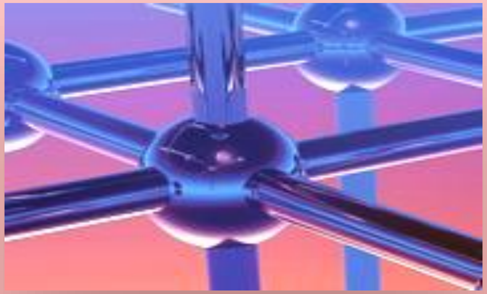
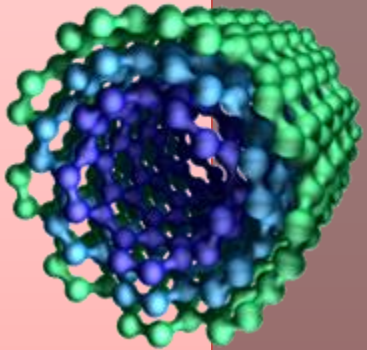
Nanotechnology for Engineers





-Surendra Shrestha, PhD

Surendra Shrestha
email: surendra@ioe.edu.np

Education:

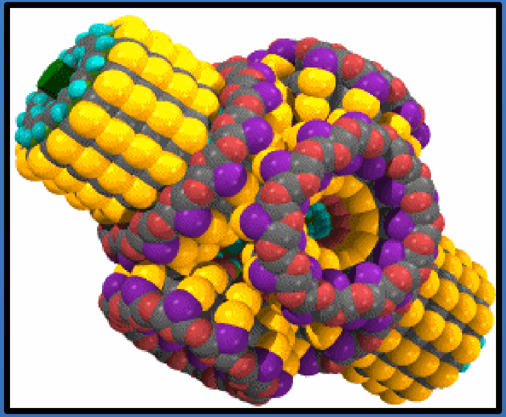
- **Post Doctorate (Graphene Technology), UPM, Spain**
- **PhD (Major: Nanoscience**), Sun Moon University, S. Korea
- **M.Sc. Engg. (Telecommunication),** Tashkent Electro-Technical Institute of Communication, Uzbekistan

PROFESSIONAL EXPERIENCE:

- **Program Coordinator,** MSc in Information & Communication Engg., Department of Electronics and Computer Engineering, Pulchowk Campus, IoE

- **Reader,** Department of Electronics and Computer Engineering, Pulchowk Campus, Institute of Engineering, Pulchowk, Lalitpur, Nepal

What is



- Derives from *nanometer*, which is one-thousandth of a micrometer (micron), or 10^{-9} of a meter
- The study, manipulation and manufacture of ultra-small structures and machines made of as few as one molecule

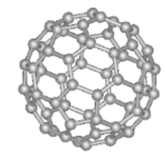
What is Nanoscale?

www.mathworks.com

12,756 Km

22 cm

Fullerenes C_{60}



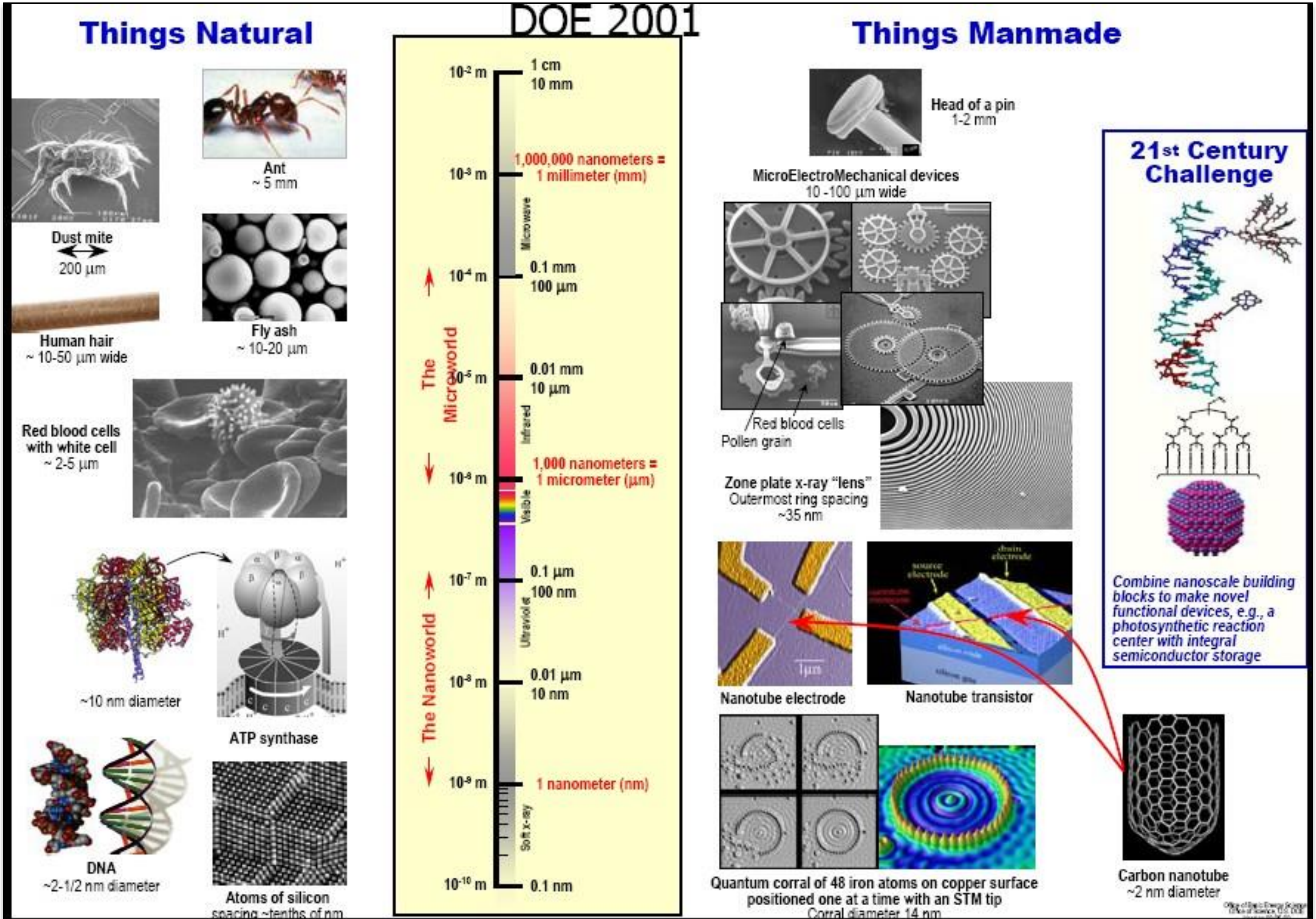
www.physics.ucr.edu

0.7 nm

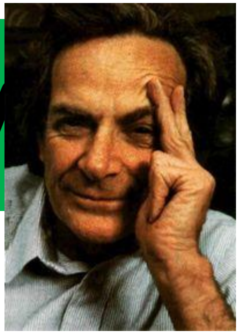
1.2756×10^7 m **0.22 m** **0.7 × 10-9 m**

10 millions times smaller

1 billion times smaller


DOE 2001
Things Natural
Dust mite
200 µm
Ant
~ 5 mm
Human hair
~ 10-50 µm wide
Fly ash
~ 10-20 µm
Red blood cells
with white cell
~ 2-5 µm
~10 nm diameter
ATP synthase
DNA
~2-1/2 nm diameter
Atoms of silicon
spacing ~tenths of nm
10⁻² m
1 cm
10 mm
10⁻³ m
1,000,000 nanometers =
1 millimeter (mm)
Microwave
10⁻⁴ m
0.1 mm
100 µm
The Microworld
10⁻⁵ m
0.01 mm
10 µm
Infrared
10⁻⁶ m
1,000 nanometers =
1 micrometer (µm)
Visible
10⁻⁷ m
0.1 µm
100 nm
Ultraviolet
The Nanoworld
10⁻⁸ m
0.01 µm
10 nm
10⁻⁹ m
1 nanometer (nm)
Soft x-ray
10⁻¹⁰ m
0.1 nm
Things Manmade
Head of a pin
1-2 mm
MicroElectroMechanical devices
10 -100 µm wide
Red blood cells
Pollen grain
Zone plate x-ray "lens"
Outermost ring spacing
~35 nm
Nanotube electrode
Nanotube transistor
Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm
Carbon nanotube
~2 nm diameter
21st Century
Challenge
Combine nanoscale building
blocks to make novel
functional devices, e.g., a
photosynthetic reaction
center with integral
semiconductor storage

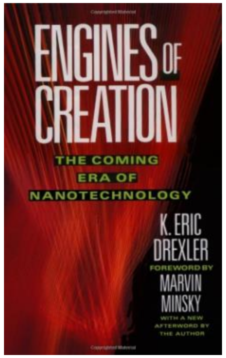
History of Nanotechnology



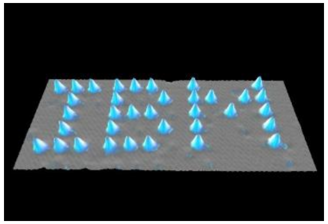
~ 2000 Years Ago – Sulfide nanocrystals used by Greeks and Romans to dye hair

~ 1000 Years Ago (Middle Ages) – Gold nanoparticles of different sizes used to produce different colors in stained glass windows

- **1959** – “There is plenty of room at the bottom” by R. Feynman
- **1974** – “Nanotechnology” - Taniguchi uses the term nanotechnology for the first time
- **1981** – IBM develops Scanning Tunneling Microscope
- **1985** – “Buckyball” - Scientists at Rice University and University of Sussex discover C_{60}
- **1986** – “Engines of Creation” - First book on nanotechnology by K. Eric Drexler. Atomic Force Microscope invented by Binnig, Quate and Gerbe



- **1989** – IBM logo made with individual atoms



- **1991** – Carbon nanotube discovered by S. Iijima
- **1999** – “Nanomedicine” – 1st nanomedicine book by R. Freitas
- **2000** – “National Nanotechnology Initiative” launched

There's Plenty of Room at the Bottom:

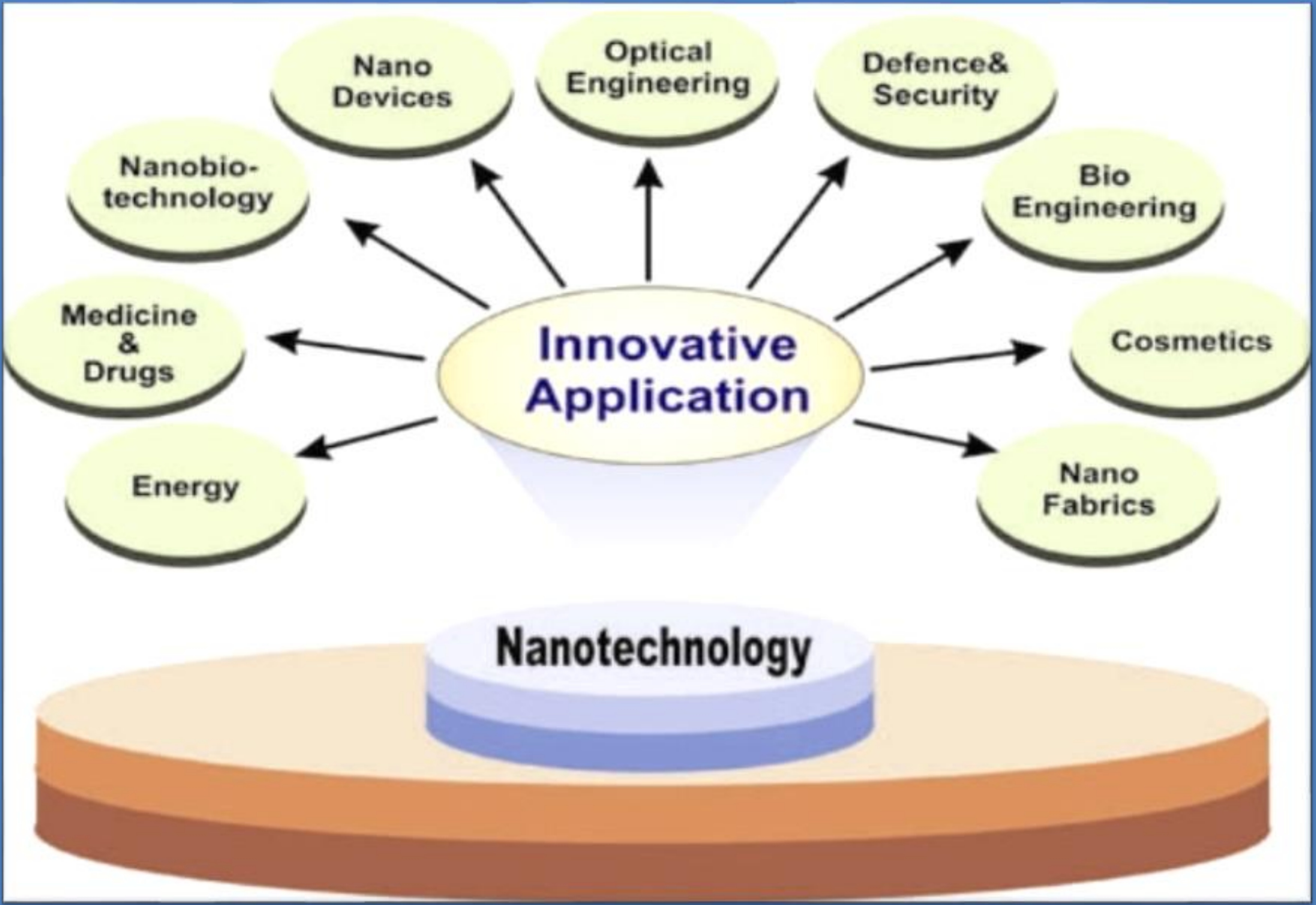
An Invitation to Enter a New Field of Physics

Richard Feynman
Cal Tech, 1959

"People tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing; that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction. *Why cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?"*

This goal requires patterning at the 10 nanometer scale.

