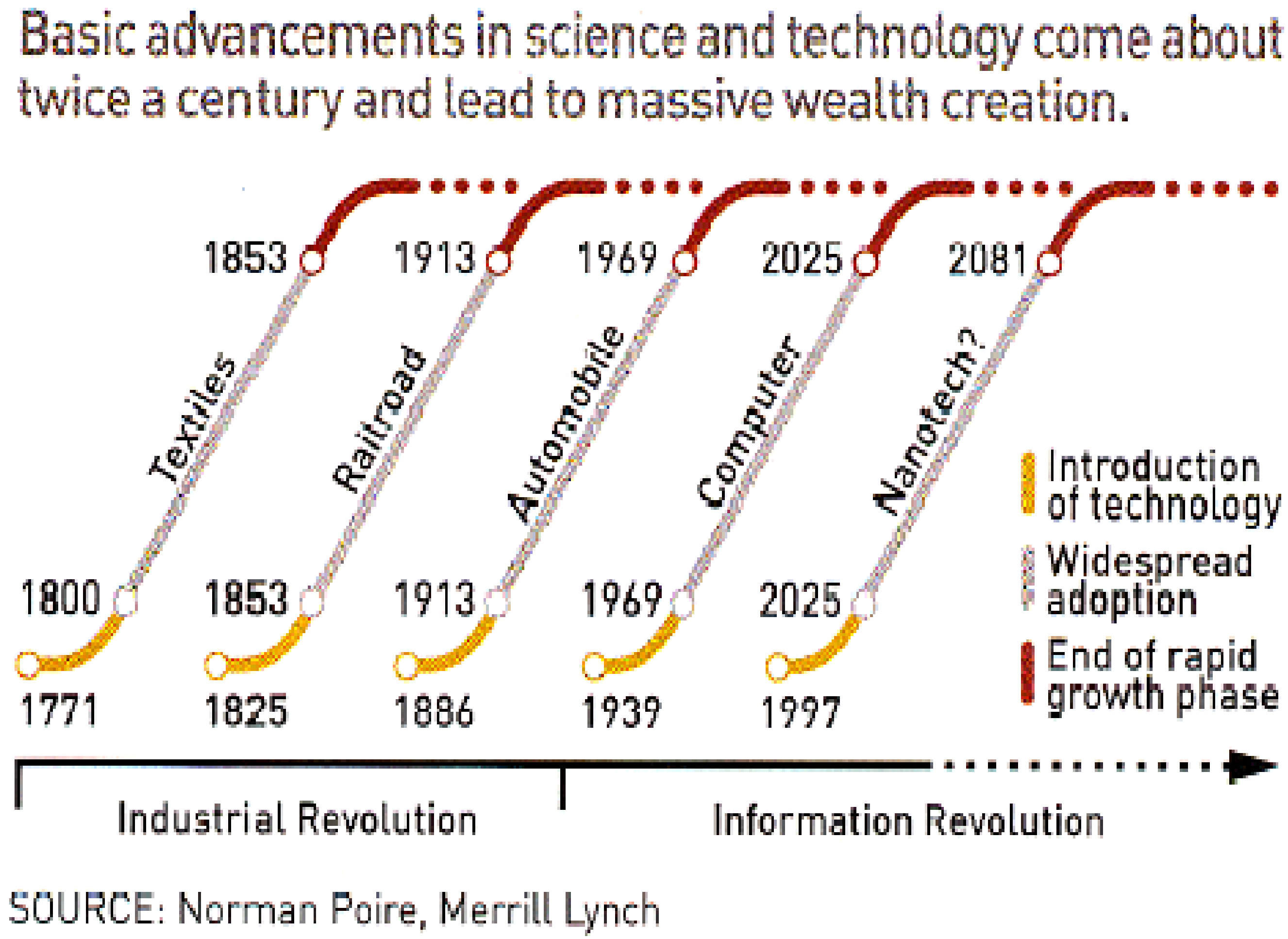
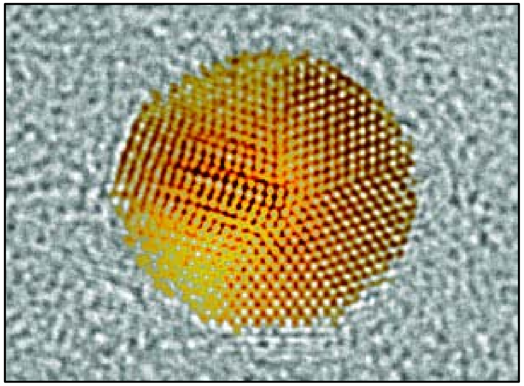


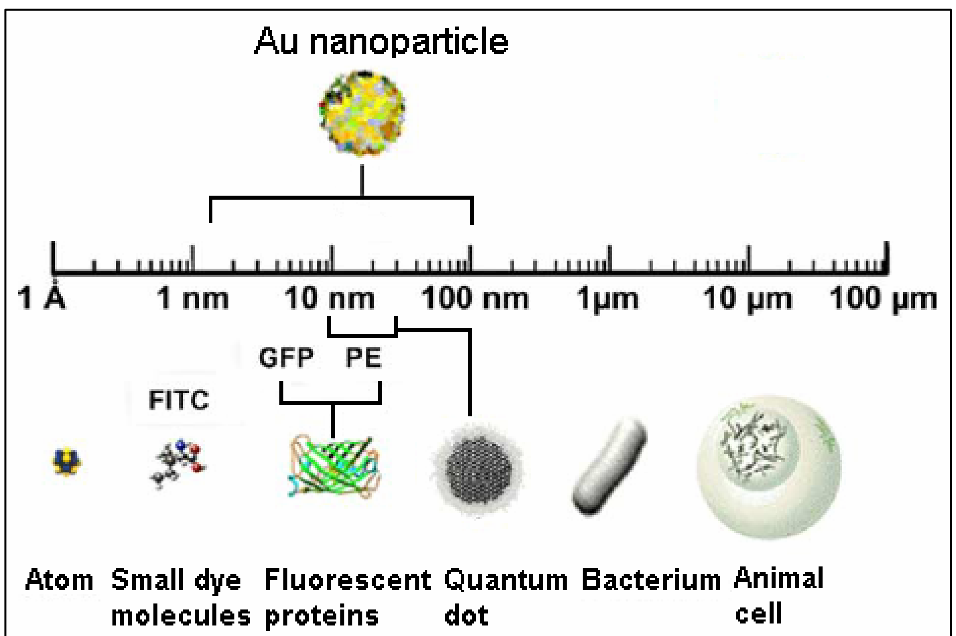
Figure 3. Historical time lag for wealth creation after the introduction of a new technology[3]

http://www.ccst.us/ccst/pubs/nano/lib/ProjectDescription.pdf, Merrill-Lynch review

What are gold nanoparticles (Au NPs)?



http://www.advancedmanufacturing.com/JanFeb06/worldwatch.htm

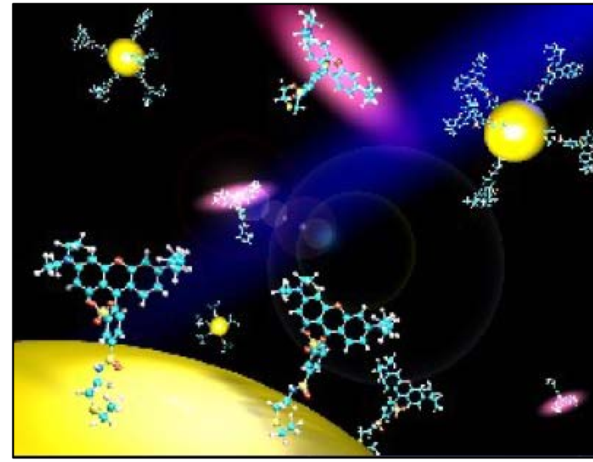


Adapted from: Trends in Analytical Chemistry (2005), 24(4), 341

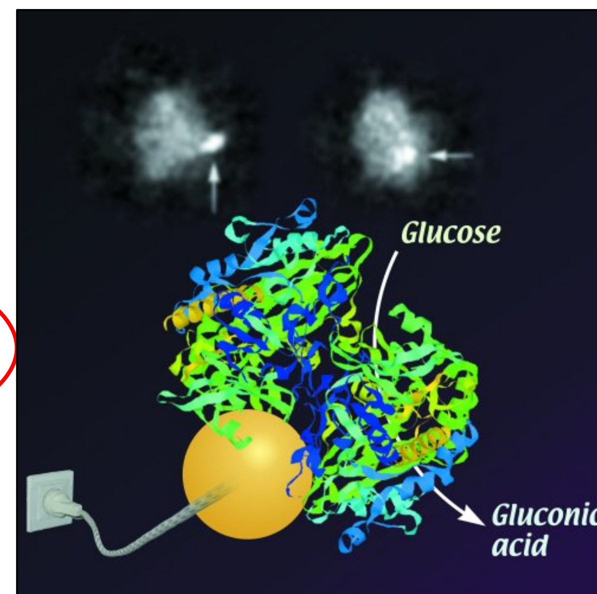
- nm dimensions
- Different shapes
- Unique properties
- Application areas:
  - Sensors
  - Immunoassays
  - Biosensing platforms
  - Imaging
- Detection strategies:
  - Optical (absorbance, scattering, SPR, SERS)
  - Electrochemistry

Why use Au NPs in Electrochemistry?

1. Modification of electrode surface
   - Gas and electrochemical sensors
2. Electron transfer
   - Electrical wiring of enzymes
3. Labeling of biomaterials
   - DNA Biosensors