Application of Nanotechnology



Nanotechnology Applications

Information Technology

- Smaller, faster, more energy efficient and powerful computing and other IT-based systems

Energy

- More efficient and cost effective technologies for energy production
  - Solar cells
  - Fuel cells
  - Batteries
  - Bio fuels

Medicine

- Cancer treatment
- Bone treatment
- Drug delivery
- Appetite control
- Drug development
- Medical tools
- Diagnostic tests
- Imaging

Consumer Goods

- Foods and beverages
  - Advanced packaging materials, sensors, and lab-on-chips for food quality testing
- Appliances and textiles
  - Stain proof, water proof and wrinkle free textiles
- Household and cosmetics
  - Self-cleaning and scratch free products, paints, and better cosmetics

Nanotechnology according to Hollywood

Nanotechnology Scientist:
Willem Dafoe in Spiderman

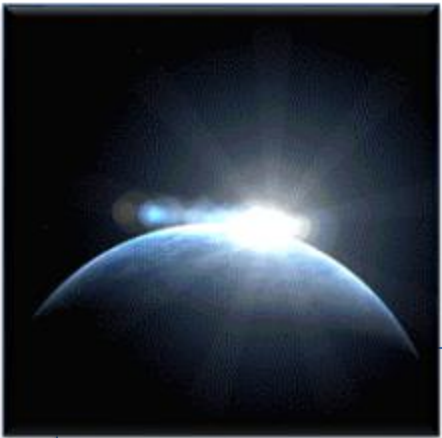
Created by Nanotechnology:
The Hulk

Nanotechnology in the Marketplace

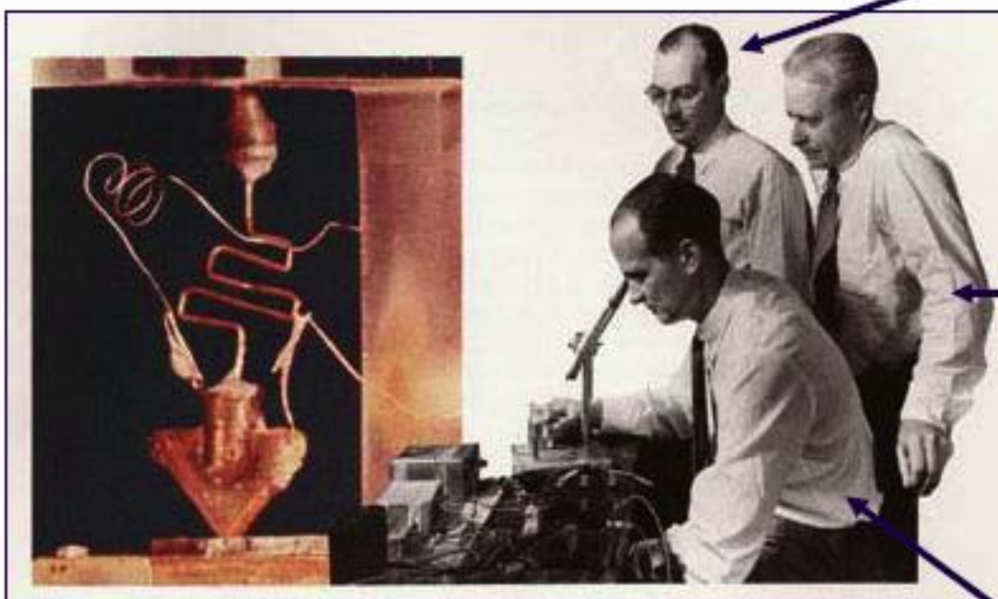
Nanotube Tennis Rackets

Nano-Care Fabric

Nanoparticle Skin Cream



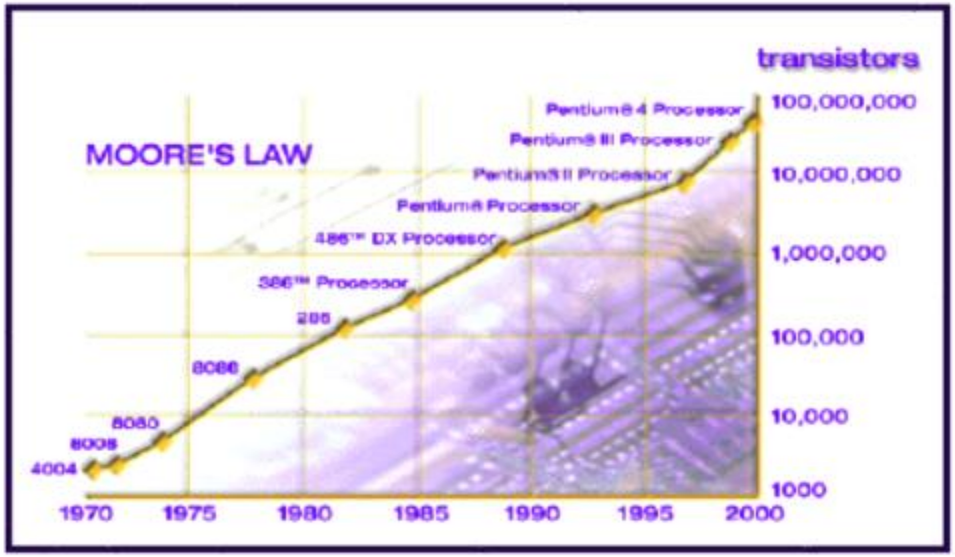
Invention of the Transistor



Bell Laboratories, 1947

Moore's Law

Intel Co-Founder
Gordon E. Moore



"Cramming More Components Onto Integrated Circuits"
Author: Gordon E. Moore
Publication: Electronics, April 19, 1965

To meet the Moore's Law,

line width(1/2 pitch) requiremen

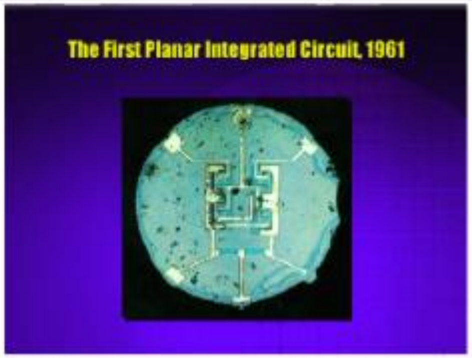
100 nm 2005

70 nm 2008

50 nm 2011

35 nm 2014

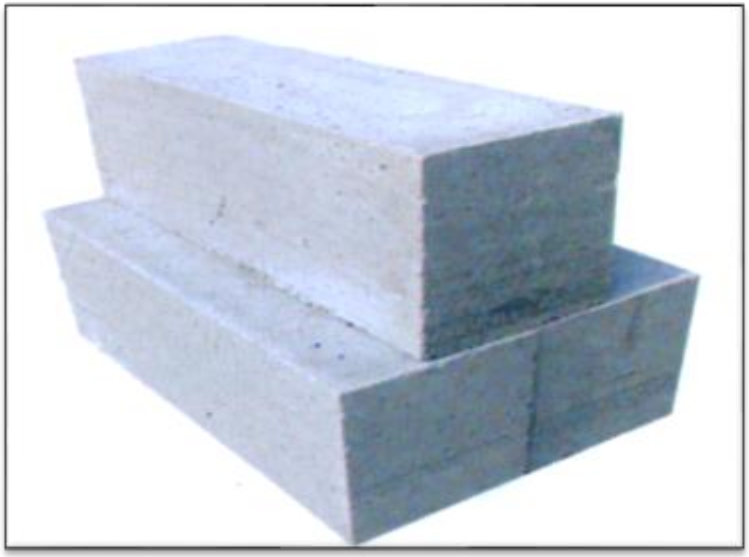
No solution yet, nanolithography?

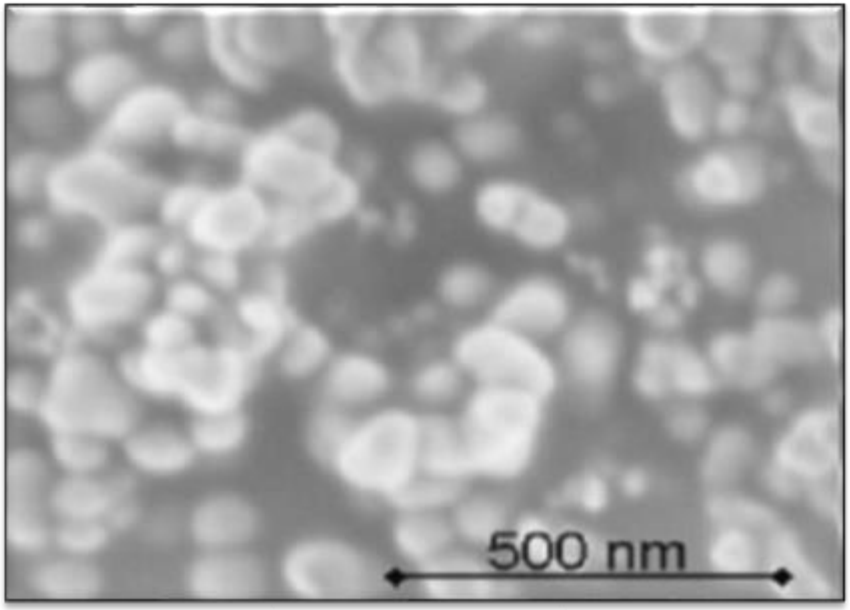


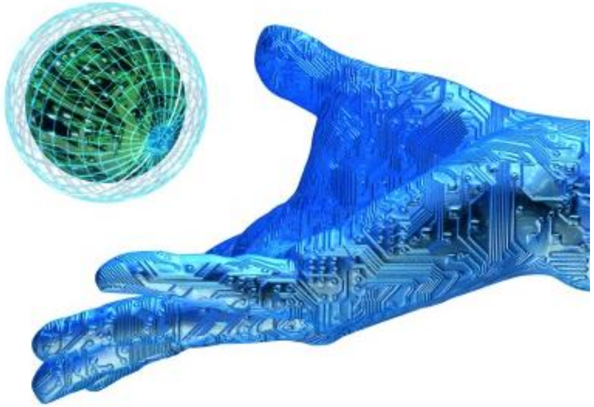
"No Exponential is Forever … but We Can Delay 'Forever'."
Gordon E. Moore, International Solid State Circuits Conference, Feb. 10, 2003.

NANOTECHNOLOGY & CONCRETE

IN CONCRETE NANO PARTICLES MAINLY USED ARE:



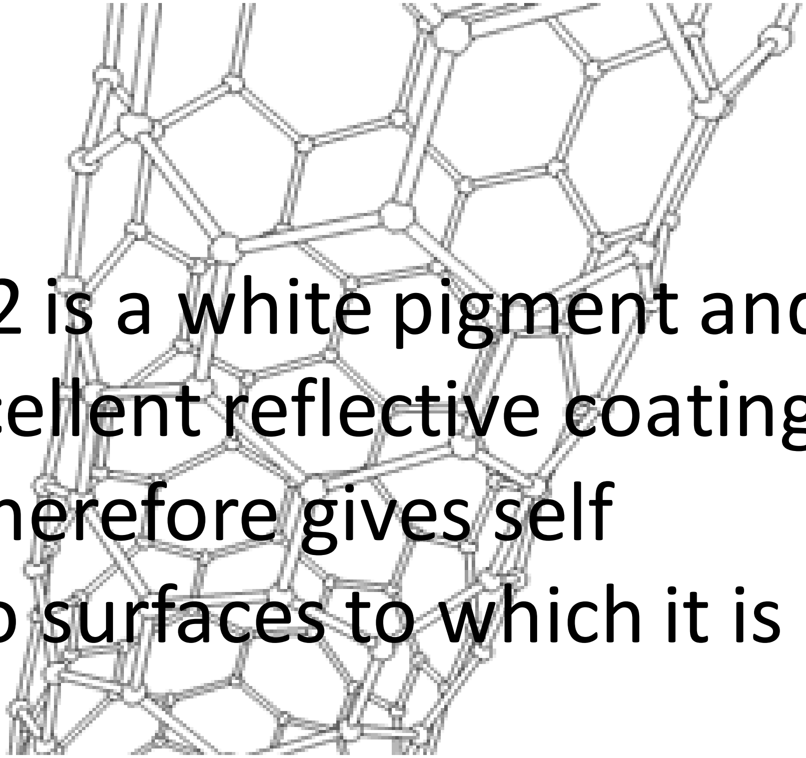




- ✓ NANO SILICA
- ✓ TITANIUM DIOXIDE
- ✓ CARBON-NANOTUBE (CNT)

Introduction To Nano Materials

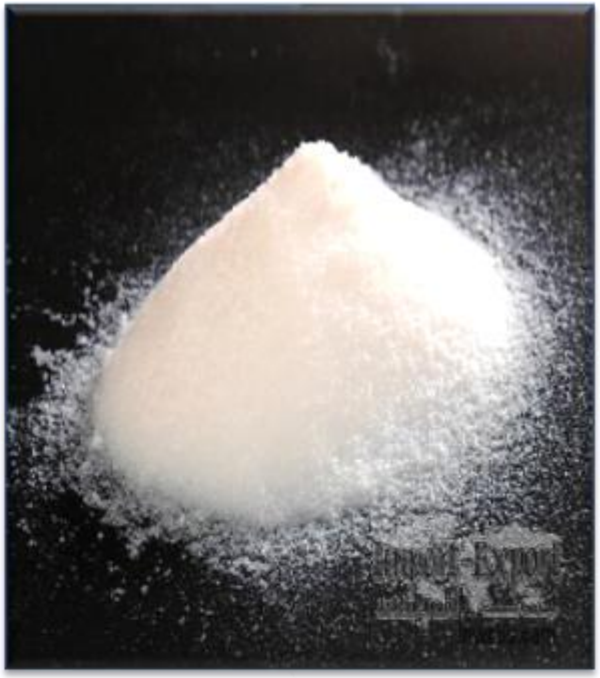
- Carbon Nano Tubes(CNT)
- NANO-SILICA
- TiO_2
- TiO_2 In Concrete:TiO_2 is a white pigment and can be used as an excellent reflective coating. it is hydrophilic and therefore gives self cleaning properties to surfaces to which it is applied.



NANO SILICA

NANO SILICA ADDITION TO CEMENT BASE MATERIALS CAN CONTROL THE DEGRADATION OF THE FUNDEMENTAL C-S-H (CALICIUM-SILICATE-HYBRATE) REACTION OF CONCRETE CAUSE BY CALICIUM LEACHING IN WATER AS WELL AS BLOCK WATER PENETRATION AND THEREFORE LEADS TO IMPROVEMENTS IN DURABLITY.

- WHEN RELEATED TO OPC AS A RESULT THE COMPRESSIVE STRENGTH OF THE MATERIAL IS **3-6** TIMES HIGHER.



FLY ASH

- IT IS ANOTHER NANO PARTICAL THAT IMPROVES CONCRETE DURABLITY,STRENGTH & IMPORTANTLY FOR SUSTANABLITY AND REPLACING CEMENT,HOWEVER ,THE CURING PROCESS OF CONCRETE IS SLOWED BY ADDITION OF FLYASH, AT EARLY STAGE STRENGTH IS ALSO LOW IN COMPARISION TO NORMAL CONCRETE .
- WITH THE ADDITION OF SIO2 NANO PARTICALS ADDED TO CONCRETE HAS SHOWN THAT THEY ALSO INCRESE STRENGTH THAT REPLACES DENCITY IN EARLYER STAGES.

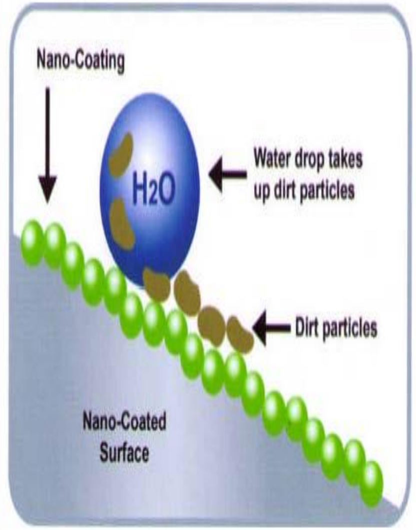
TITANIUM-DIOXIDE

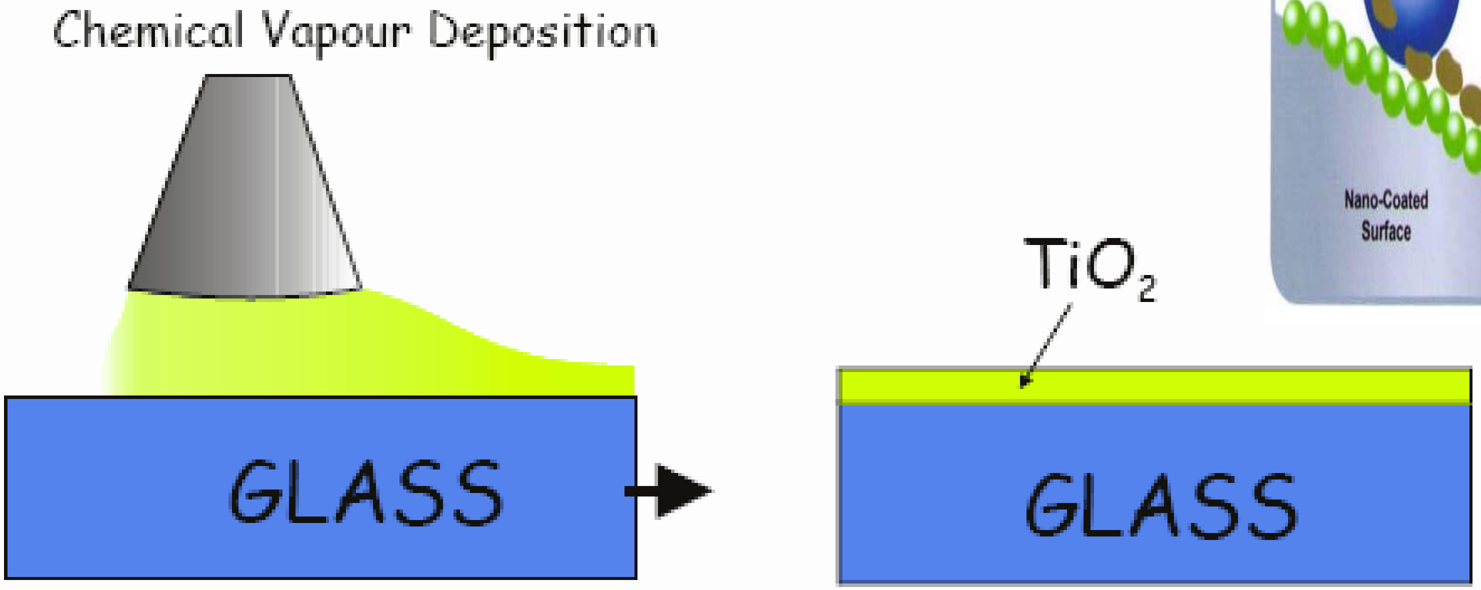
- ANOTHER TYPE OF NANO PARTICLE ADDED TO CONCRETE TO IMPROVE ITS PROPERTIES IS TI02
- TIO2 IS A WHITE PIGMENT AND CAN BE USED AS AN EXCELLENT REFLECIVE COATING .
- TIO2 BREAKS DOWN ORGANIC POLLUTANTS ,VOLATILE ORGANIC COMPONDS ,BACTERIAL MEMBRANE'S THROUGH POWERFUL CATALYTIC RECTIONS.
- ADDITIONALLY IT IS HYDRO PHILIC AND THEREFORE GIVES SELF CLEANING PROPERTIES TO SURFACE TO WHICH IT IS A PLANE.

NANOTECHNOLOGY & GLASS

Hydrophilic route to self-cleaning surfaces

New technology - self cleaning glass (windows)





Glass is treated with chemical vapour method to deposit a mechanically stable nanolayer of titanium dioxide on the glass surface. (layer thickness ~50 nm)

- Unusual properties.

Pilkington Activ® glass www.pilkington.com

TiO_2 coating is bonded permanently to the surface of the glass on-line during manufacture of the glass. The overall thickness of the coating, which has several distinct chemical layers, is around 50 nm and is virtually indistinguishable in appearance compared to standard glass.

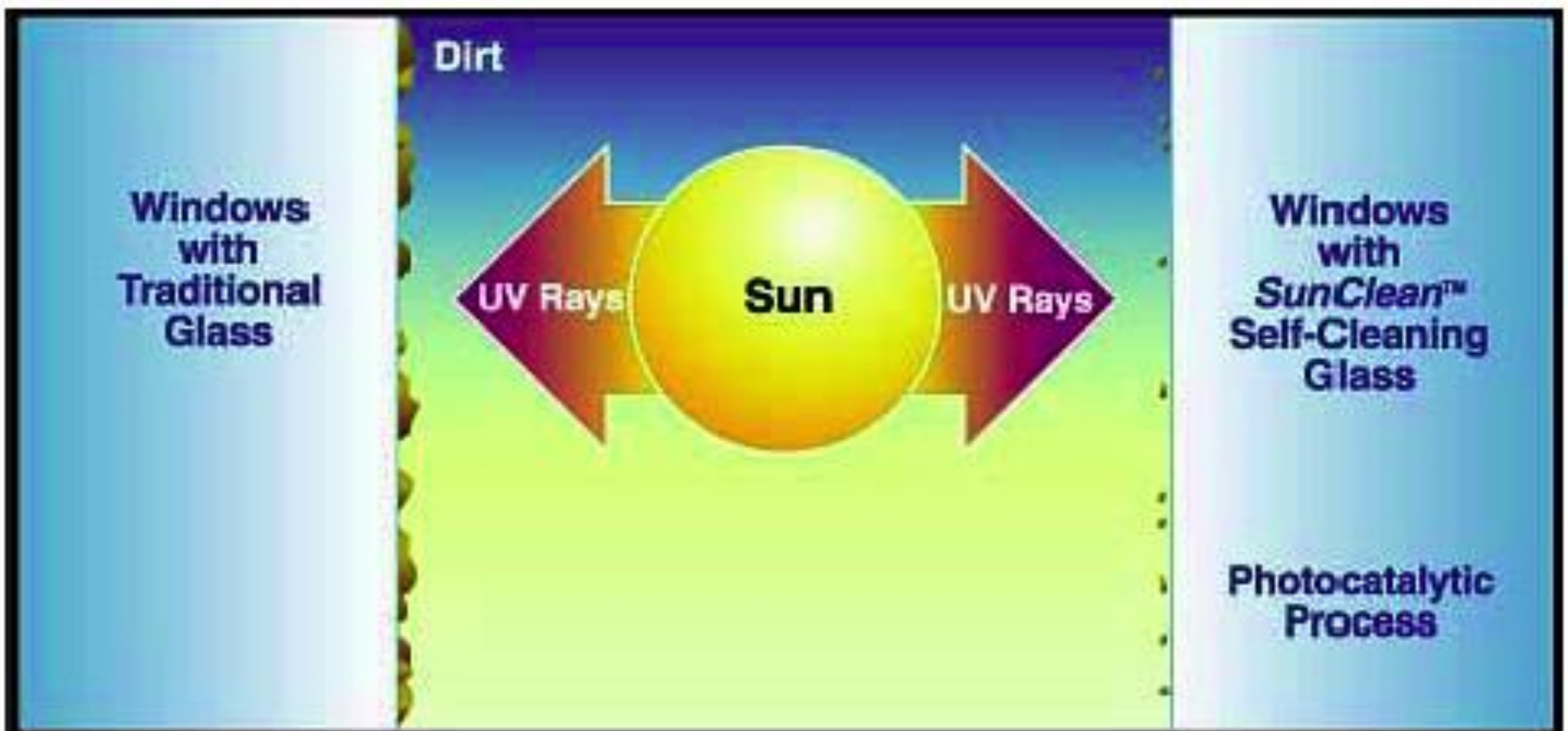
TiO_2 has a catalytic function to oxidize organic based dirt on the glass surface

Water drops on the TiO_2 coating has nearly zero contact angle and spread by forming of a stable aqueous film

Oxidized organic material and dust particles are carried away by the film flow (on vertical glass surface).

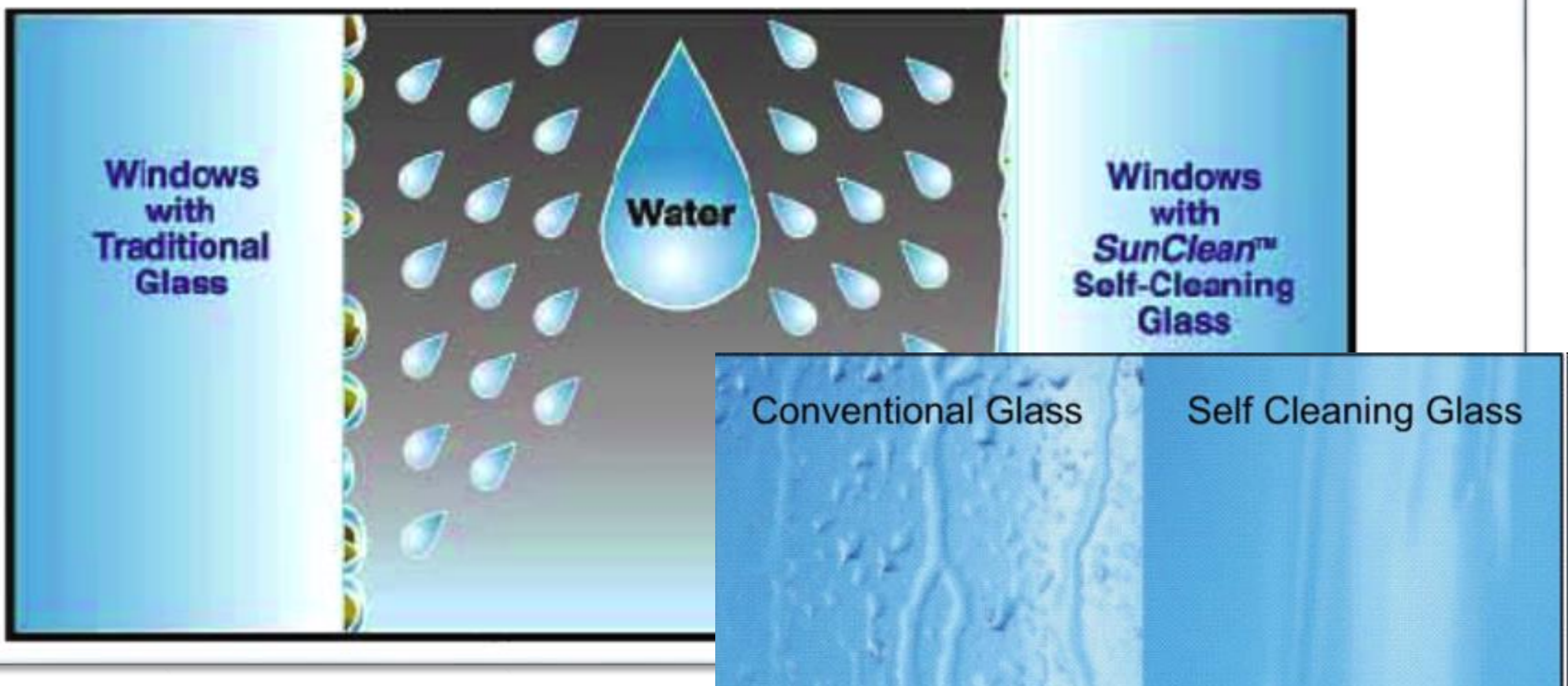
Self-cleaning window - how does it work ?

1) PHOTOCATALYTIC PROCESS: The nanolayer of titanium dioxide (TiO_2) on the glass surface is activated by ultraviolet light (UV) from the sun. In the presence of oxygen from the atmosphere it oxidises the organic dirt deposited on the glass surface.

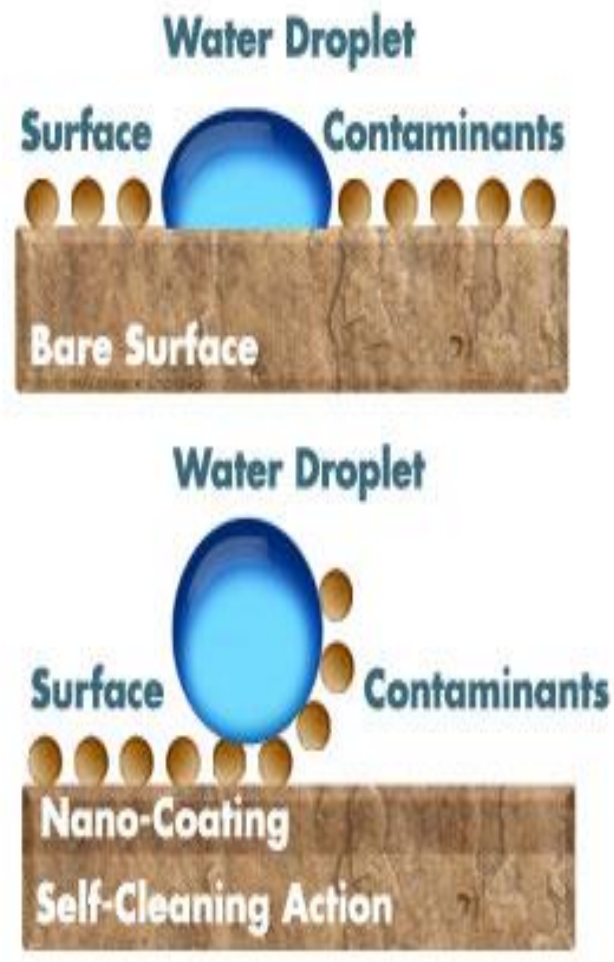


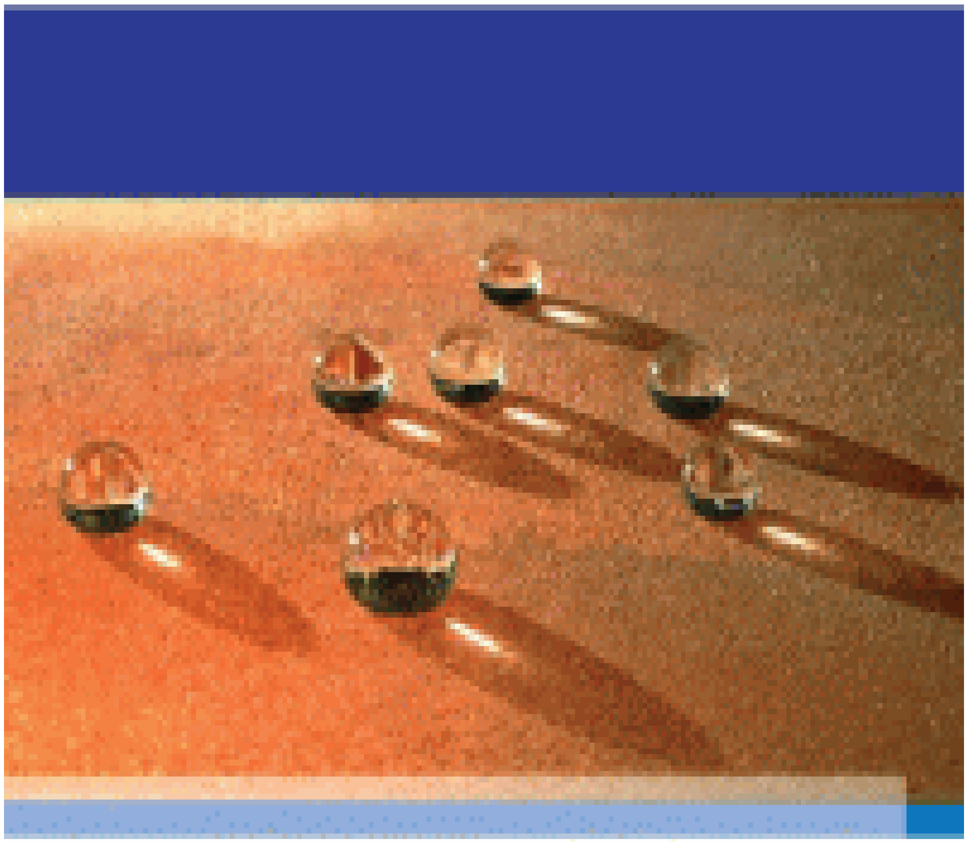
Self-cleaning window - how does it work ?