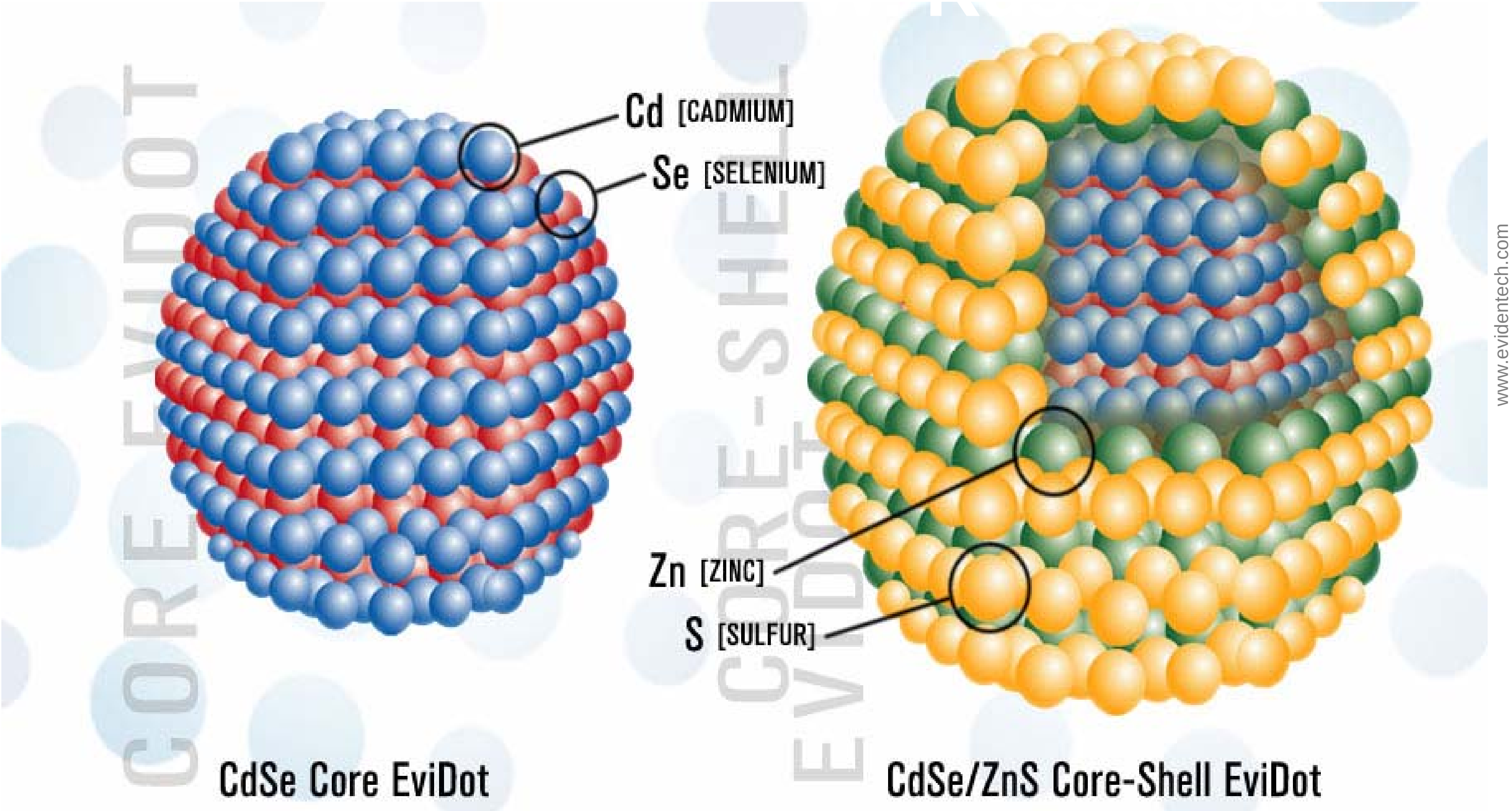


http://nanotechweb.org/articles/news/2/3/11/1



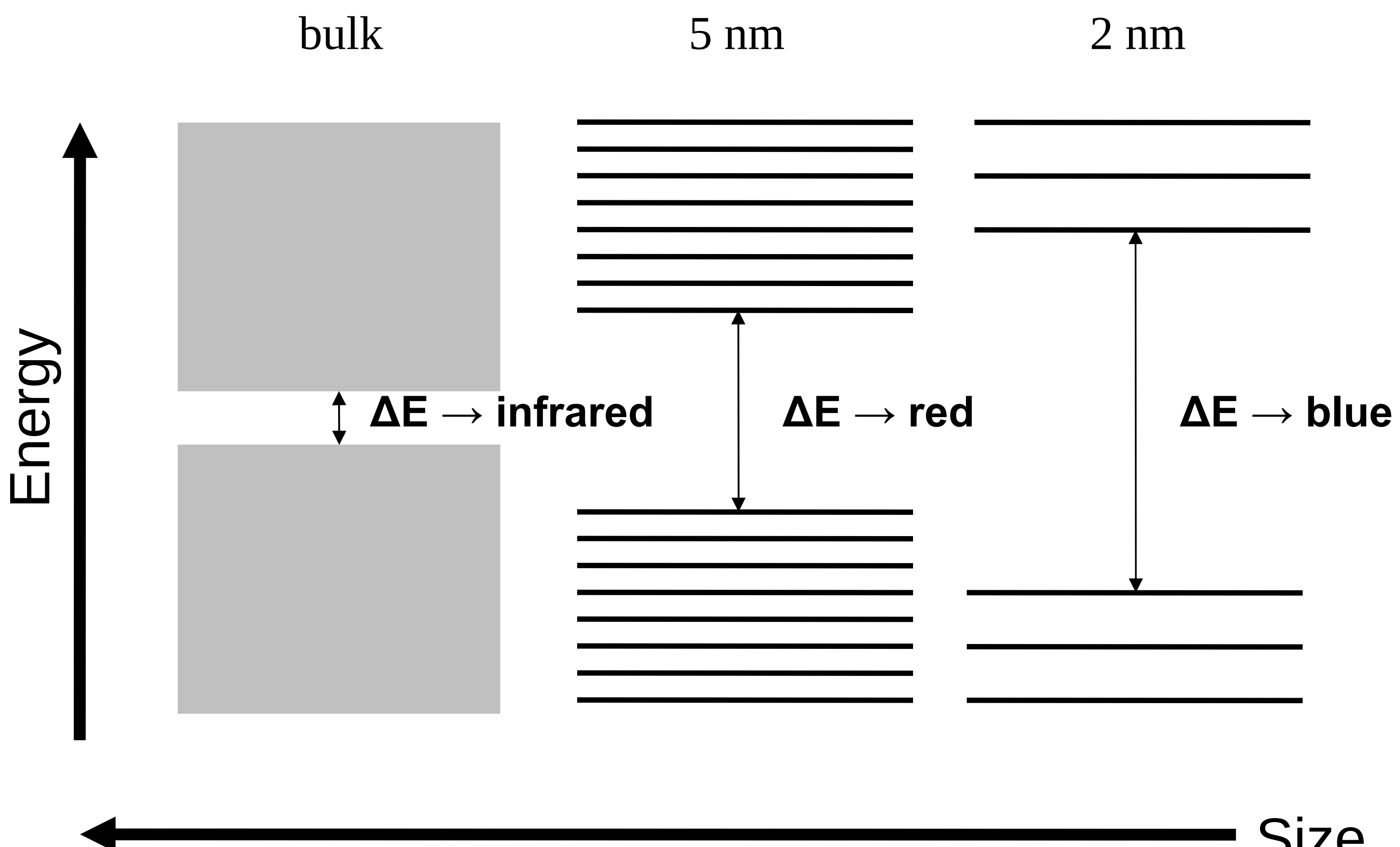
http://nanotechweb.org/articles/news/2/3/11/1

Russ Algar



CdS, CdSe, CdTe, PbS, ZnS, InAs, GaAs

Energy levels of the solid state as size is scaled



Energy levels of Quantum Dots

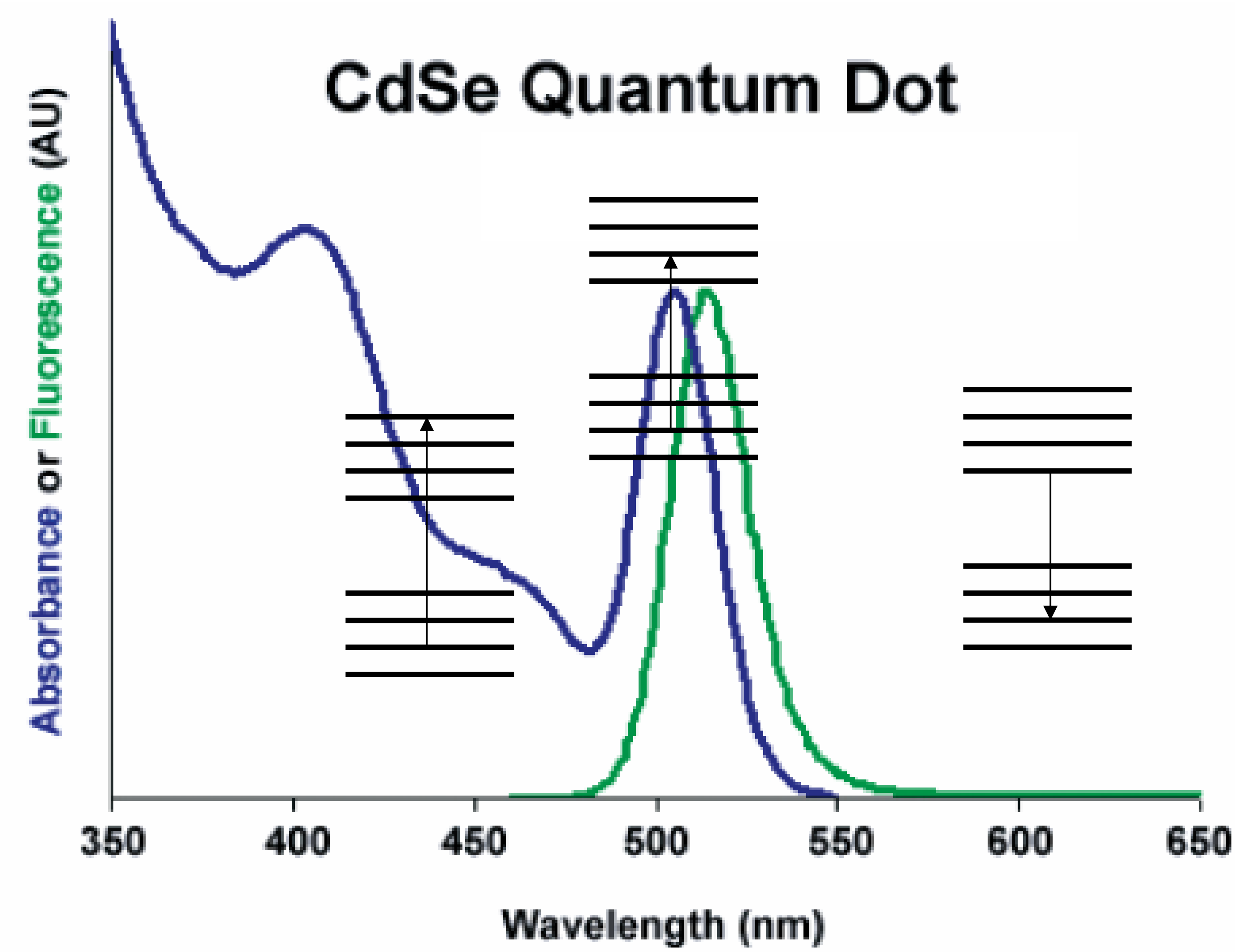


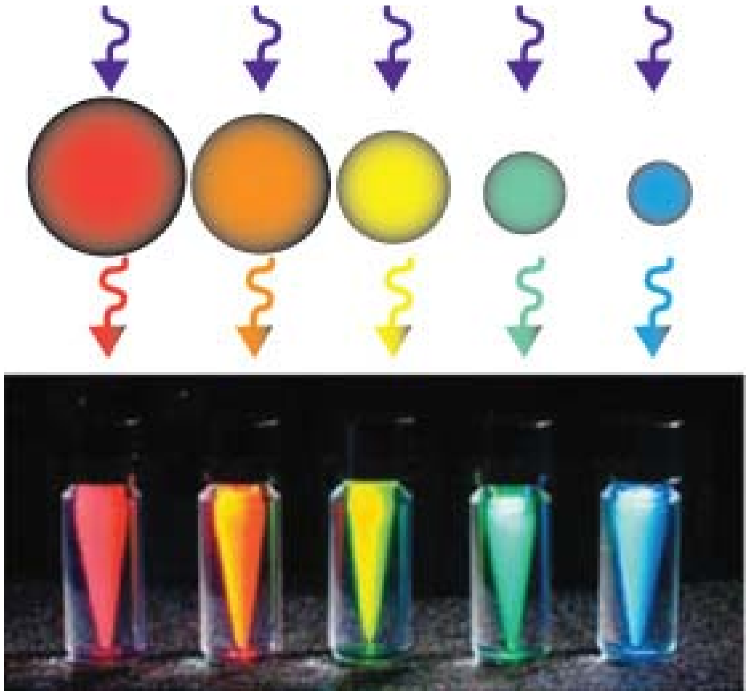
Figure modified from: A.M. Smith, X. Gao, S. Nie, Photochem. Photobiol., 80 (2004) 377-385.

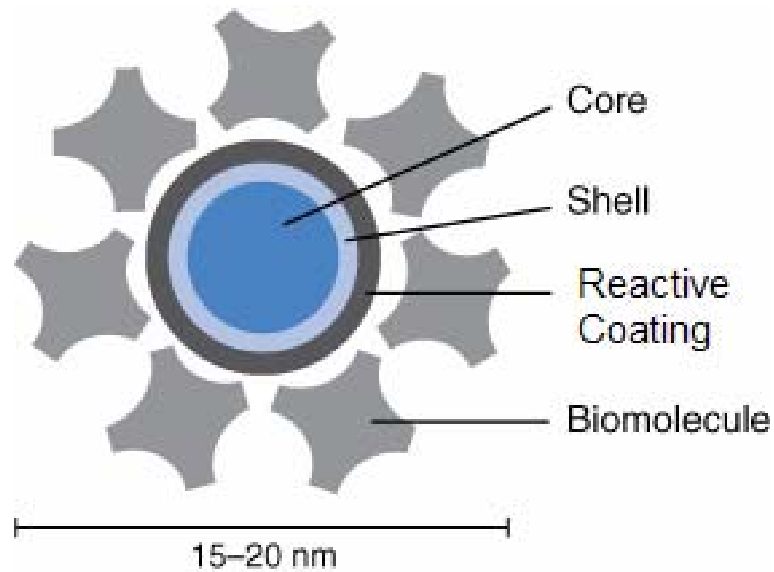
Blinking Dots?

- 35 msec video clip showing individual point sources of emission of quantum dots in a hydrogel matrix

(Proceedings of the National Academy of Sciences USA, pnas_0506523102)

Inorganic Semiconductor Quantum Dots (QD)