2) HYDROPHILIC PROCESS: The coating also has a **hydrophilic property** that makes water droplets spread out, or sheet, across the surface of the glass. When rain or a light spray of water hits the window, the water carries away the loosened dirt. This sheeting action also helps the window dry quickly with minimal spotting.



WATER REPELLENT PROCESS





Smart air-cleaning paints (ecopaints)

Paint base: polysiloxane, a silicon-based polymer

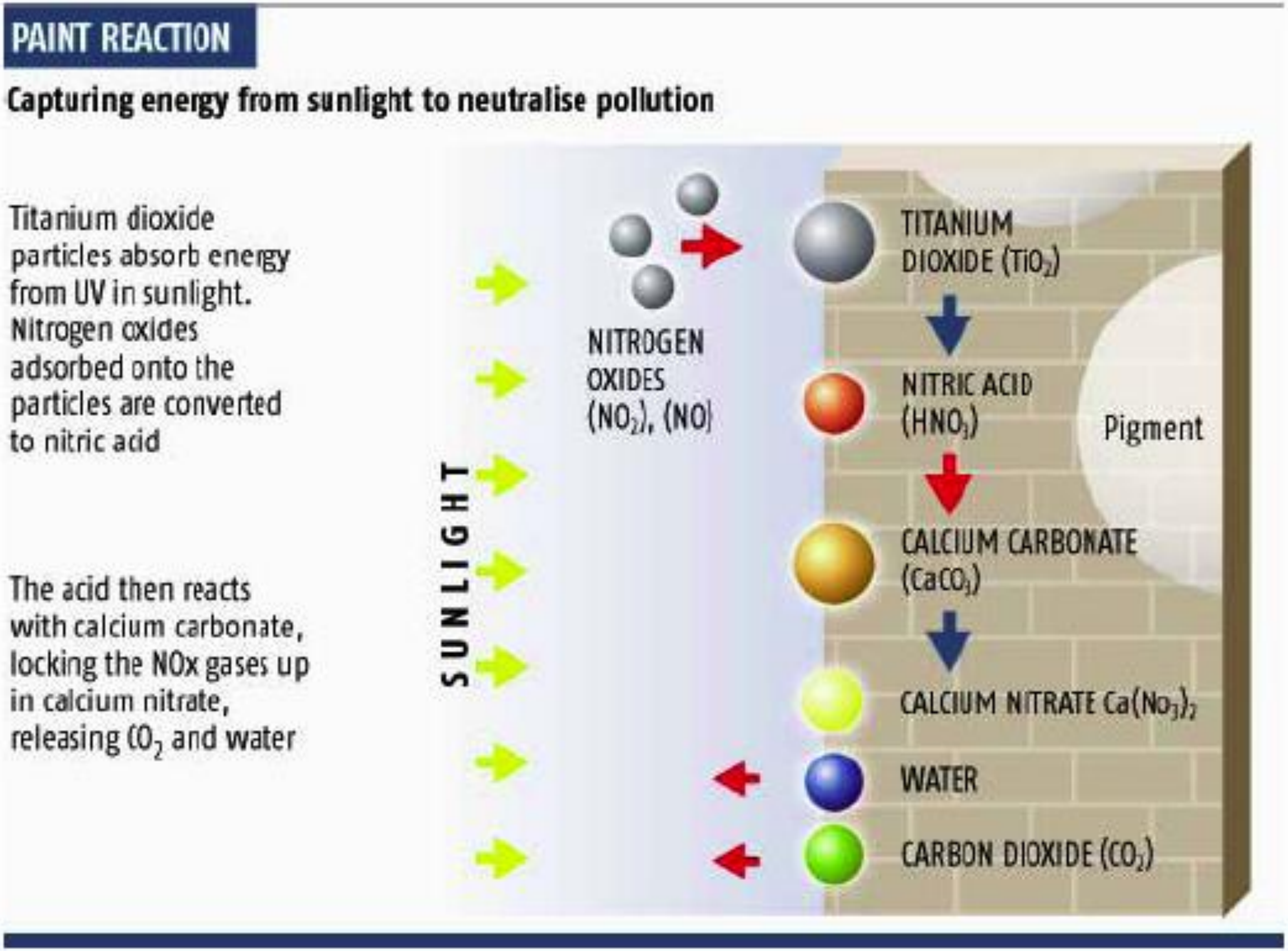
Additives embedded in the polysiloxane:

TiO_2 nanoparticles (30 nm in diameter)
$CaCO_3$ nanoparticles

Nanoparticles of such size do not scatter light - hence the paint is clear (other pigments can be added).

Important: The polysiloxane base is porous enough to allow NOx to diffuse though it and adhere to the titanium dioxide particles.

Smart air-cleaning paints (ecopaints)



NANOTECHNOLOGY IN STEEL

Nanotechnology and Steel

- **Fatigue is a significant issue that can lead to failure of steel subject to cyclic loading, such as in bridges or towers. This can happen at stresses significantly lower than the yield stress of the material**

MMFX2

SANDVIK ANOFLEX

- STEEL HAS BEEN WIDELY AVAILABLE SINCE THE SECOND INDUSTRIAL REVOLUTOIN IN LATE PART OF 19TH AND EARLY PART OF THE 20TH CENTUARY HAS PLAYED A MAJOR PART IN THE CONSTRUCTIN SINCE THAT TIME .

- IT MAINLY DEALS WITH ……..
  - FATIGUE
    - ✓ CABLES
    - ✓ JOINTS
    - ✓ WELDS

FATIGUE

- IT IS A SIGNIFICANT ISSUE THAT CAN LEAD TO THE STRUCTURAL FAILURE OF STEEL SUBJECT TO CYCLIC LOADING .

- STRESS RISERS ARE RESPONSIBLE FOR INICIATING CRACKS FROM WHICH FATIGUE FAILURE RESULTS THAT THE ADDITION OF COPPER NANO PARTICALS REDUCES THE SURFACE ROUGHNESS OF STEEL WHICH THEN LIMITS TO THE NUMBER OF STRESS RISES HENCE FATIGUE CRACKING

CABLES, JOINTS & WELDS

- CABLE: THE REFINEMENT OF THE PHASE OF STEEL TO ANANO SIZE HAS PRODUCED STRONGER CABLES HIGH STRENGH STEEL CABLES BEING USED IN CAR TYRES ARE USED IN BRIDGE CONSTRUCTION AND PRE CASTING CONCRETE.

- JOINTS: HIGH –RISE STRUCTURE REQUIRE HIGH STRENGTH JOINTS THIS INTURN LEADS TO NEED FOR HIGH STRENGH BOLTS WHICH ARE GENERALLY GONE THROUGH QUENCHING AND TEMPERING MARTENSITE.

NANOTECHNOLOGY & FIRE PROTECTION

- NANO CEMENT HAS THE POTENTIAL TO CREATE A NEW PARADIGM IN THIS AREA CAN BE USED AS TOUGH, DURABLE HIGH TEMPARATURE COATING THIS IS ACHIVED BY MIXING CNT'S WHICH CEMENT MATERIAL TO FABRICATE FIBER COMPOSITES WHICH RESULTS OUTSTANDING PERFORMANCES .
- POLY PROPOLINE ALSO ARE BEING CONSIDER AS THE METAL OF INCREASING FIRE RESISTANCE AND THIS IS CHEAPER OPTION THAN CONVENTIONAL

- NANO CEMENT HAS THE POTENTIAL TO CREATE A NEW PARADIGM IN THIS AREA CAN BE USED AS TOUGH, DURABLE HIGH TEMPARATURE COATING THIS IS ACHIVED BY MIXING CNT'S WHICH CEMENT MATERIAL TO FABRICATE FIBER COMPOSITES WHICH RESULTS OUTSTANDING PERFORMANCES .

- POLY PROPOLINE ALSO ARE BEING CONSIDER AS THE METAL OF INCREASING FIRE RESISTANCE AND THIS IS CHEAPER OPTION THAN CONVENTIONAL

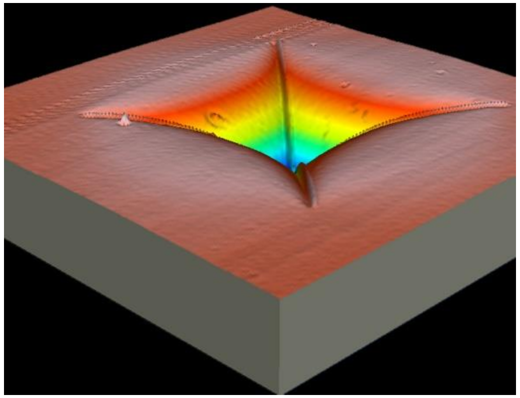
Fire Protection and Detection

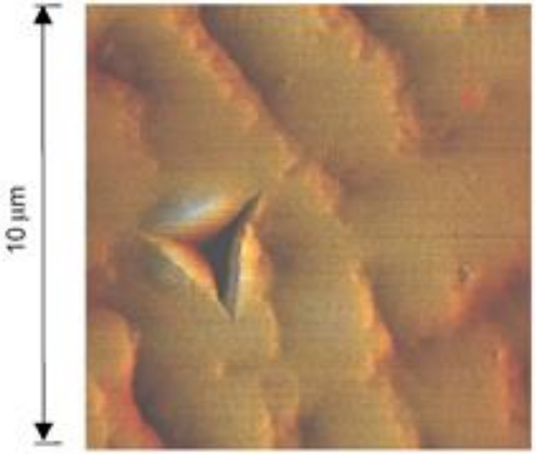
- Fire resistance of steel structures is often provided by a coating produced by a spray-on cementitious process. Current portland cement based coatings are not popular because they need to be thick, tend to be brittle and polymer additions are needed to improve adhesion.

- Nano-cement can be used as a tough, durable, high temperature coating. Achieved by the mixing of carbon nanotubes (CNT's) with the cementious material to fabricate fibre composites that can inherit some of the properties of the nanotubes such as strength.

- Polypropylene fibres also are being considered as a method of increasing fire resistance and this is a cheaper option than conventional insulation.

Introduction to the Nano-Indentation Tester





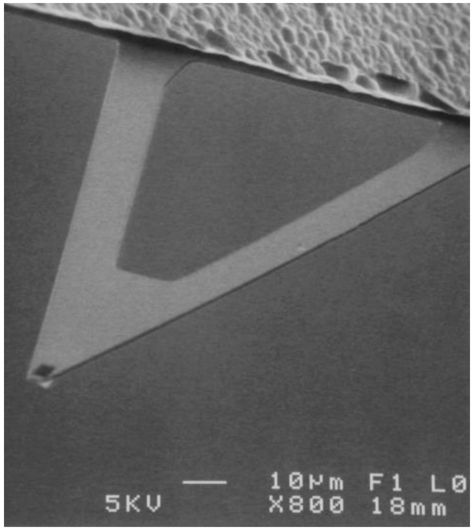
Nano-Indentation Tester is a high precision instrument for the determination of the nano mechanical properties of thin films, coatings and substrates.

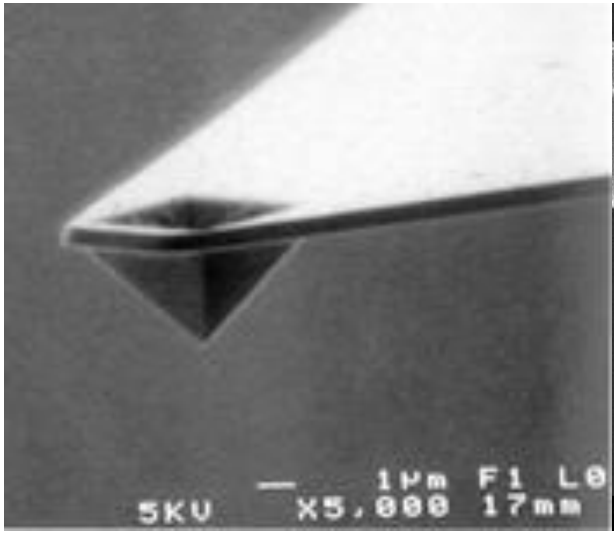
With a Nano-Indentation Tester you can quickly determine properties such as hardness and Young's modulus on almost any type of material - soft, hard, brittle or ductile.

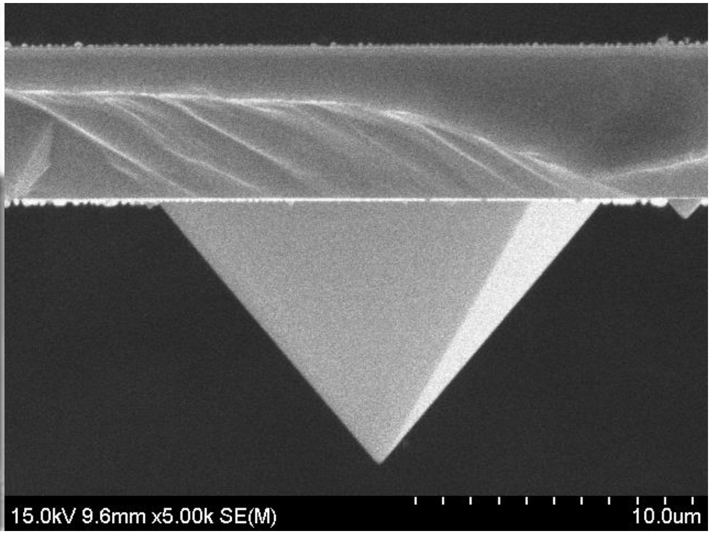
General Applications Nano-Indentation Tester

- **Semiconductor Technology**
  - Passivation Layers
  - Metallization
  - Bond Pads
- **Mass Storage**
  - Protective coatings on magnetic disks
  - Magnetic coatings on disk substrates
  - Protective coatings on CD's
- **Optical Components**
  - Contact lenses
  - Eye glass lenses
  - Fibre Optics
  - Optical scratch-resistant coatings
- **Decorative coatings**
  - Evaporated metal coatings
- **Wear Resistant Coatings**
  - TiN, TiC
  - Cutting Tools
- **Pharmacological**
  - Tablets and pills
  - Implants
  - Biological tissue
- **Automotive**
  - Paints and polymers
  - Varnishes and finishes
  - Windows
- **General Engineering**
  - Rubber resistance
  - Touch screens
  - MEMS

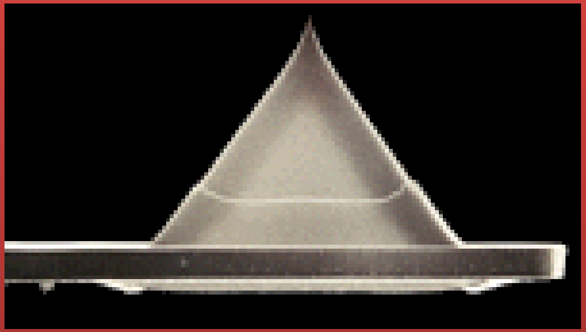
SNOM / AFM probes





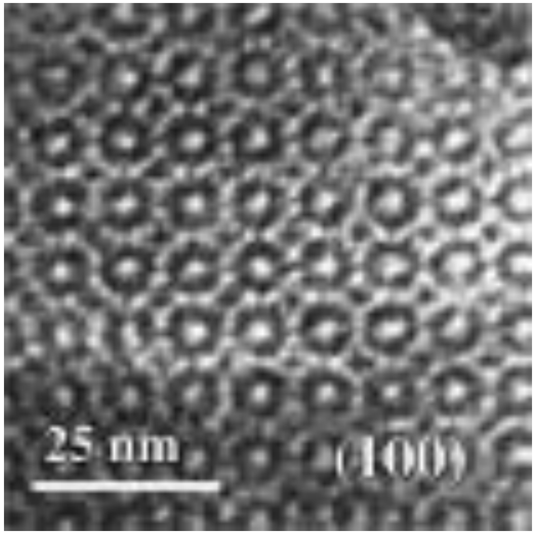


- Cantilever and probe made of Si_3Ni_4
- Square pyramidal shape with apex radius around 10-50 nm
- Cantilever length : 50-500µm
- Spring constant ~0.1 - 0.7 N/m
- Used both in air and liquid for contact
- Used in liquid for tapping



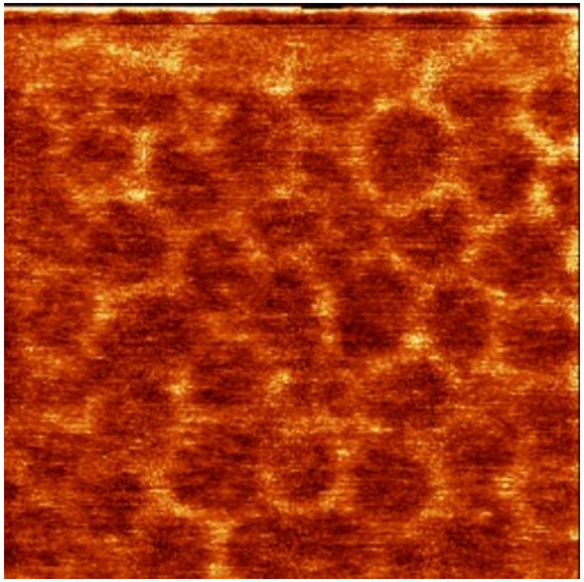
Transmission Electron Microscope (TEM)

- Uses high-energy electron beam to probe material with thickness < 100 nm.
- Some electrons are absorbed or bounced off object; some pass through the object and make magnified images
- Digital camera records images.



Scanning Tunneling Microscope (STM)

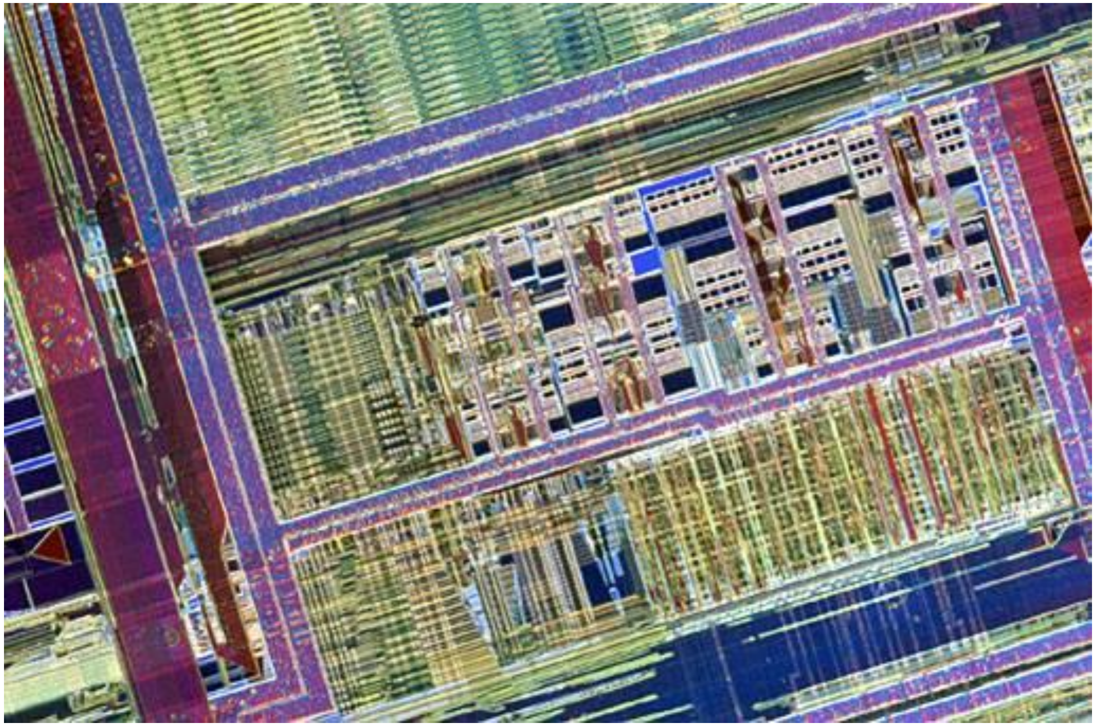
- Uses nanosized probe to scan objects and materials
- Uses tunneling to detect surface and creates a map of surface
- Rate of electrons that tunnel from probe to surface related to distance between probe and surface



12 nanometer gold clusters of particles look red

Computer Circuits

- Computer circuits are small pieces of semiconducting material containing an electronic circuit.
- Most commonly used in computers
- Consists of as many as millions of transistors.

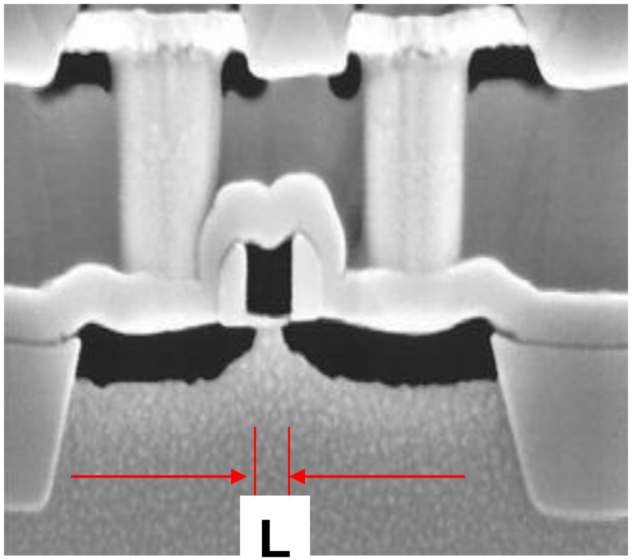


Nanotechnology is applied to the reduction in the size of these computer circuits!!!

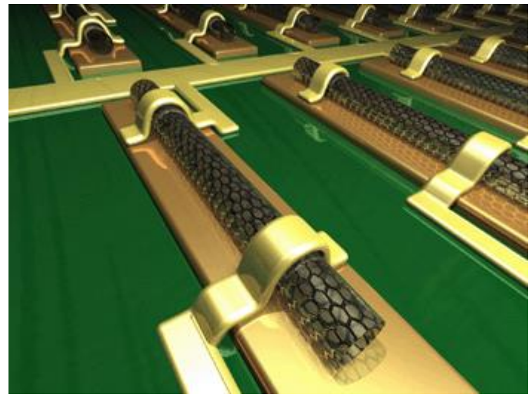
- **In the computer world, nanotechnology is important to the development of small computer circuits that can reduced the size of computers.**

Molecular Nanoelectronics:

From Hamiltonians to Circuits

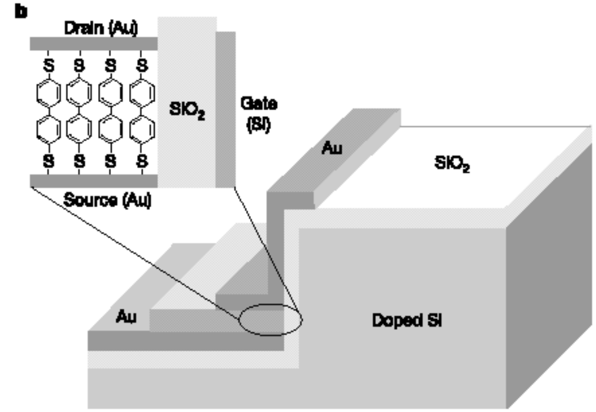


MOSFET



CNTFET

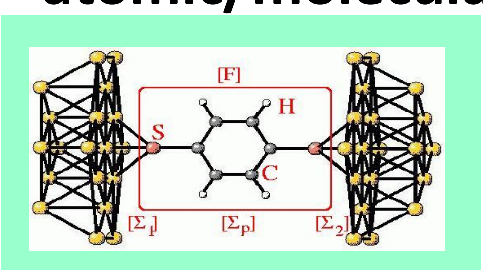
Bachtold, et al.,
Science, Nov. 2001

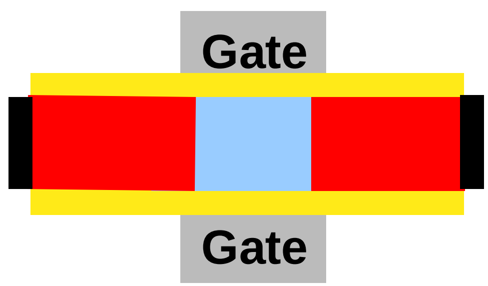


SAMFET

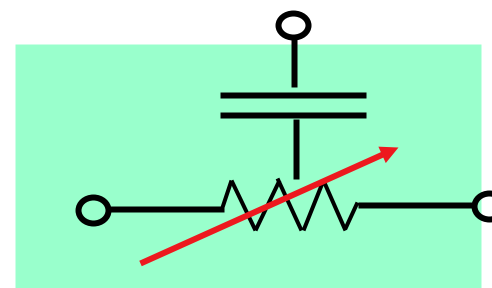
Schön, et al.,
Nature,**413**,713,2001

atomic/molecular





mesoscale devices

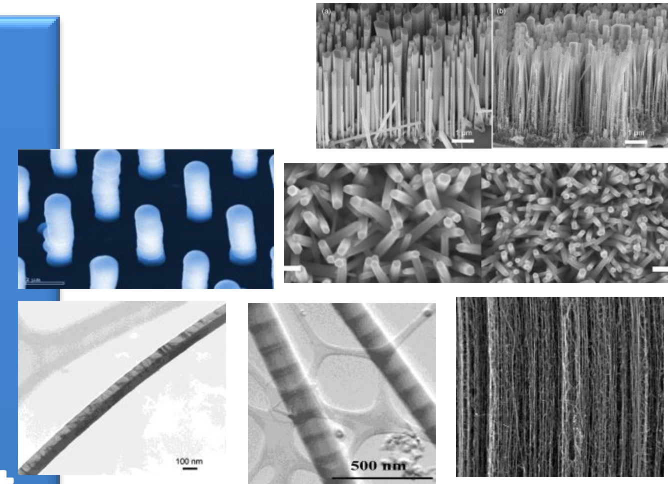


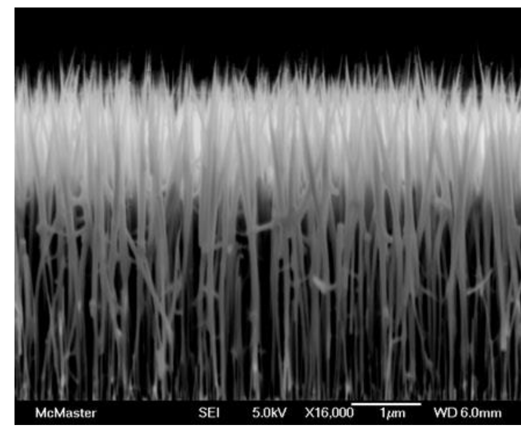
circuit models

Nanoscale Materials

Nanowires and Nanotubes

- Lateral dimension: 1 – 100 nm
- Nanowires and nanotubes exhibit novel physical, electronic and optical properties due to
  - Two dimensional quantum confinement
  - Structural one dimensionality
  - High surface to volume ratio
- Potential application in wide range of nanodevices and systems
  - Nanoscale sensors and actuators
  - Photovoltaic devices – solar cells
  - Transistors, diodes and LASERs