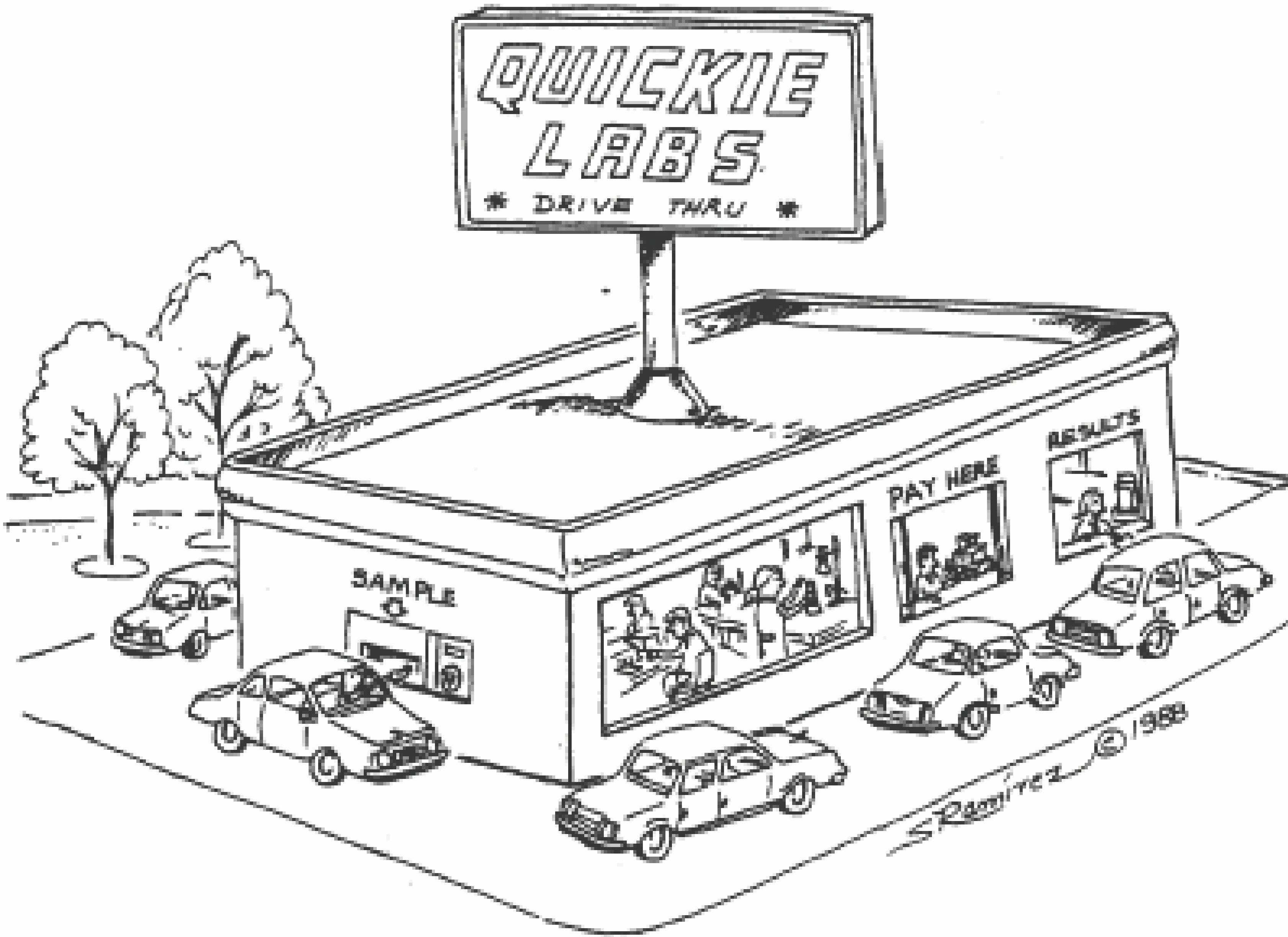




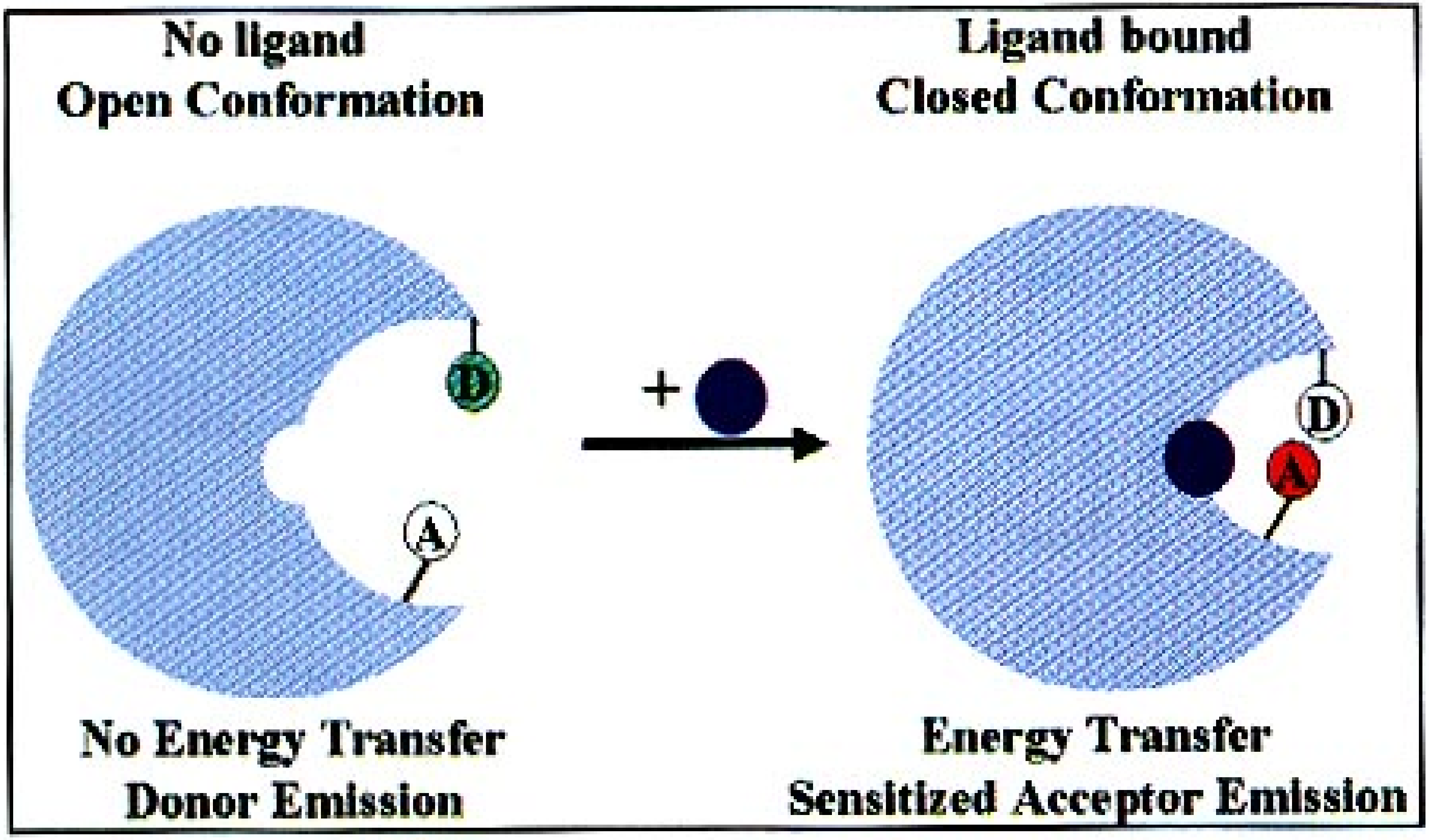
http://probes.invitrogen.com/products/qdot/overview.html

- Wavelength tuning based on size
- Excitable in UV region
- FRET applications
- Multicolour detection

- Core/shell structure
- Functionalize surface with species capable of covalently binding DNA, dye

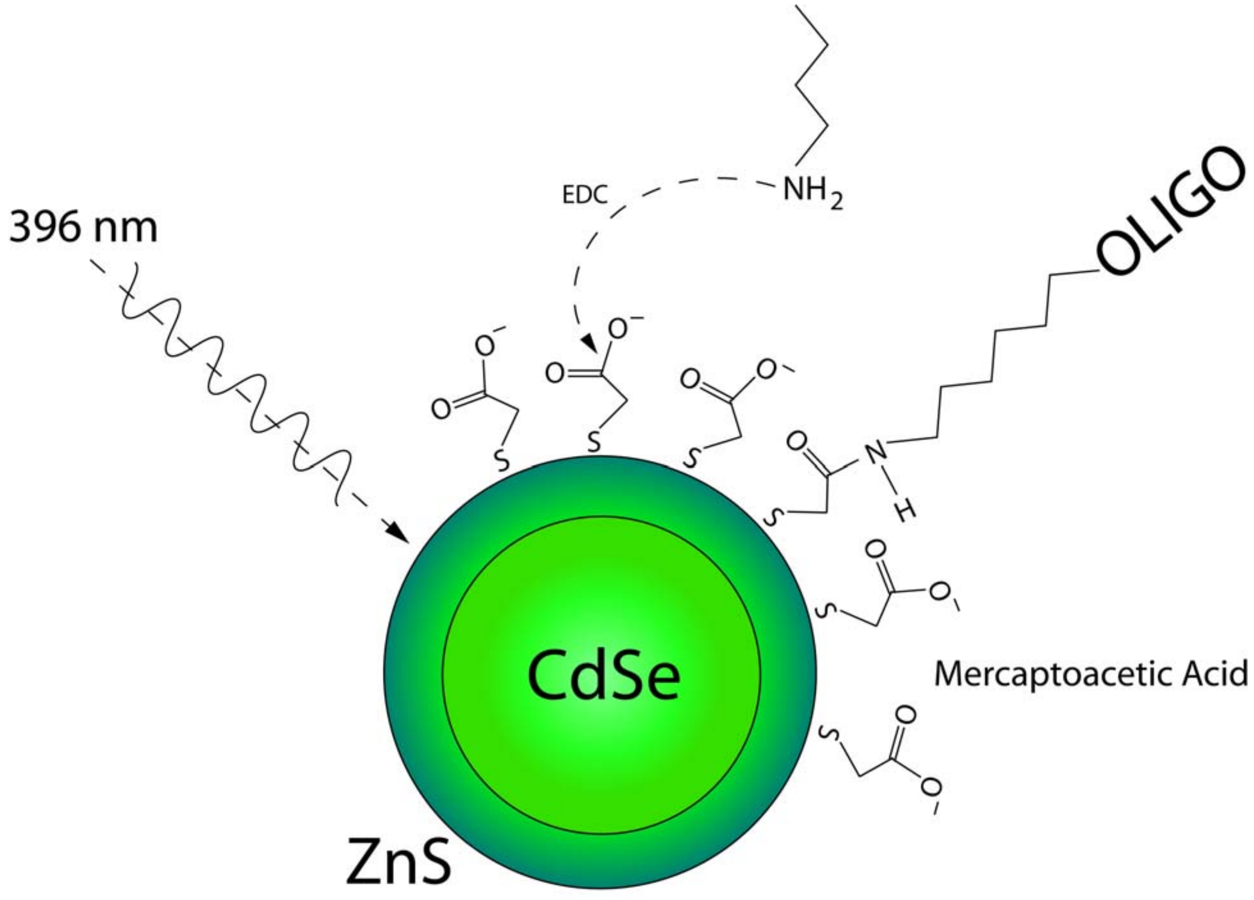

QUICKIE
LABS
DRIVE THRU
SAMPLE
PAY HERE
RESULTS
S Ramirez © 1988

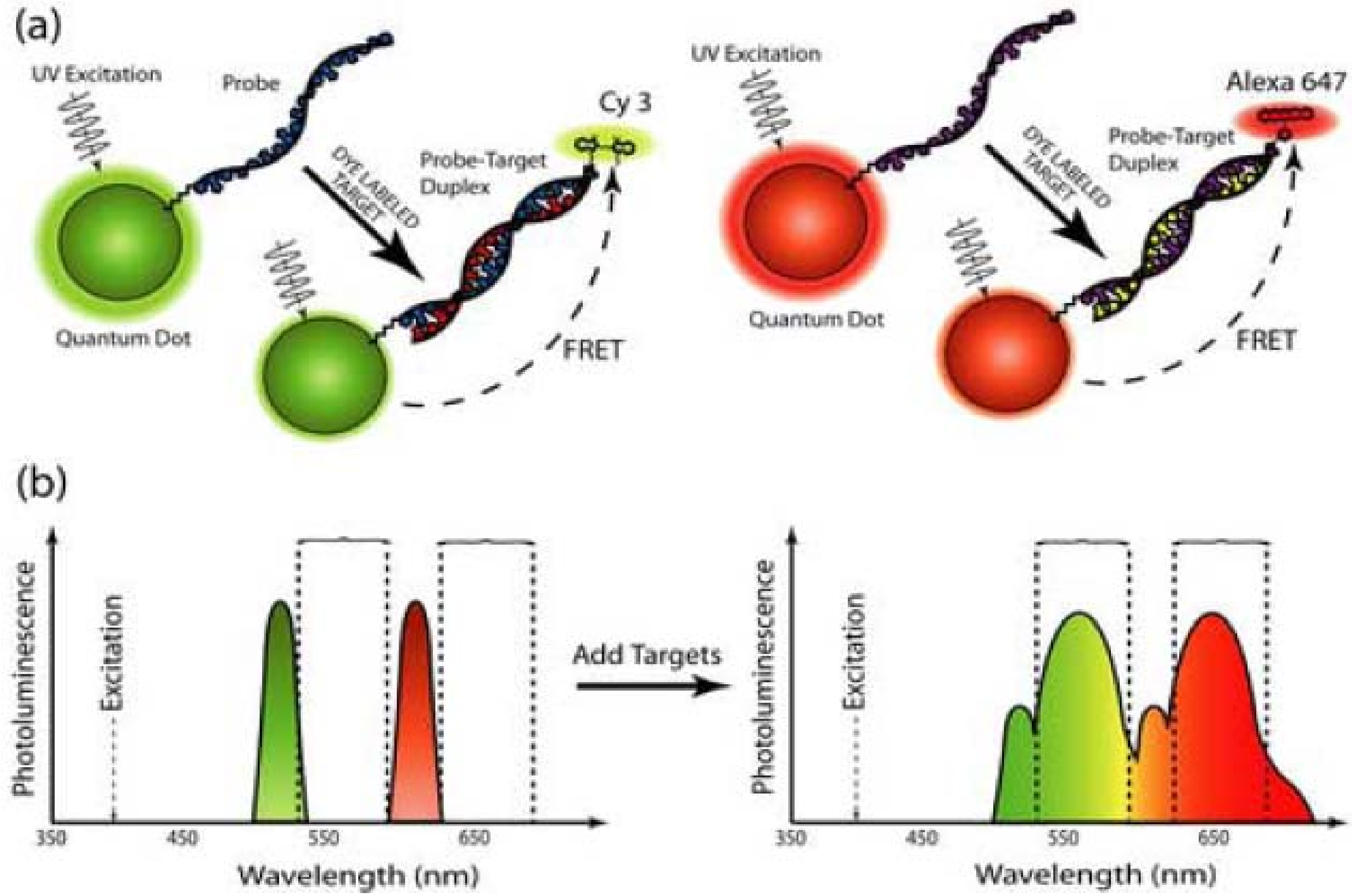
Tools to measure position – THE "MOLECULAR RULER"



Cardullo, Microscopy and Analysis, Issue 53 (2002) 5.

Building a Quantum Dot Biosensor – Molecular Ruler Principle



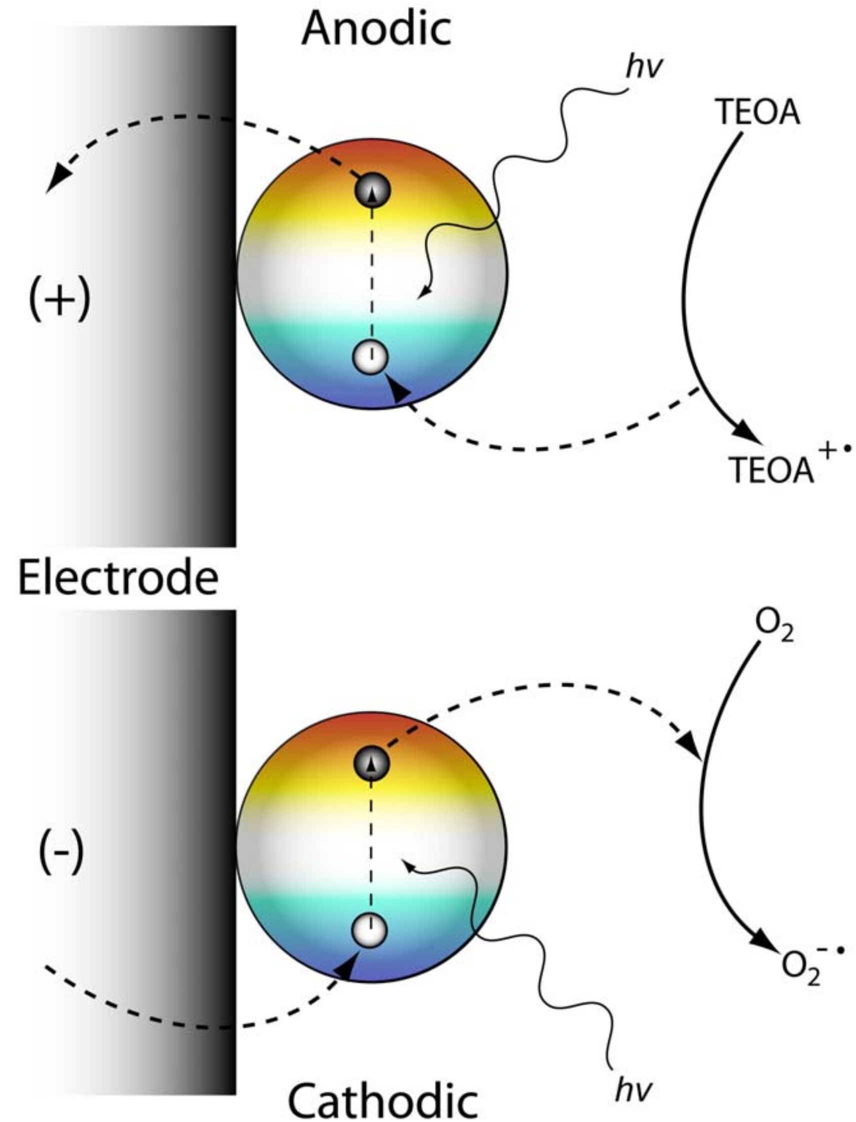


QD-FRET-based strategy for two-colour nucleic acid detection. a) Simultaneous and efficient excitation of green and red quantum dots in the ultraviolet-region without significant excitation of Cy3 or Alexa647 in solution. When probe oligonucleotides were conjugated to QDs, hybridization with a Cy3 or Alexa647 labeled target oligonucleotide yielded FRET sensitized emission from the dyes, which was used as the analytical signal. The green QD-Cy3 FRET pair utilized the SMN1 sequence and the red QD-Alexa647 pair utilized the LacZ sequence. b) A cartoon of the expected emission profiles, where the bracketed regions are of particular analytical interest.