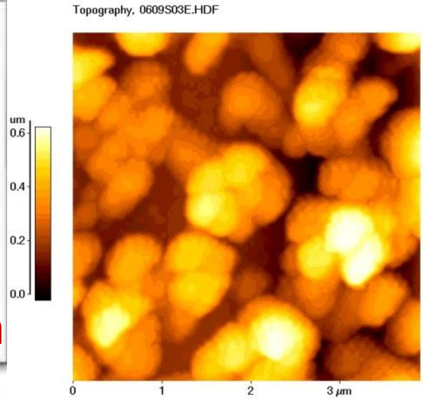


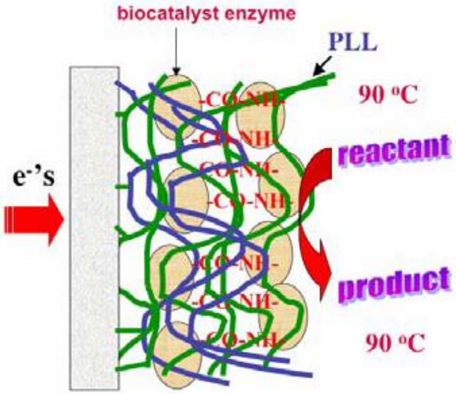


Nanowire Solar Cell: The nanowires create a surface that is able to absorb more sunlight than a flat surface – *McMaster Univ., 2008*

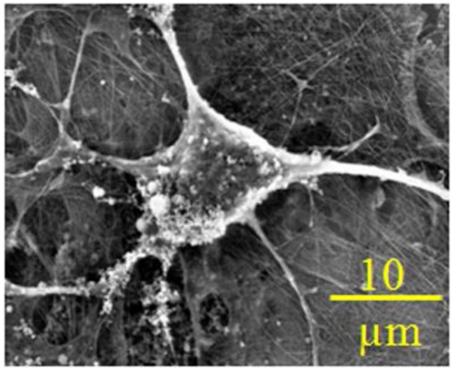
Bio-nanomaterials

1) Biological materials utilized in nanotechnology
   - Proteins, enzymes, DNA, RNA, peptides
2) Synthetic nanomaterials utilized in biomedical applications
   - Polymers, porous silicon, carbon nanotubes

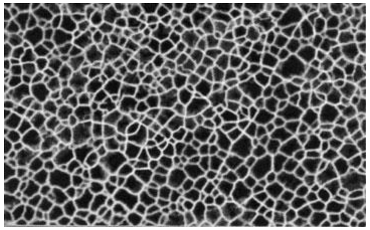




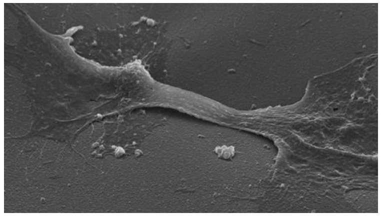
Cross-linked enzymes used as catalyst – *Univ. of Connecticut, Storrs, 2007*



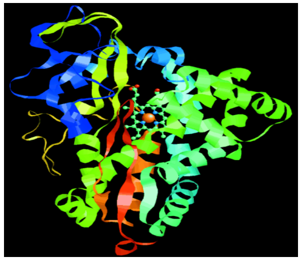
Bone cell on porous silicon – *Univ. of Rochester, 2007*



Porous silicon (PSi)



Human cell on PSi

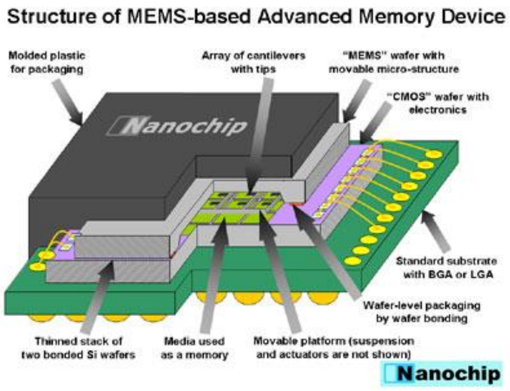


Enzymes are used as oxidation catalysts

Nanoscale Devices and Integrated Nanosystems

Nanochip

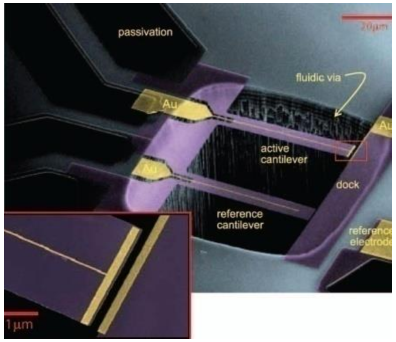
- Currently available microprocessors use resolutions as small as 32 nm
- Houses up to a billion transistors in a single chip
- MEMS based nanochips have future capability of 2 nm cell leading to 1TB memory per chip



A MEMS based nanochip
– Nanochip Inc., 2006

Nanoelectromechanical System (NEMS) Sensors

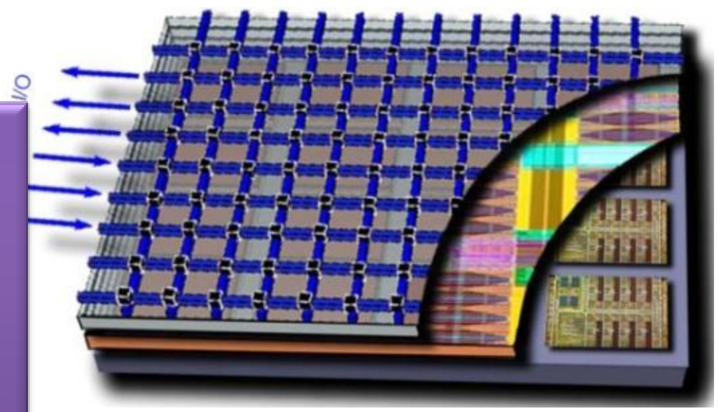
- NEMS technology enables creation of ultra small and highly sensitive sensors for various applications
- The NEMS force sensor shown in the figure is applicable in pathogenic bacteria detection



A NEMS bacteria sensor
– Nano Lett., 2006, DOI: 10.1021/nl060275y

Nanophotonic Systems

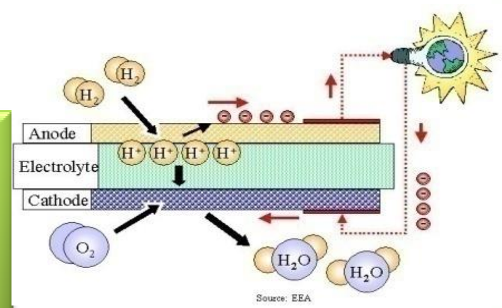
- Nanophotonic systems work with light signals vs. electrical signals in electronic systems
- Enable parallel processing that means higher computing capability in a smaller chip
- Enable realization of optical systems on semiconductor chip



A silicon processor featuring on-chip nanophotonic network *– IBM Corp., 2008*

Fuel Cells

- Fuel cells use hydrogen and air as fuels and produce water as by product
- The technology uses a nanomaterial membrane to produce electricity

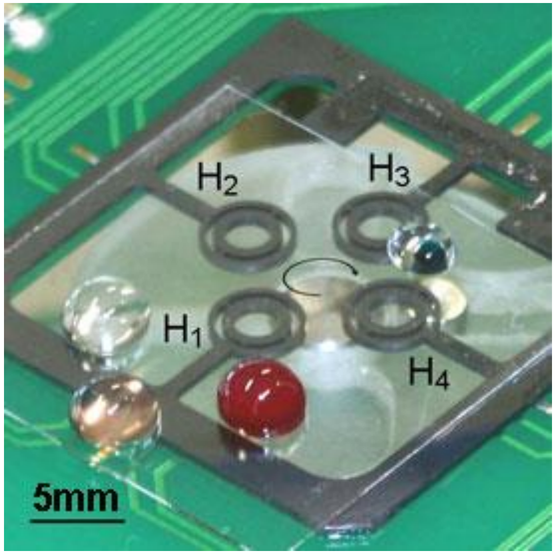


Schematic of a fuel cell *– Energy solution center Inc.*

500 W fuel cell – *H2economy.com*

Lab on Chip

- A lab on chip integrates one or more laboratory operation on a single chip
- Provides fast result and easy operation
- Applications: Biochemical analysis (DNA/protein/cell analysis) and bio-defense

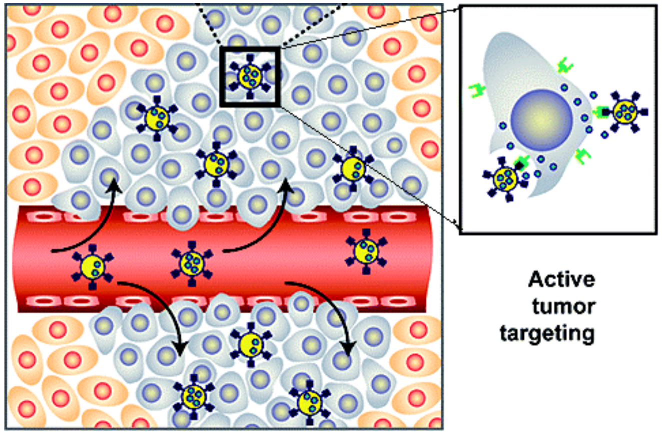


Lab on chip gene analysis device
– IBN Singapore, 2008

Drug Delivery Systems

Impact of nanotechnology on drug delivery systems:

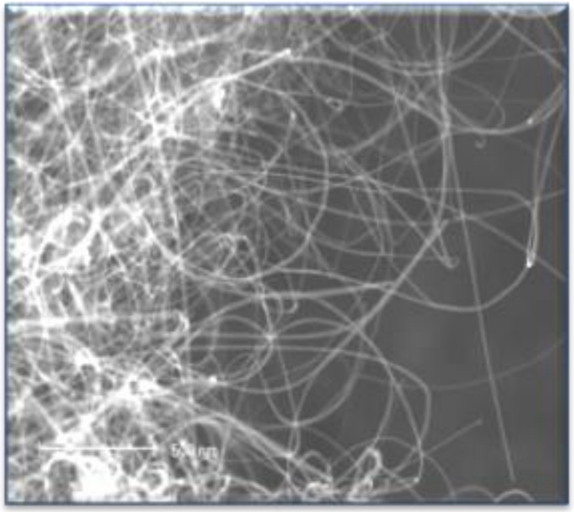
- Targeted drug delivery
- Improved delivery of poorly water soluble drugs
- Co-delivery of two or more drugs
- Imaging of drug delivery sites using imaging modalities



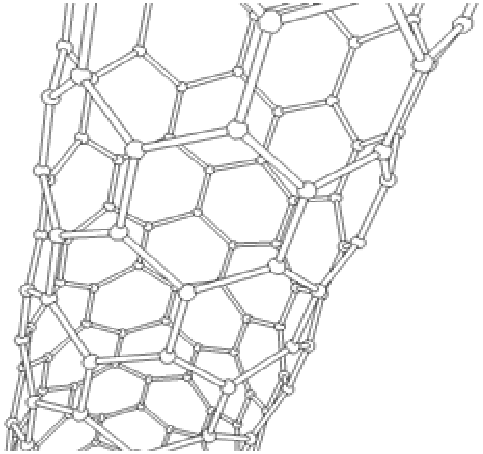
Targeted drug delivery
– *ACS Nano 2009, DOI: 10.1021/nn900002m*

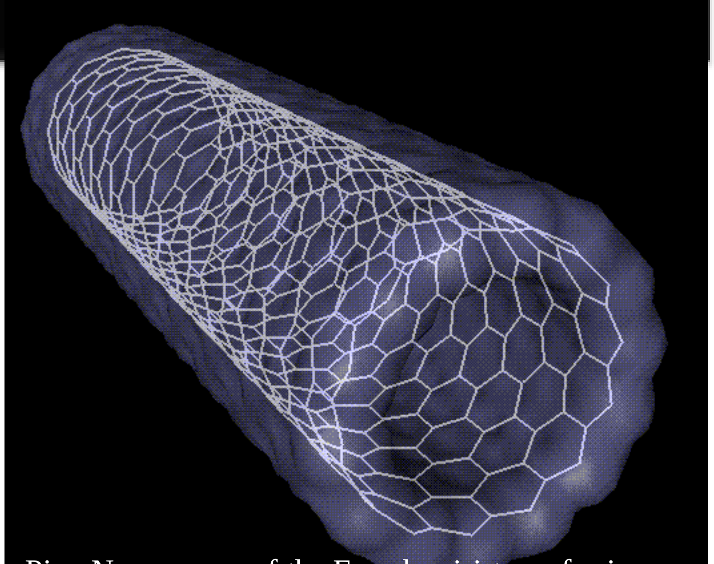
Carbon Nanotube (CNT)

- The addition of small amounts (1% wt) of CNT's can improve the mechanical properties of samples consisting of the main portland cement phase and water.
- Oxidized multi-walled nanotubes (MWNT's) show the best improvements both in compressive strength (+25 N/mm^2) and flexural strength (+8 N/mm^2) compared to the reference samples without the reinforcement

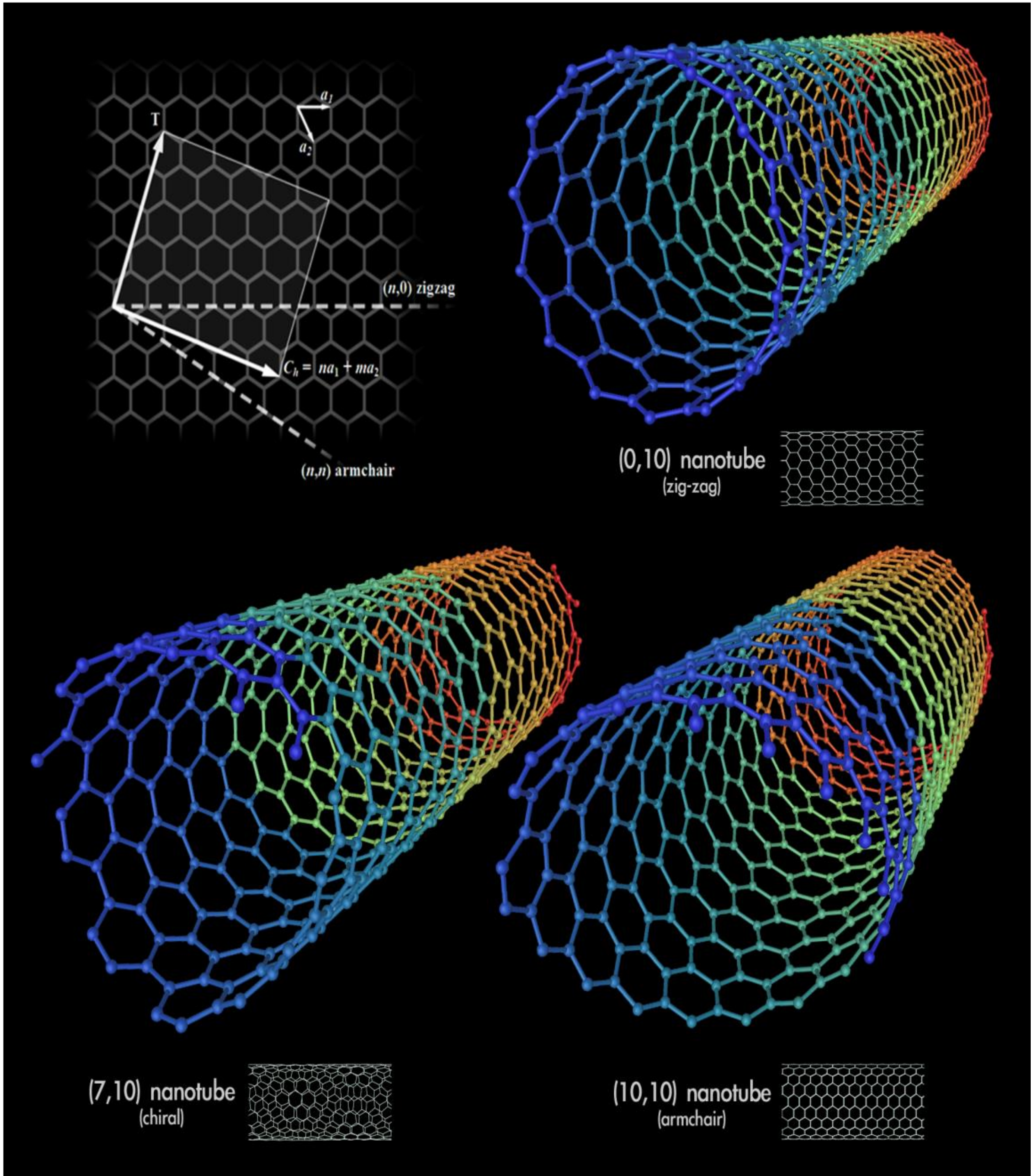


SEM images. Diameter range: 5nm - 15 nm





Pic.: Nano-pages of the French ministry of science


T
a_1
a_2
$(n,0)$ zigzag
$C_h = na_1 + ma_2$
(n,n) armchair
(0,10) nanotube
(zig-zag)
(7,10) nanotube
(chiral)
(10,10) nanotube
(armchair)

Carbon Nanotubes Properties

Everything changes at nanometer scale!