QDs & Photocurrents

QDs represent a photo-activated junction for current flow.

Sacrificial electron donors (e.g. triethanolamine) or electron acceptors (e.g. oxygen).



QDs & Photocurrents with DNA

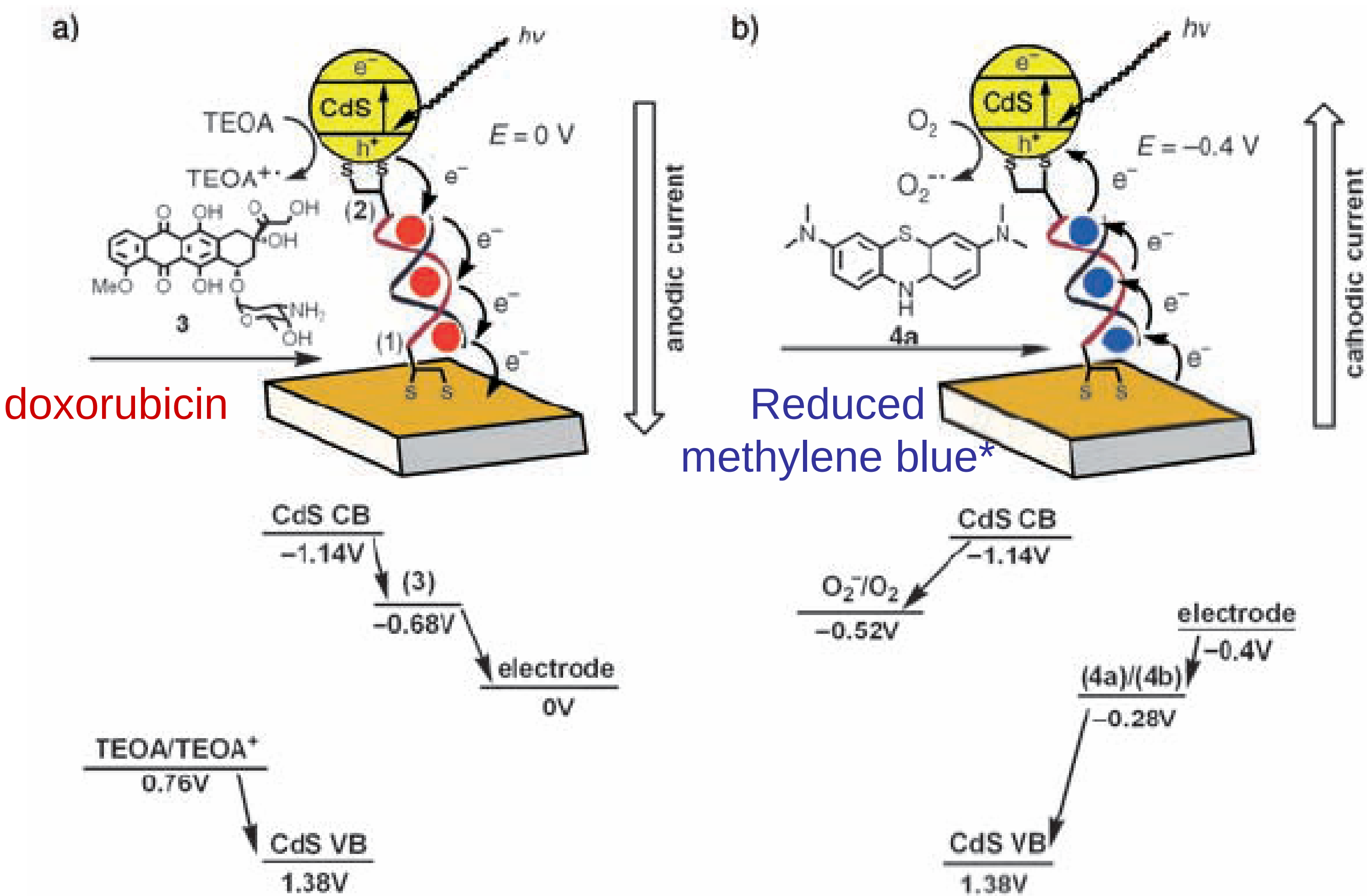
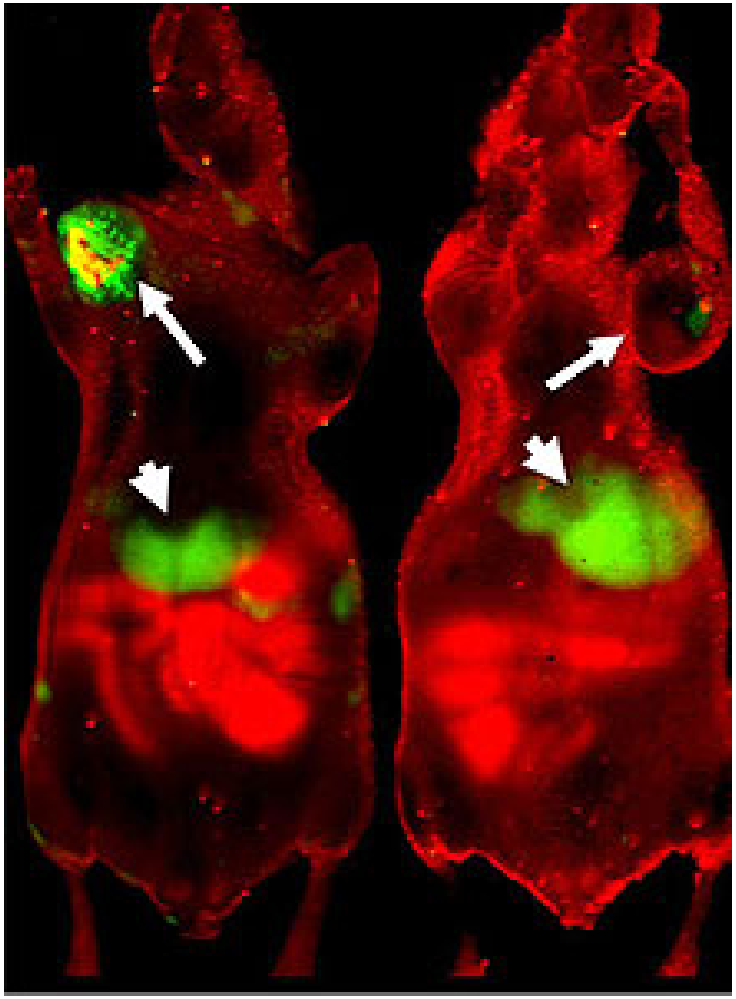


Figure modified from: [23]

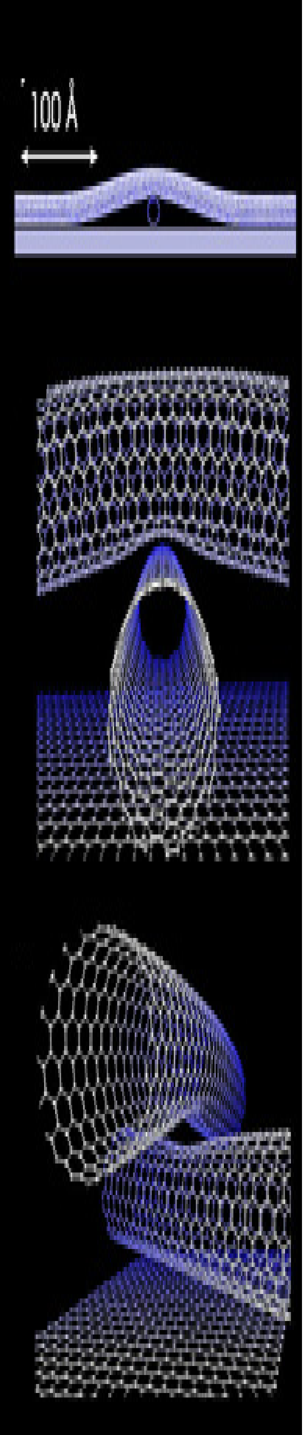
*oxidized methylene blue reverses direction of photocur

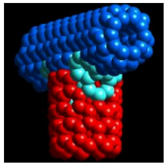


Fluorescent-tagged peptides attached to the surface of iron oxide nanoparticles show up bright green in an image of a breast cancer tumor in mice. The peptides bind to blood protein clots found in tumor blood vessels, helping the nanoparticles seek out tumors, where they play a role in accumulating more nanoparticles.