Physical properties

Mechanical	strength, toughness
Chemical	bonding, reactivity
Thermal	insulators, conductors
Electrical	conductivity
Optical	absorption, reflectivity

Applications

high strength
low weight composites

chemical and biological
sensors and receptors

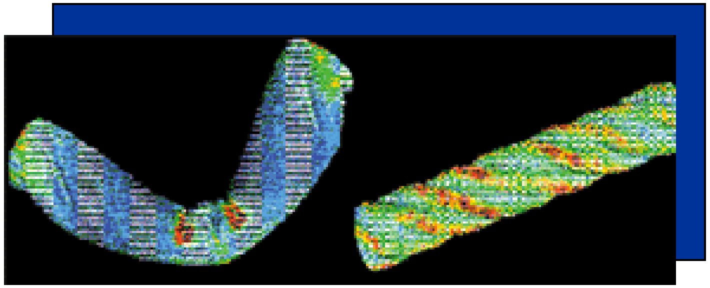
high power or
high temperature application

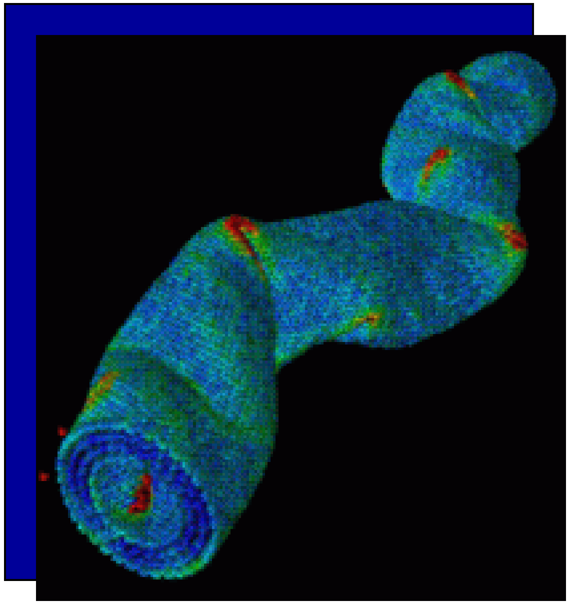
Microelectronics

high bandwidth fibers
or waveguides

Carbon Nanaotubes Properties

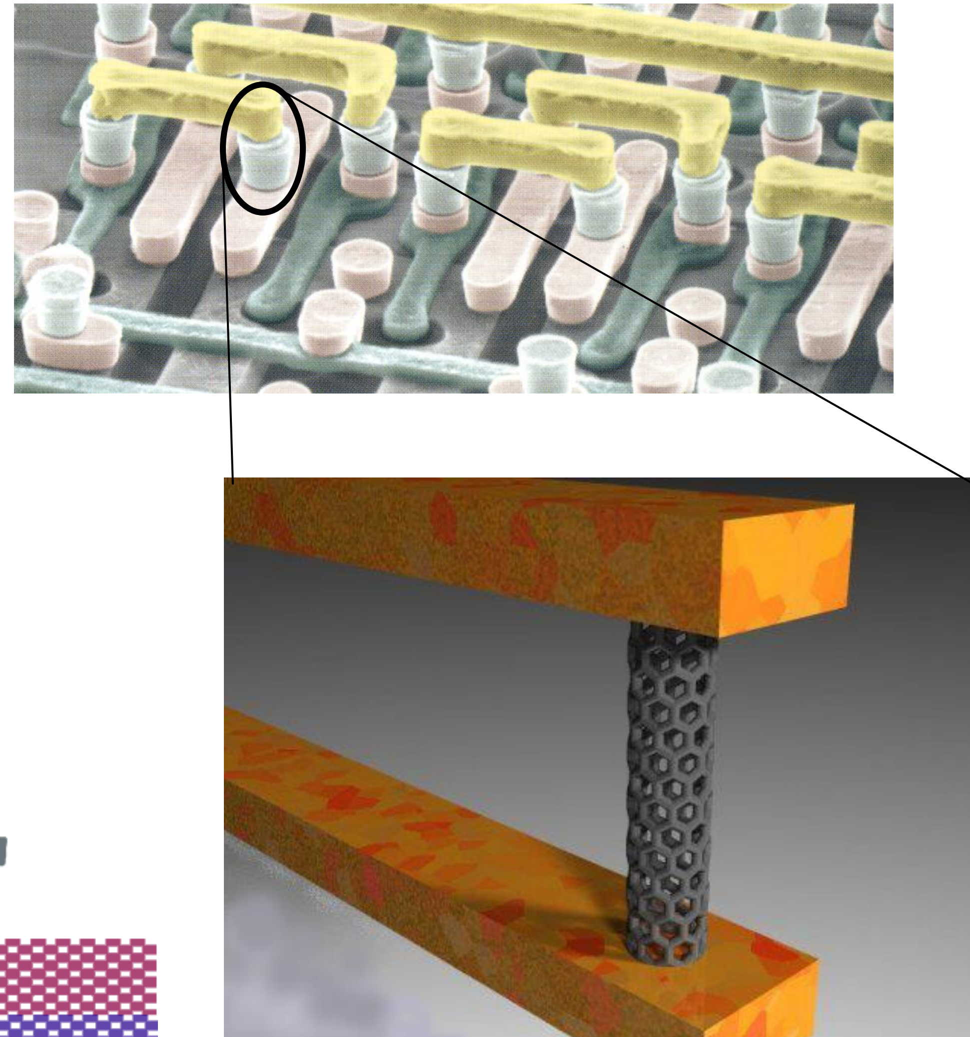
- The strongest and most flexible molecular material because of C-C covalent bonding
- Young's modulus of over 1 TPa vs. 70 GPa for Aluminum, 700 GPA for C-fiber
- Maximum strain ~10% much higher than any material

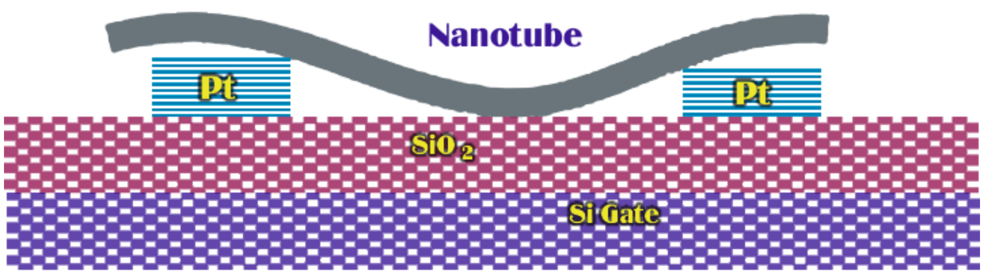




CNT Application: Electronics

- Diodes and transistors for Computing
- Capacitors
- Data Storage
- Field emitters for instrumentation
- Flat panel displays





Copper, Vanadium & Molybdenum nanoparticles

- **Stress risers are responsible for cracks. Copper nanoparticles reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking.**
- **The microstructures of high strength bolts consist of tempered martensite. When the tensile strength of tempered martensite steel exceeds 1,200 MPa even a very small amount of hydrogen embrittles the grain boundaries and the steel material may fail during use. This is called delayed fracture.**
- **The highest strength has long been limited to somewhere around 1,000 to 1,200 MPa. Research work on vanadium and molybdenum nanoparticles has shown that they improve the delayed fracture problems associated with high strength bolts.**

Nanoparticles and Welds

- **Welds and the Heat Affected Zone (HAZ) adjacent to welds can be brittle and fail without warning when subjected to sudden dynamic loading, and weld toughness is a significant issue especially in zones of high seismic activity.**

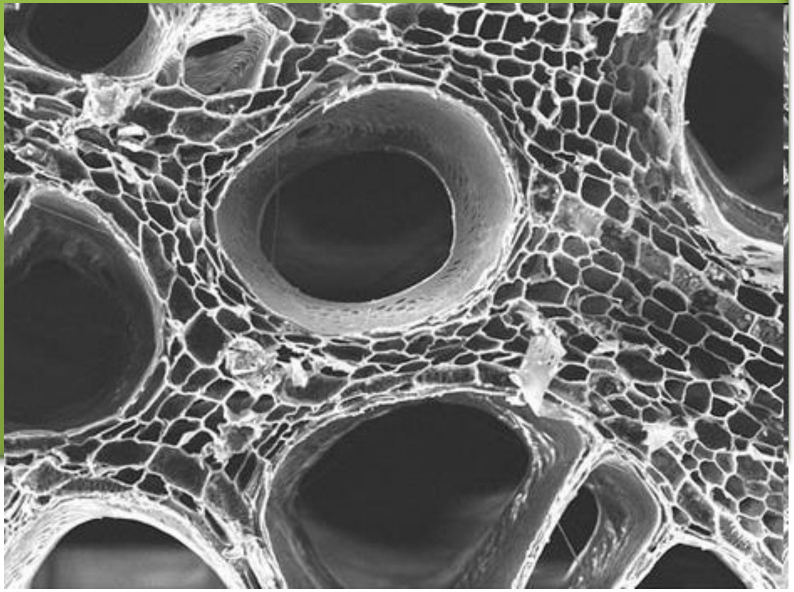
- **The addition of nanoparticles of magnesium and calcium makes the HAZ grains finer (about 1/5th the size of conventional material)**

  in plate steel and this leads to

  an increase in weld toughness.

Nanotechnology and Wood

- **Wood is composed of "nanofibrils"; namely, lignocellulosic (woody tissue) elements which are twice as strong as steel. Harvesting these nanofibrils would lead to a new paradigm in sustainable construction as both the production and use would be part of a renewable cycle.**



Picture: University of Utah

Reducing Solar Gain

- Thin film coatings, spectrally sensitive surface applications, filter out unwanted infrared frequencies of light (which heat up a room) and reduce the heat gain in buildings.
- Thermochromic technologies react to temperature and provide thermal insulation to give protection from heating at the same time as maintaining adequate lighting.
- Photochromic technologies react to changes in light intensity by increasing absorption.
- Electrochromic coatings react to changes in applied voltage by using a tungsten oxide layer; become more opaque at the touch of a button.

Nanotechnology and Coatings

- **Chemical Vapour Deposition (CVD), Dip, Meniscus, Spray and Plasma Coating produce a layer which is bound to the base material to produce a surface of the desired protective or functional properties.**

- **Research is being carried out through experiment and modelling of coatings and the one of the goals is the endowment of self healing capabilities through a process of "self-assembly".**

- **Applied to paints and insulating properties, produced by the addition of nano-sized cells, pores and particles, giving very limited paths for thermal conduction (R values are double those for insulating foam), are currently available. This type of paint is used, at present, for corrosion protection under insulation since it is hydrophobic and repels water from the metal pipe and can also protect metal from salt water attack.**

Nanotechnology and Coatings

- **Chemical Vapour Deposition (CVD), Dip, Meniscus, Spray and Plasma Coating produce a layer which is bound to the base material to produce a surface of the desired protective or functional properties.**

- **Research is being carried out through experiment and modelling of coatings and the one of the goals is the endowment of self healing capabilities through a process of "self-assembly".**

- **Applied to paints and insulating properties, produced by the addition of nano-sized cells, pores and particles, giving very limited paths for thermal conduction (R values are double those for insulating foam), are currently available. This type of paint is used, at present, for corrosion protection under insulation since it is hydrophobic and repels water from the metal pipe and can also protect metal from salt water attack.**

Nanotechnology and Stone Products

- In these materials it is common to use resins for reinforcing purposes in order to avoid breakage problems, however, these resin treatments can affect the aesthetics and the adhesion to substrates.
- Nanoparticle based systems can provide better adhesion and transparency than conventional techniques.
- In addition to the self-cleaning coatings mentioned above for glazing, TiO2 nanoparticles are being put to use as a coating material on roadways in tests around the world.
- The TiO2 coating captures and breaks down organic and inorganic air pollutants by a photocatalytic process (a coating of 7000m^2 of road in Milan gave a 60% reduction in nitrous oxides). This research opens up the intriguing possibility of putting roads to good environmental use.

Nanotechnology in Sustainability & Environment

- Sustainability: "the ability to provide for the needs of the world's current population without damaging the ability of future generations to provide for themselves".

- A key aspect of sustainability is conservation through the efficient use of the resources that are tied up in the already built environment. As existing stock increases so will the need for effective maintenance and significant benefits will be offered by a realistic assessment of material lifetimes.

- A key aspect of sustainability is the efficient use of energy. over 40% of total energy produced is consumed by buildings

Picture: Sthelens.gov.uk

Insulation

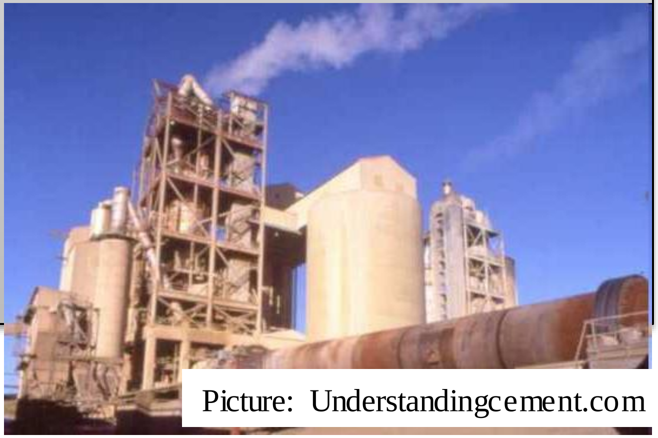
- Micro and nanoporous aerogel materials are very good candidates for being core materials of vacuum insulation panels but they are sensitive to moisture which is not acceptable.