MIT Technology Review, Tuesday, January 16, 2007

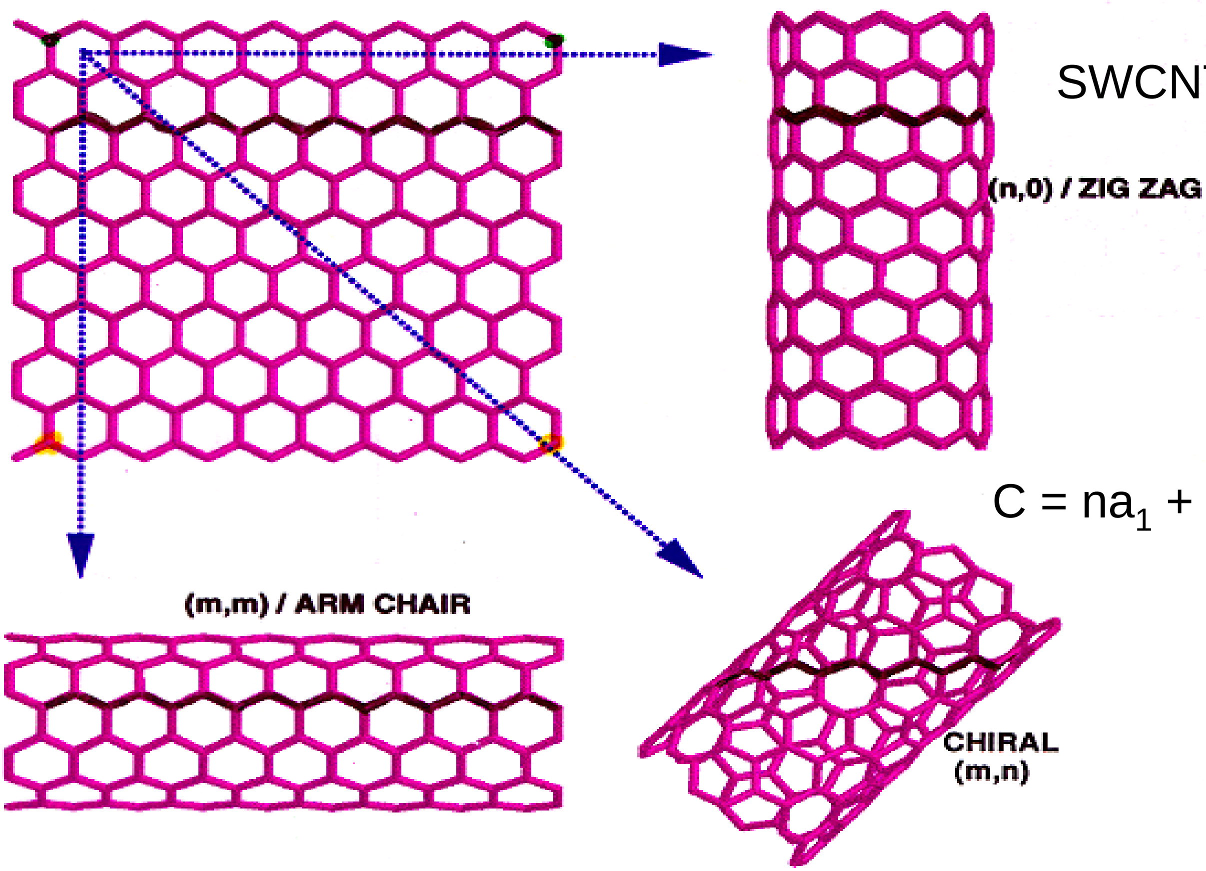
Danny Puzzo





Carbon Nanotubes

- STRIP OF A GRAPHENE SHEET ROLLED INTO A TUBE

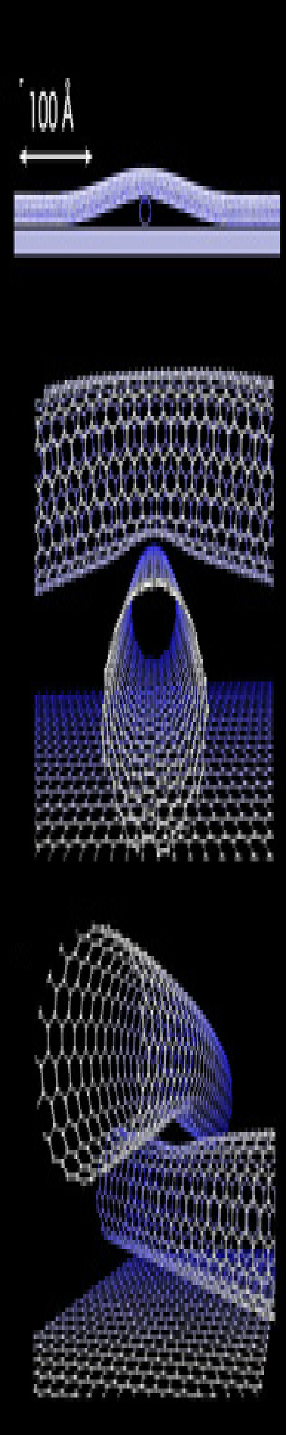


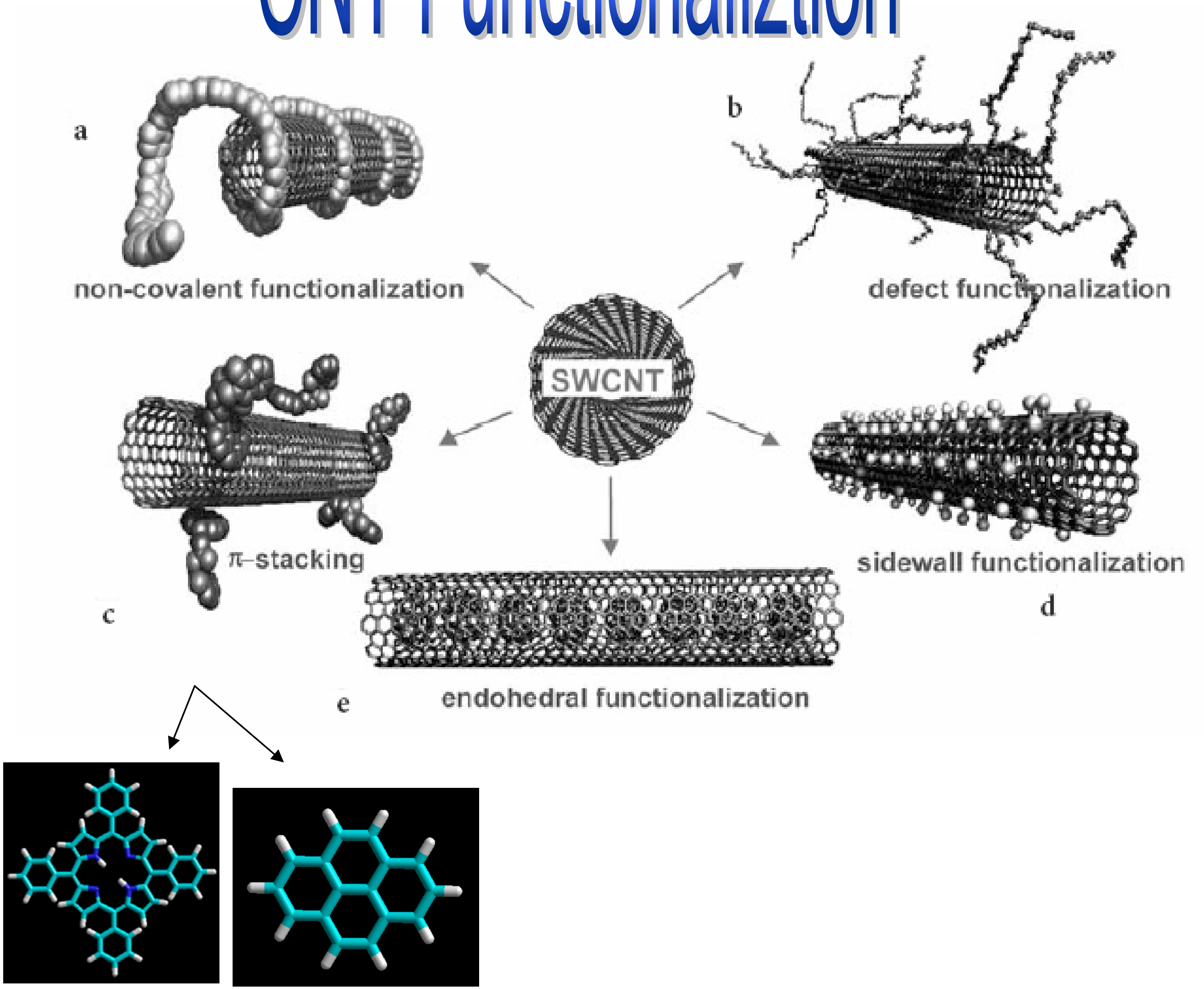
SWCNTs

$C = na_1 + ma_2$

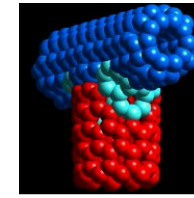
CNT are prepared as either single-walled or multi-walled tubes with diameter as small as 1 nm and length of few nm to micrometers.

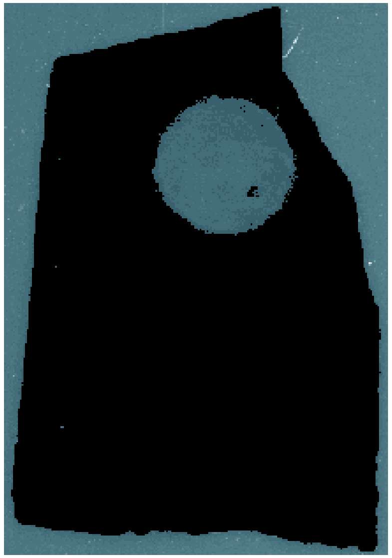
CNT Functionaliztion



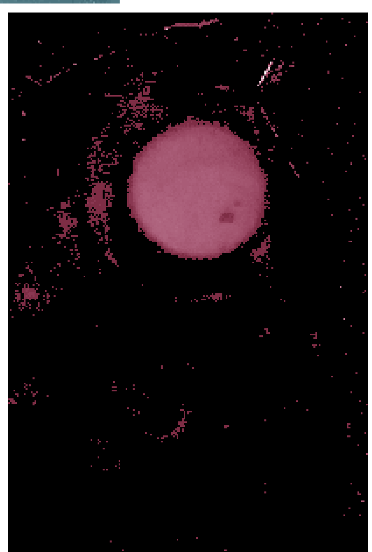


Covalent Functionalization of CNTs

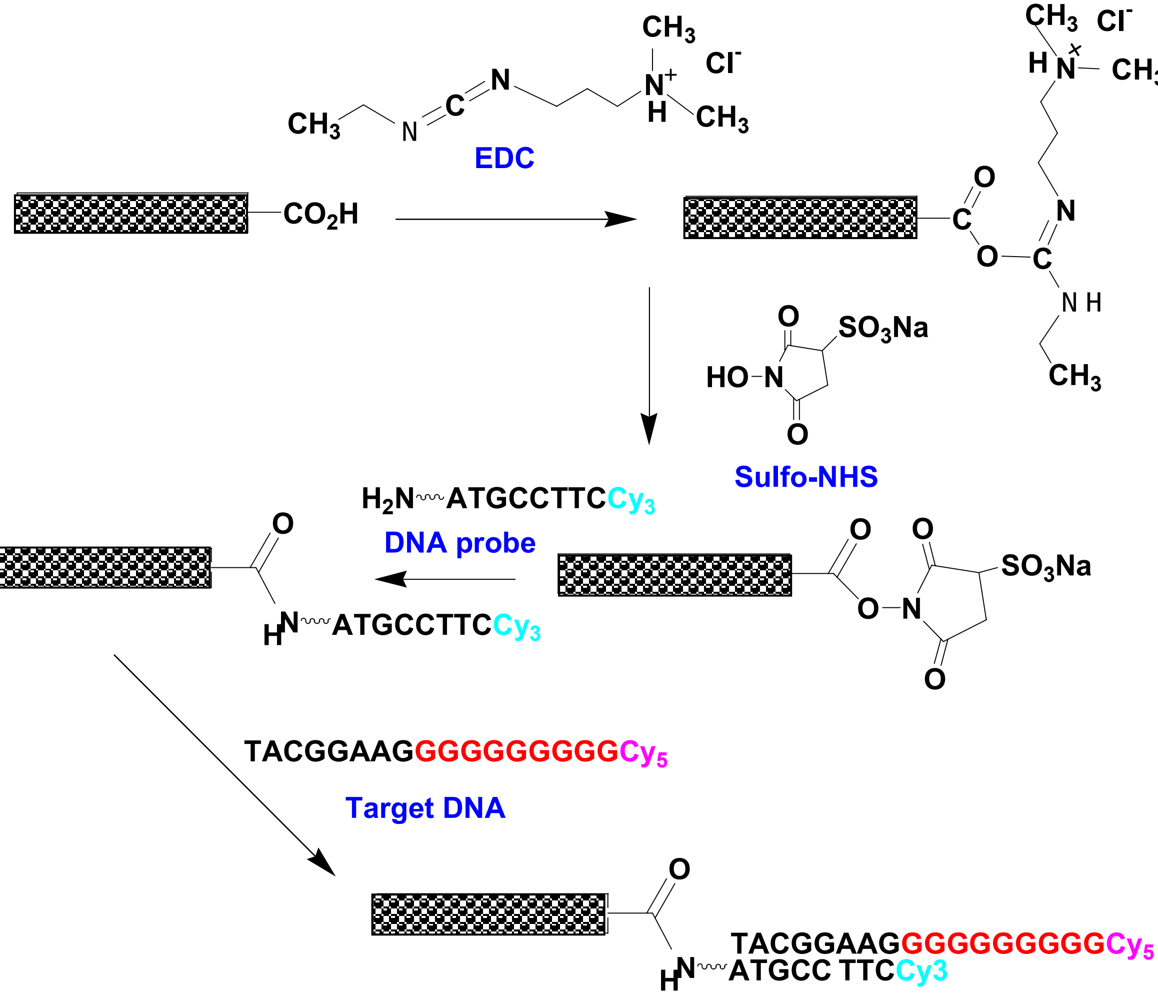


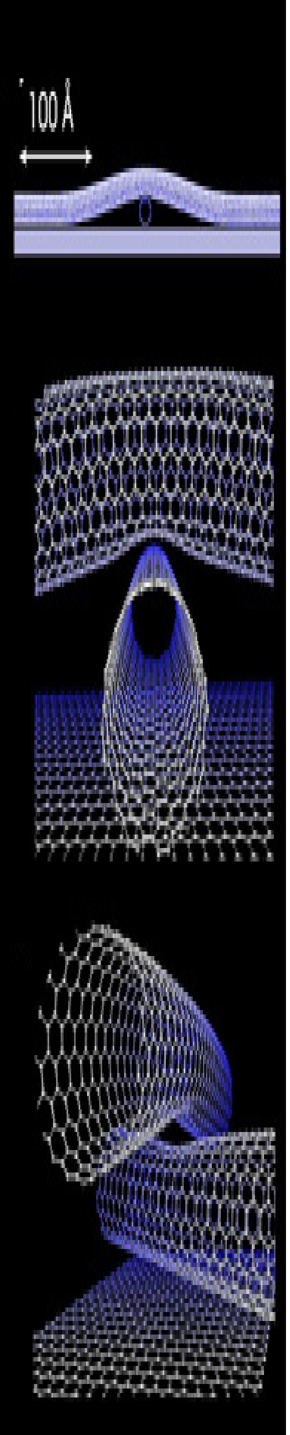


Cy3 image



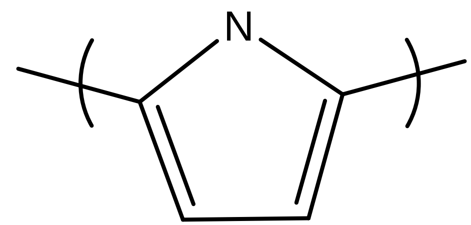
Cy5 image



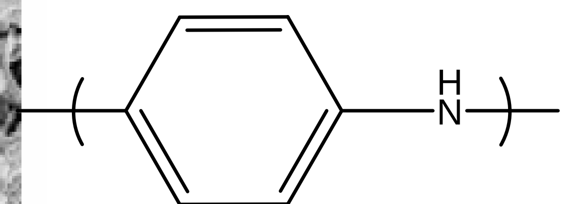


CNT-Polymer Nanocomposite Electrodes

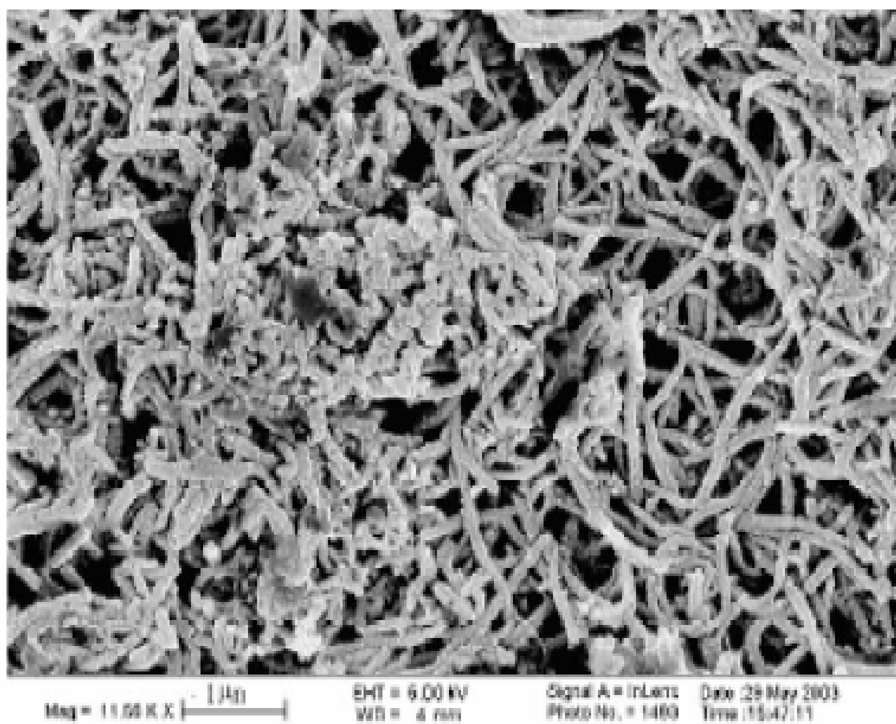
- Conductive Polymer/CNT Electrodes
- Easily Prepared via Electropolymerization
- PANI and PPy/CNT Composite



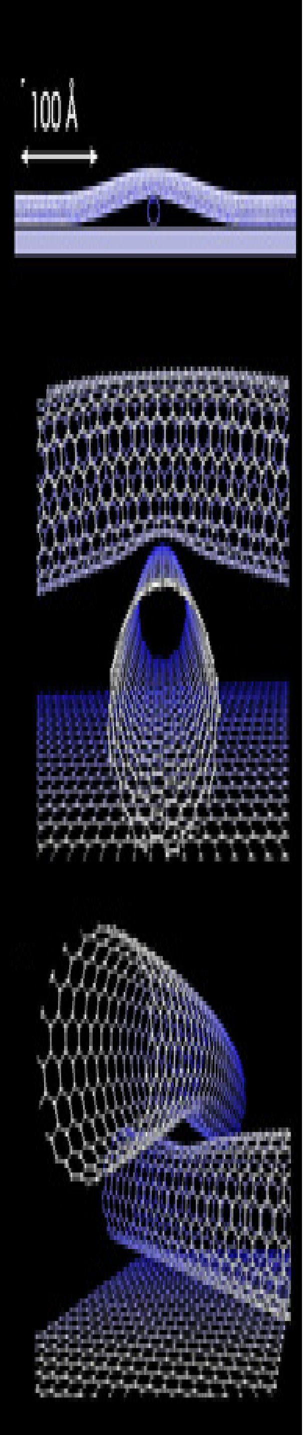
Polypyrrole



Polyaniline

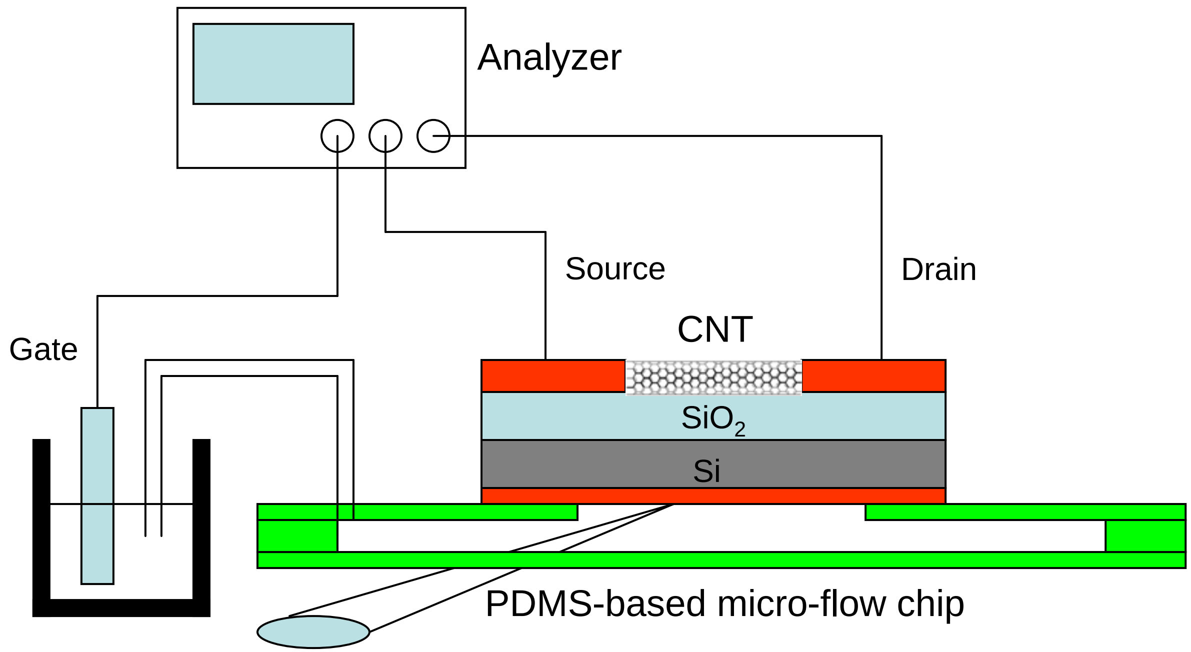


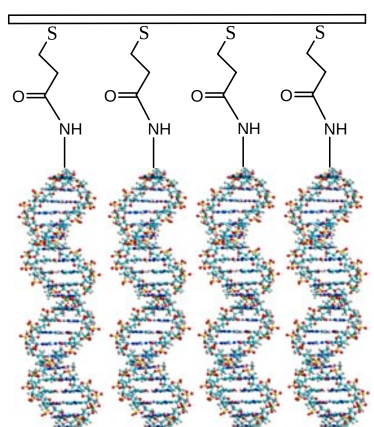
- Microelectrodes can be fabricated



Biosensing with CNTFETs

- Electroanalytical chem. meets Si microfabrication





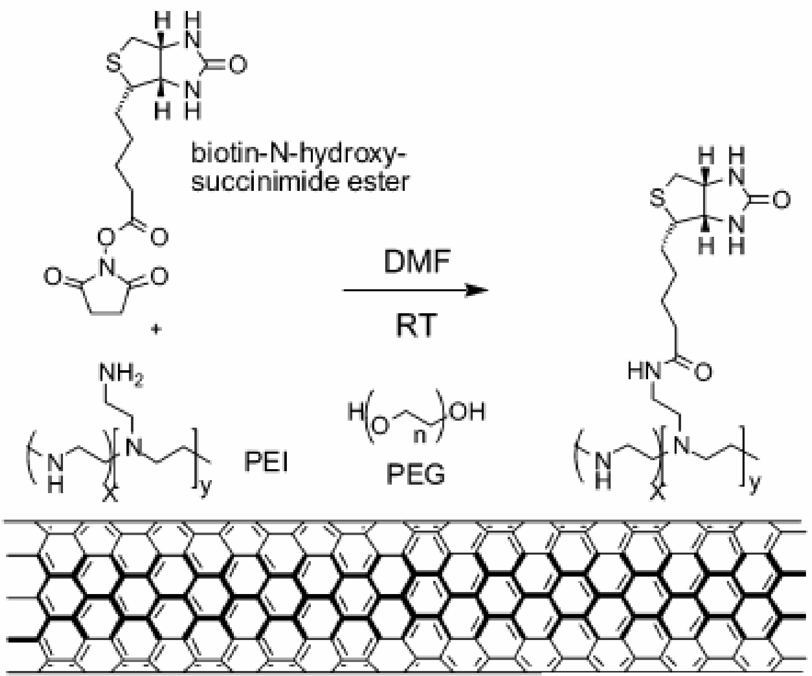
← Hybridization occurs at Gate

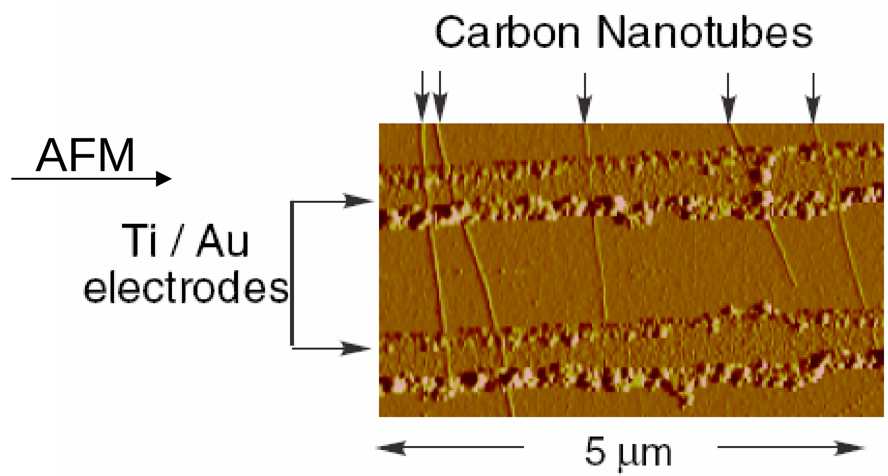
- Offers very high sensitivity

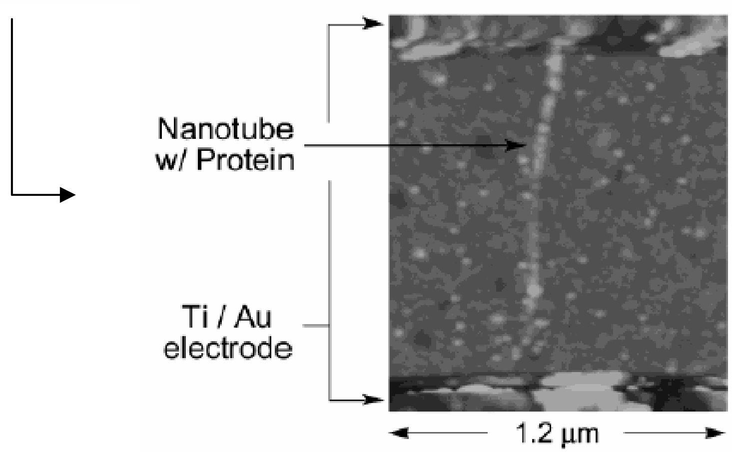
Detection Limit = 6.8 fM

Japanese Journal of Applied Physics
Vol. 43, No. 12A, 2004, pp. L 1558–L 1560

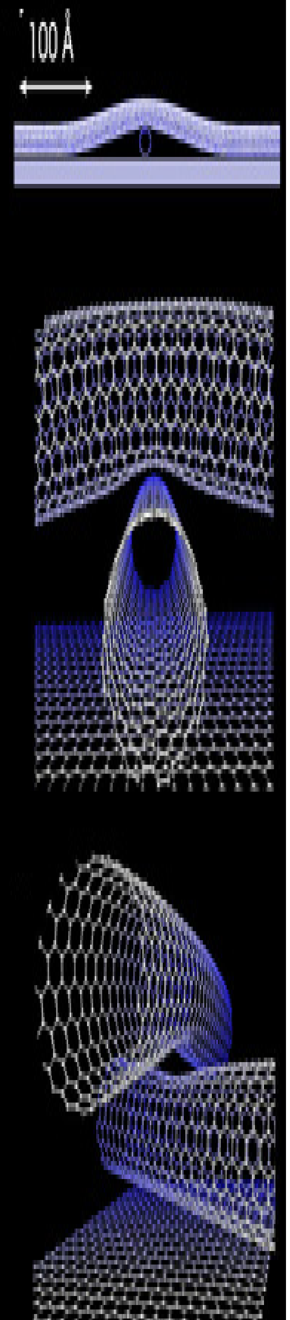
Protein Detection with CNTFETs



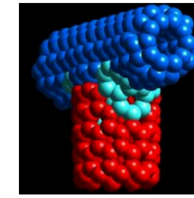


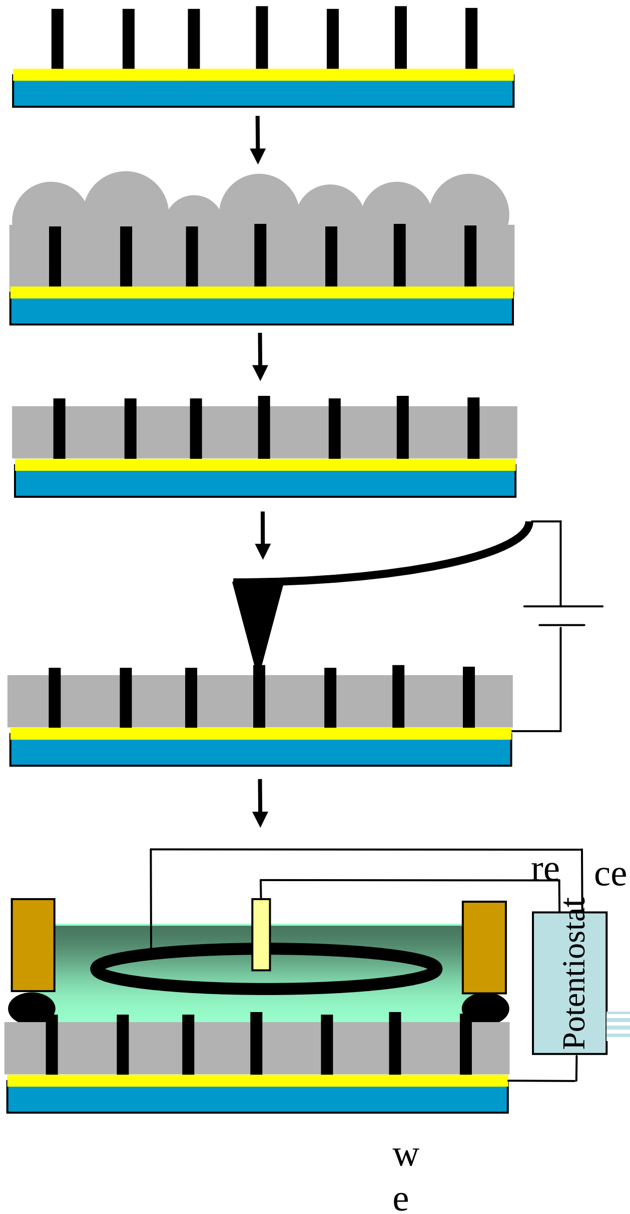


AFM image of the polymer-coated and biotinylated NTFET after exposure to streptavidin labeled with gold nanoparticles.



The Fabrication of CNT Nanoelectrode Array





(1) Growth of Vertically Aligned CNT Array
Avg. MWCNT diameter =80nm,Spacing of 200-300nm, Density = 2 x 10^9 CNTs/cm^2

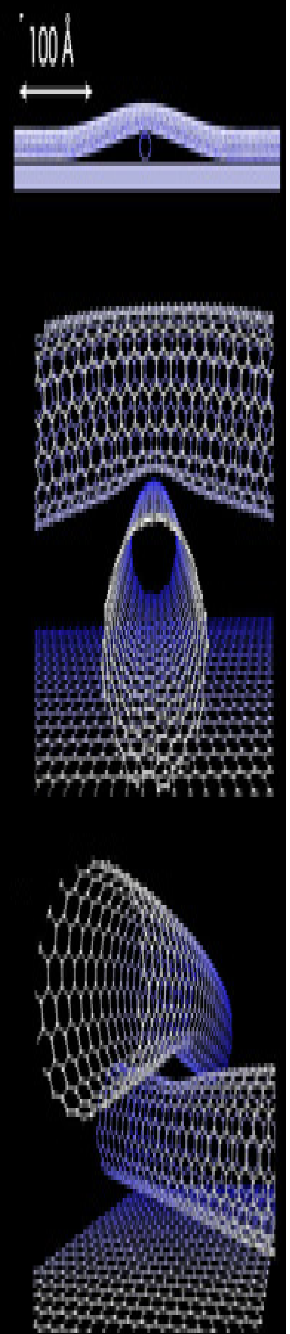
(2) Dielectric Encapsulation

(3) Planarization

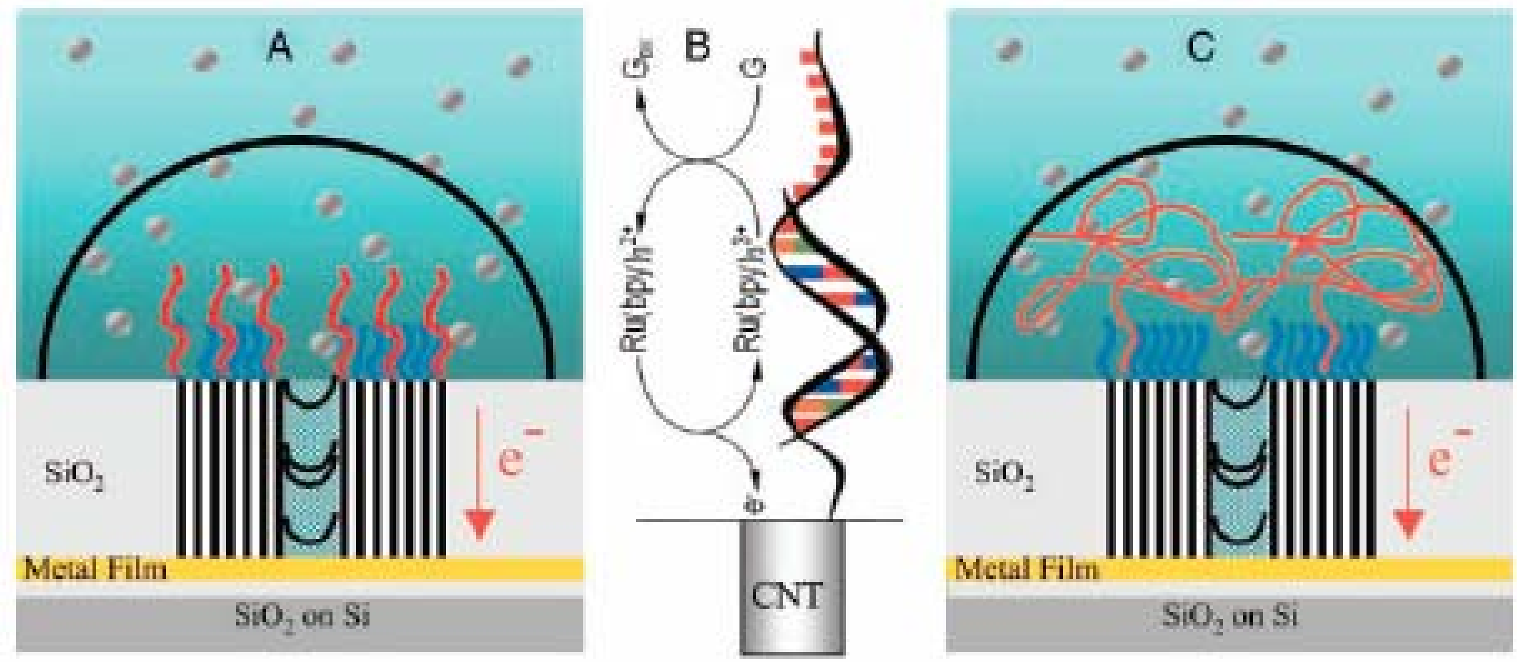
(4) Electrical Property Characterization By Current-sensing AFM

(5) Electrochemical Characterization

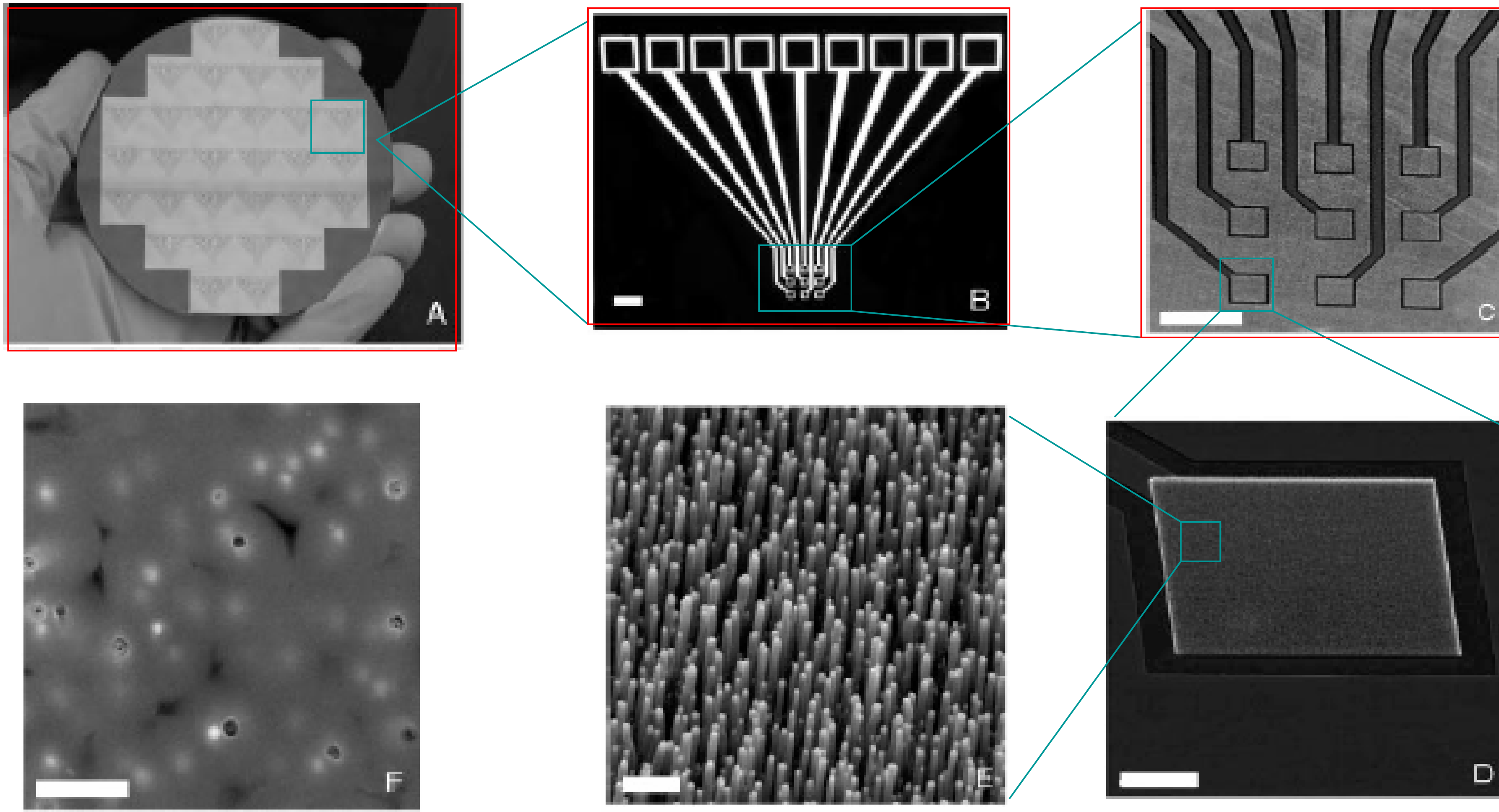
Electroanalysis 2005, 17(1), 15



DNA Detection with NEA CNTs

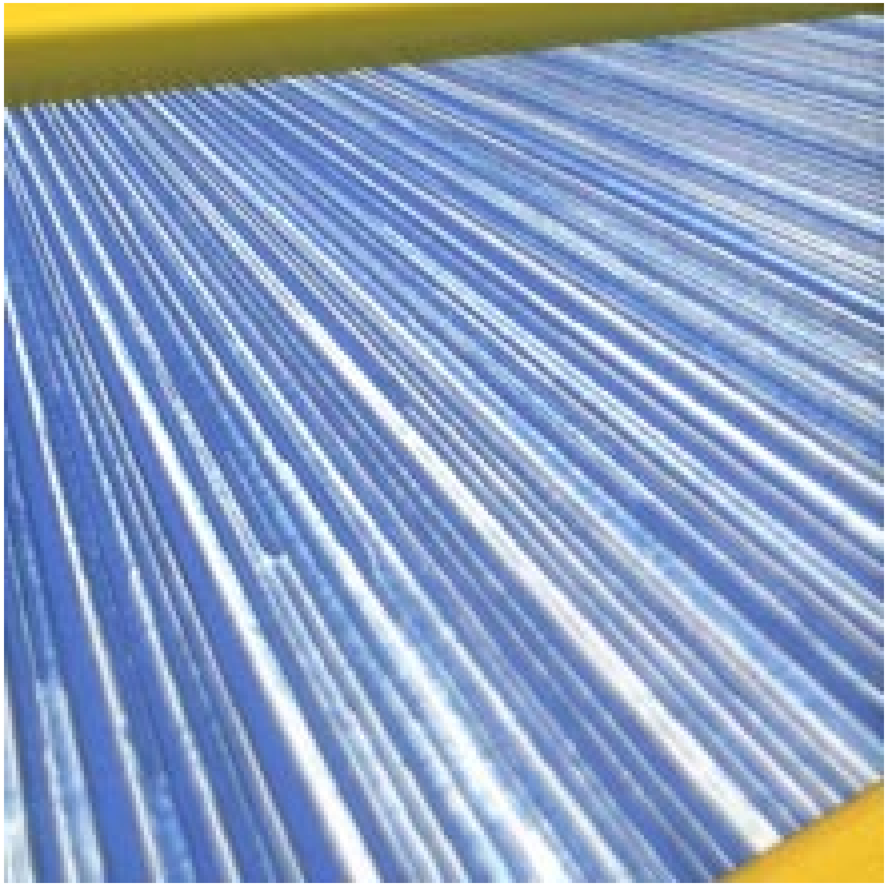


Multiplexing Demonstration



- The detection sensitivity can reach below 1000 DNA molecules at each microelectrode pad

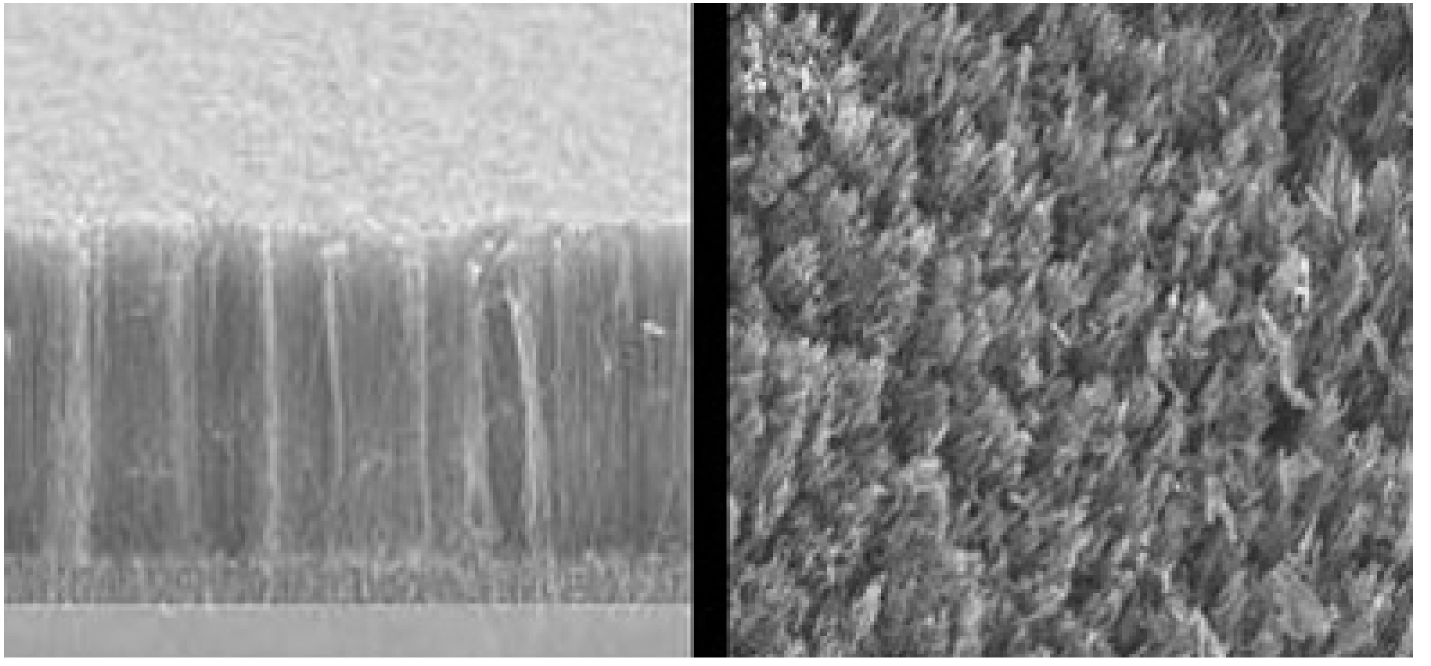
Electroanalysis 2005, 17(1), 15



Tube transistors: Researchers at the University of Illinois at Urbana Champaign have developed a technique to grow thousands of carbon nanotubes (shown in blue and white in this colorized scanning electron micrograph). The researchers deposit electrodes (shown in gold) on two sides of the nanotube arrays to create transistors that have hundreds of nanotubes bridging the electrodes.
Credit: John Rogers, UIUC

MIT technology Review, Thursday, March 29, 2007

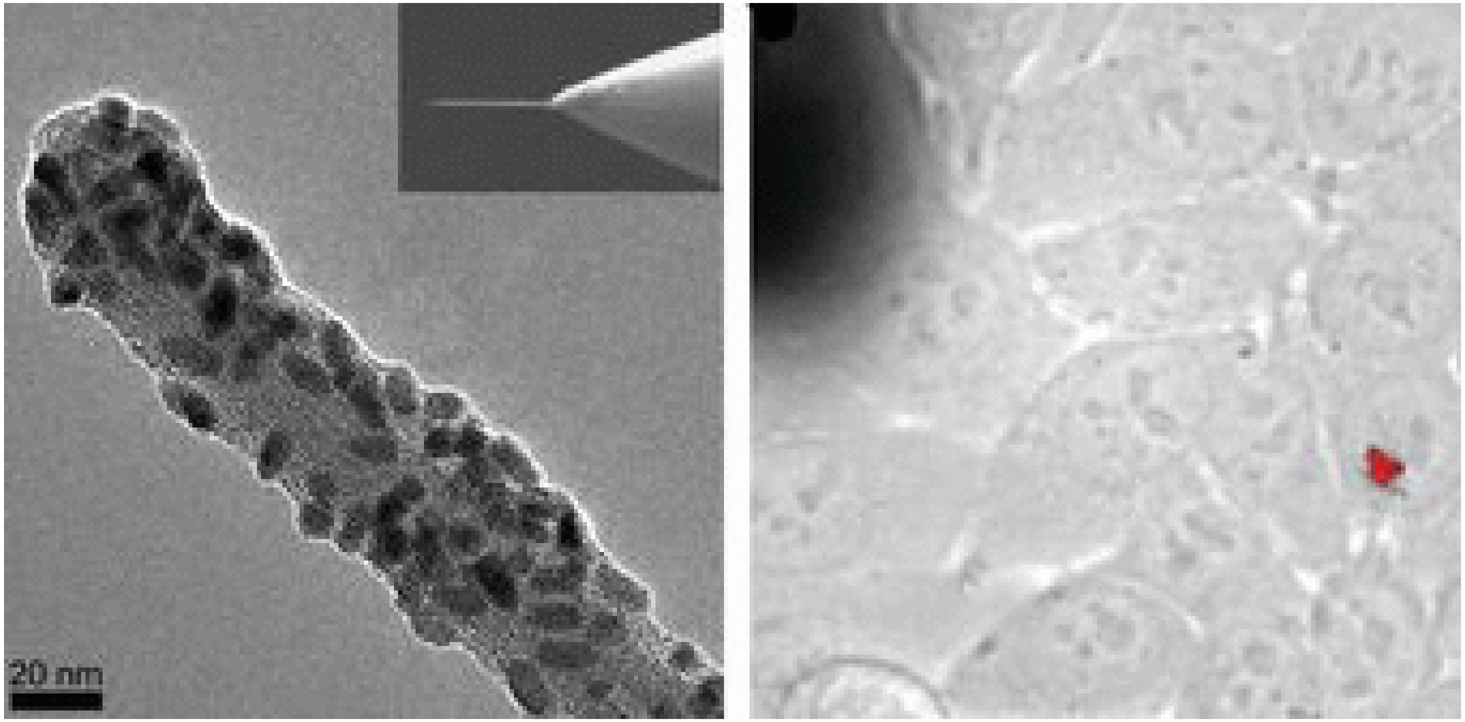
Gecko and ‘nanoglue’



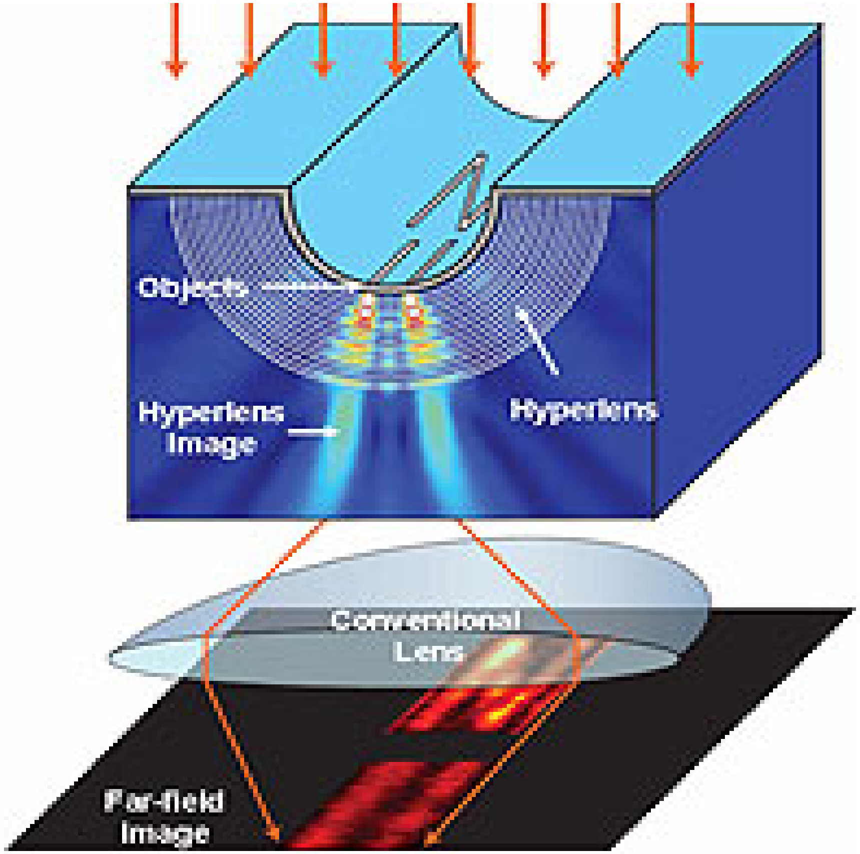
In 2002, a team of scientists studying the creatures explained to the world just **how geckos stay stuck**. By fabricating synthetic gecko hairs from different materials, they found that the geckos' adhesive powers came not from chemistry, but from geometry -- the size and shape of the tips of the gecko foot hairs.

Geckos have very hairy feet. Each gecko foot is covered by half a million setae, tiny hairs 50,000 nanometers long. The length is often compared to the width of a human hair. Each setae branches off into hundreds of even more miniscule hairs, called spatulae, just 200 nanometers wide.

http://www.wired.com/medtech/health/news/2005/08/68639



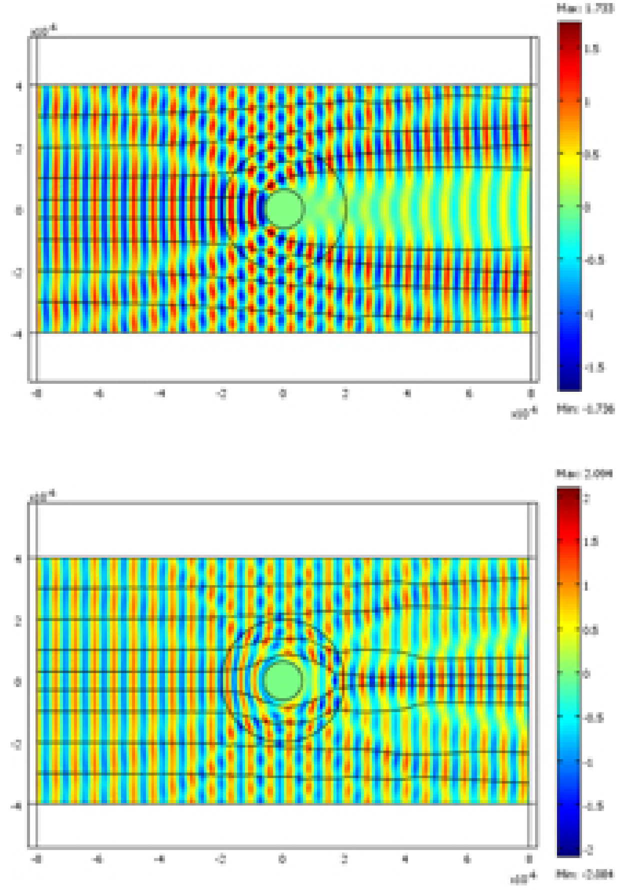
Carbon Nanotube Nanoinjector



Hyperlens: A new lens overcomes the limits of optical microscopes that make it impossible to see the real-time movement of viruses. Light (orange arrows) passes through designs with nanoscale features etched into a sheet of chromium (light blue). It then encounters a series of alternating silver and aluminum-oxide layers. These layers magnify the image carried by light waves until it is big enough to be observed with a conventional optical microscope.

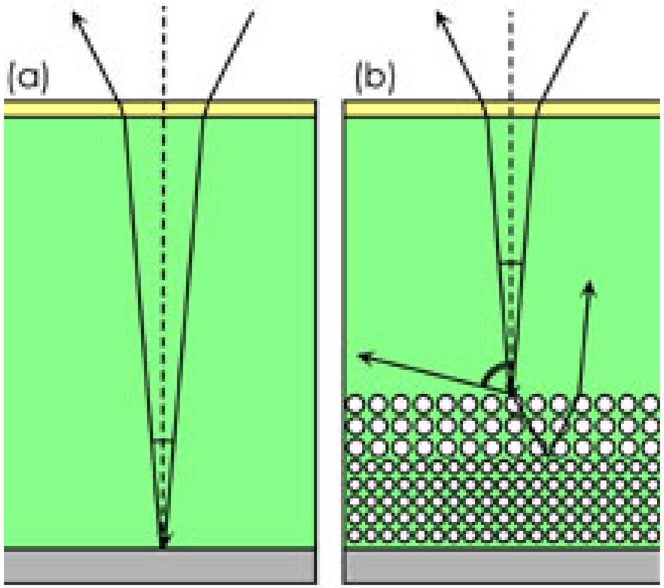
MIT Technology Review, Friday, March 23, 2007

A hairbrush-shaped device has been theoretically designed that would use bristles made out of nanowires to bend light around it, rendering the object invisible. The researchers who came up with the design say that it's the first practical design for an "optical cloak" to work in the visible spectrum.



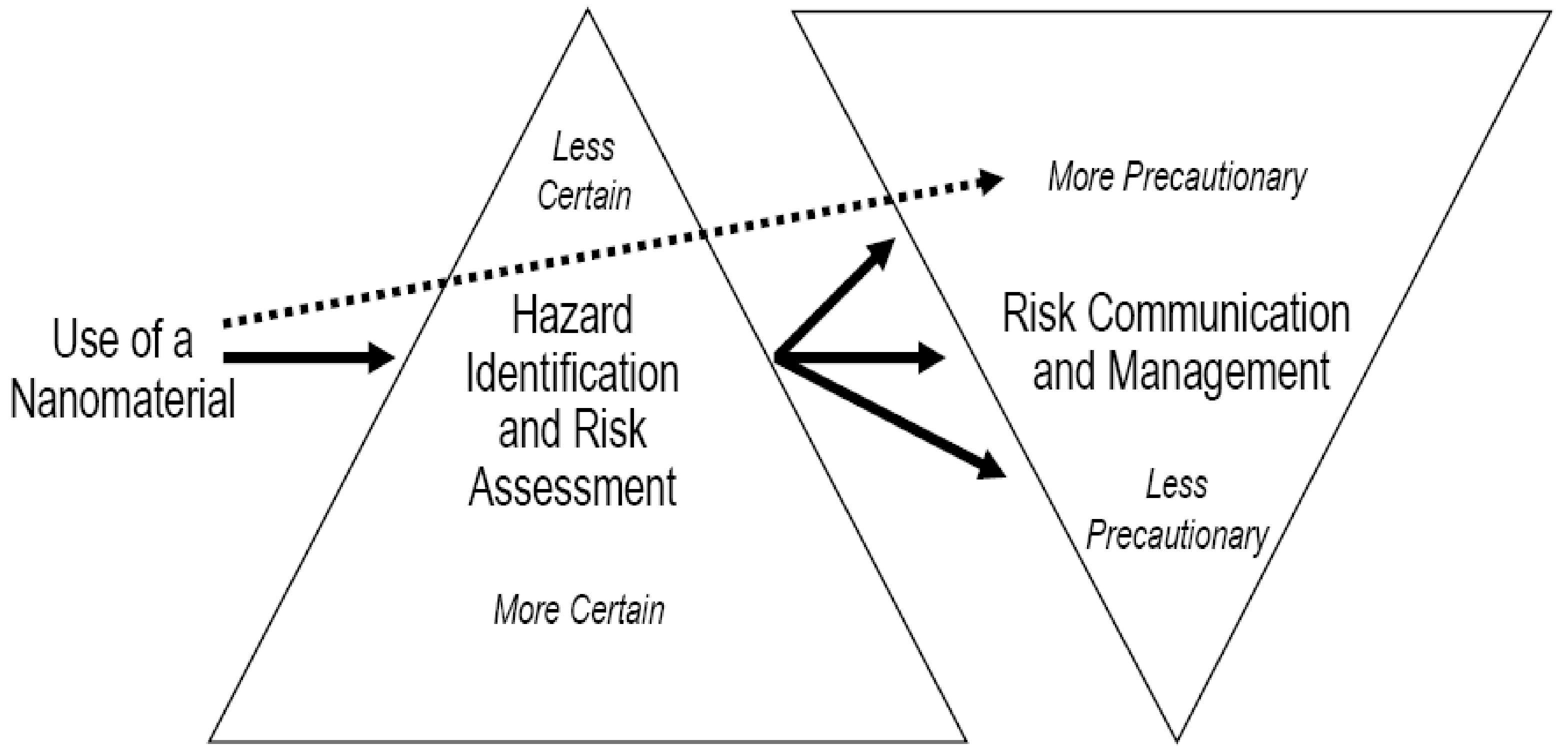
Cloak on, cloak off: Simulations show how light interacts with the cross section of the cloaking device. When it’s uncloaked (top), light is reflected off the object. But when it’s cloaked (bottom), light is guided around the object and anything within it.

MIT Technology Review, Wednesday, April 11, 2007



Better solar: In conventional solar cells (a), light (dashed line) enters an antireflective layer (yellow) and then a layer of silicon (green) in which much of the light is converted into electricity. But some of the light (solid arrows) reflects off an aluminum backing, returns through the silicon, and exits without generating electricity. A new material (represented by the dots in [b]) makes it possible to convert more of this light into electricity. Instead of reflecting back out of the solar cell, the light is diffracted by one layer of the material (larger dots). This causes the light to reenter the silicon at a low angle, at which point it bounces around until it is absorbed. The light that makes it through the first layer is reflected by the second layer of material (smaller dots) before being diffracted into the silicon.

MIT Technology Review, Wednesday, March 21, 2007



Ethical and Scientific Issues of Nanotechnology in the Workplace

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Nanotechnology Will Change Our World