- Work by Aspen Aerogels has produced an ultra-thin wall insulation which uses a nanoporous aerogel structure which is hydrophobic and repels water so it is mould free. Another intriguing application of aerogels is silica based products for transparent insulation, which leads to the possibility of super-insulating windows.

- Micro or Nano Electomechanical Systems (MEMS or NEMS) also offer the possibility of monitoring and controlling the internal environment of buildings (through a potentially integrated network). This could lead to energy savings much in the way that current motion detectors switch on light only when needed.

Cement Manufacture

- Stearic acid (a natural, saturated vegetable oil) can be added to the grinding process to reduce this energy use required to grind clinker into cement.*
- Increases cement fineness without a loss of strength, by retarding the caking and agglomeration of the cement during grinding. Unsaturated oil however reduces strength due to the oxidation of double carbon bonds in the unsaturated fats by available water.*



Picture: Understandingcement.com

*European Nanotechnology Gateway - *Nanotechnology and Construction Report (2006)*

Water

- Clean water has been one of the great leaps forward in public health provided by civil engineering and nanotechnology is being used to further this advance.
- Iron nanoparticles, which have a high surface area and high reactivity are being used to transform and detoxify chlorinated hydrocarbons (some of which are carcinogens) in groundwater.*
- These nano-materials also have the potential to transform heavy metals such as soluble lead and mercury to insoluble forms, thus limiting their transport and contamination.*

*European Nanotechnology Gateway -
<u>*Nanotechnology and Construction Report (2006)*</u>

Energy and Environment

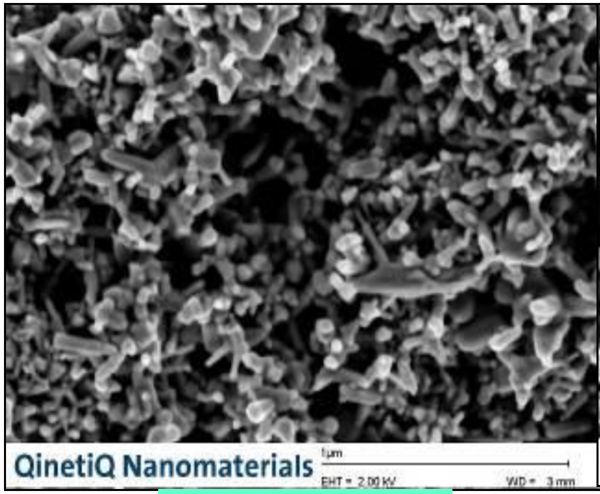
- Energy Production
  - Clean, less expensive sources enabled by novel nanomaterials and processes

- Energy Utilization
  - High efficiency and durable home and industrial lighting
  - Solid state lighting can reduce total electricity consumption by 10% and cut carbon emission by the equivalent of 28 million tons/year (*Source: Al Romig, Sandia Lab*)
- Materials of construction sensing changing conditions and in response, altering their inner structure

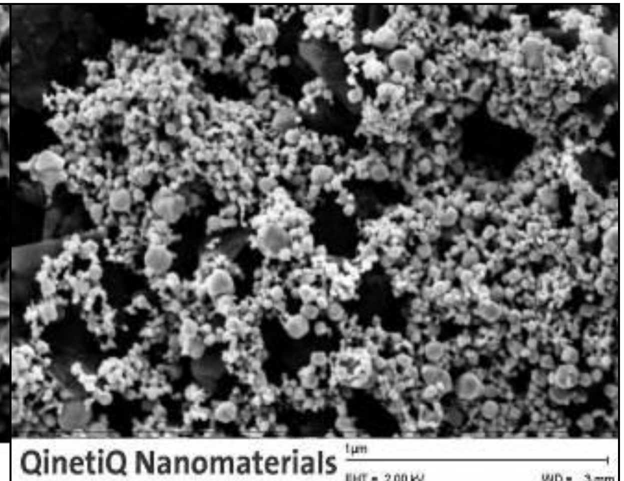
Benefits of Nanotechnology in Transportation

- Thermal barrier and wear resistant coatings
- High strength, light weight composites for increasing fuel efficiency
- High temperature sensors for 'under the hood'
- Improved displays
- Battery technology
- Wear-resistant tires
- Automated highways

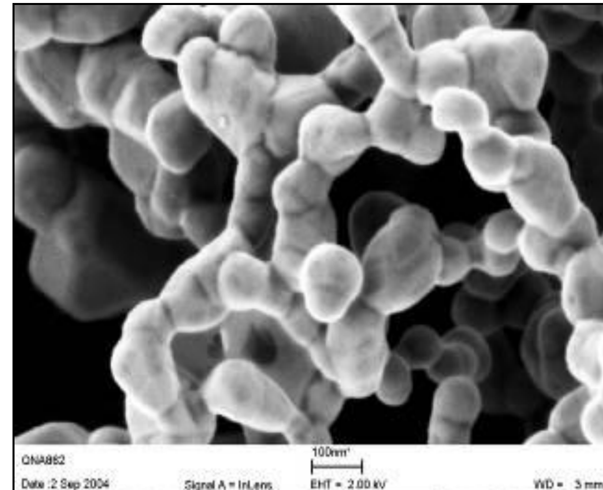
Examples of Nanomaterials



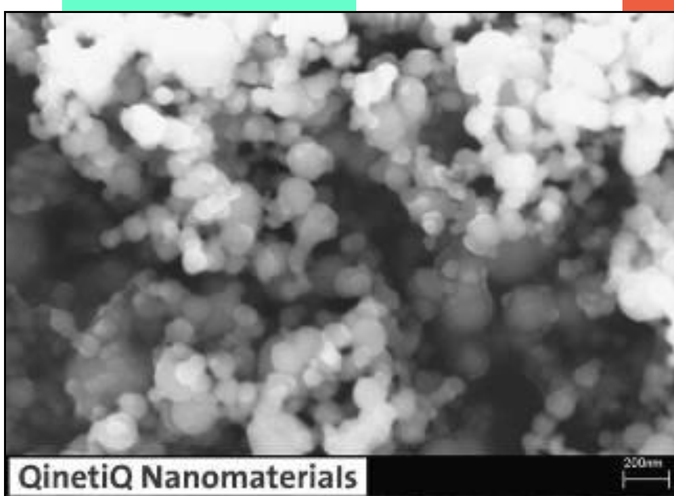
Zinc Oxide



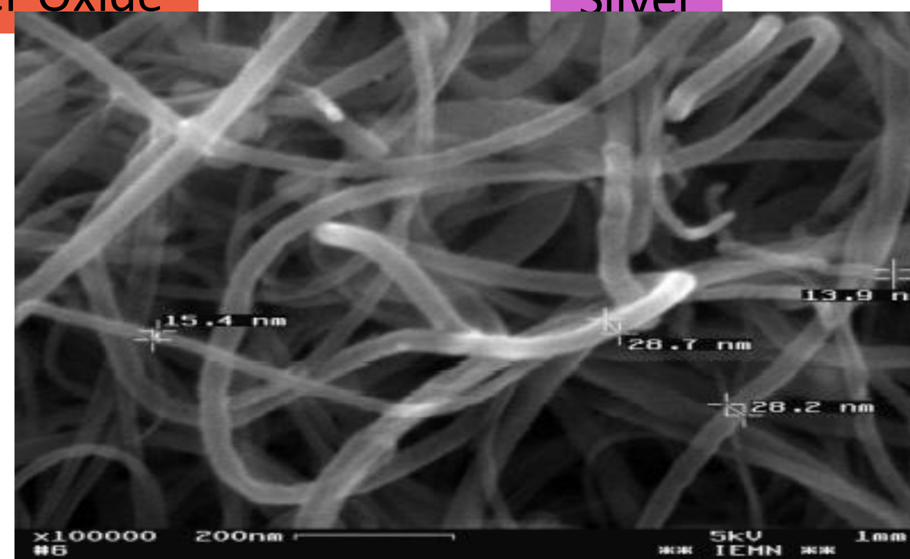
Copper Oxide



Silver

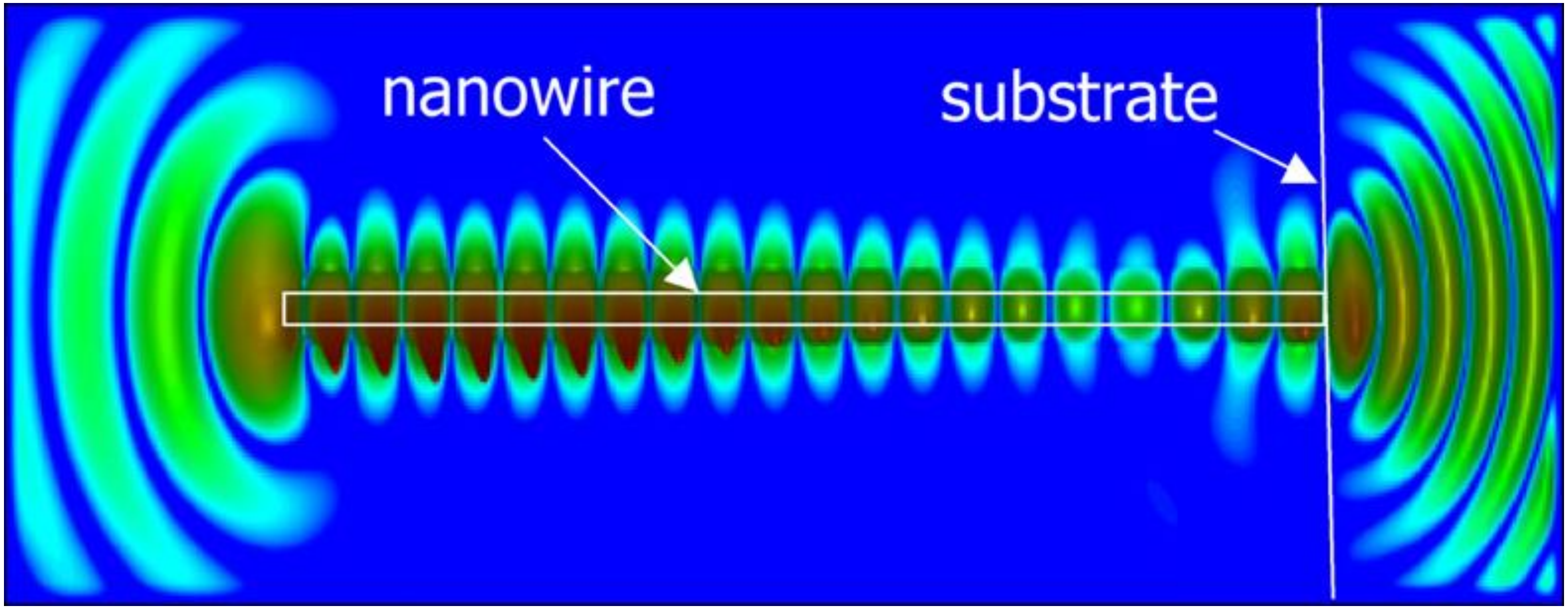


Aluminium



Carbon Nanotubes

Nanolasers



Light emission from a semiconductor nanowire - typically 10-100 nanometers wide and a few micrometers long-functions as a laser.

Lasers made from arrays of these wires have many potential applications in communications and sensing

Nanotechnology in Food Industry

A microscopic biological sensor that detects Salmonella bacteria in lab tests has been developed by an Agricultural Research Service (ARS) scientist and university colleagues. The sensor could be adapted to detect other food borne pathogens as well.

Stopping Bacterial Infections Without Antibiotics

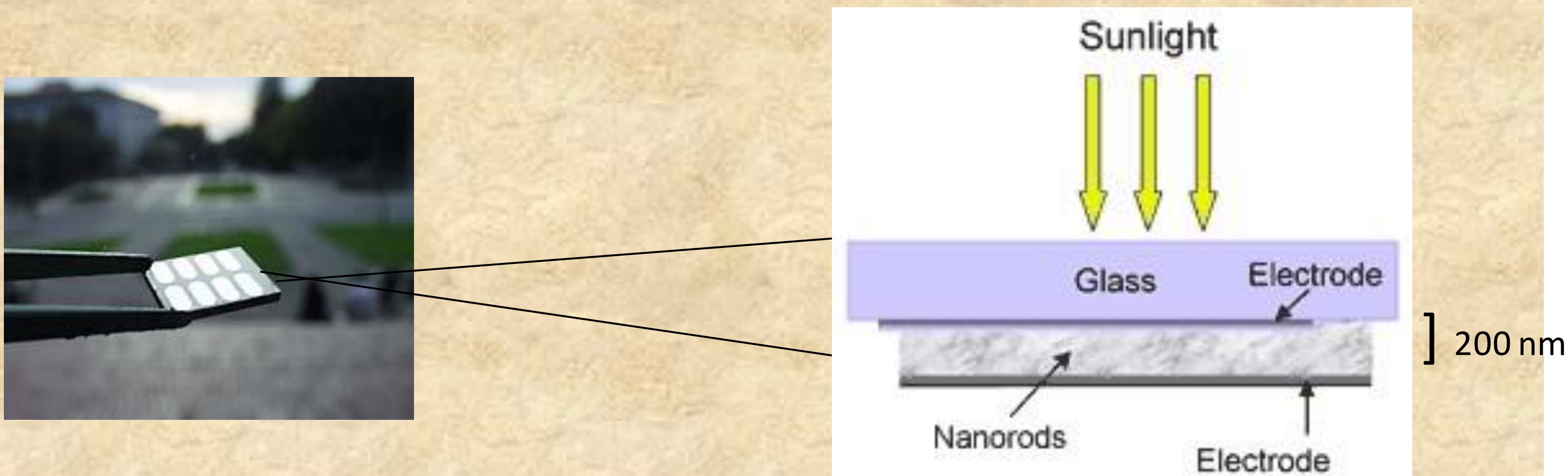
- Nanoengineering could prevent bacterial infections using tiny biochemical machines nanofactories that can confuse bacteria and stop them from spreading, without the use of antibiotics

PRIORITY AREAS on Nanomedicine

- DNA Vaccines for parasitic, bacterial and viral diseases
- Oral and pulmonary routes for systemic delivery of proteins and peptides
- Nanotechnology in Tissue Engineering

Environment: Nano Solar Cells

- **Nano solar cells mixed in plastic could be painted on buses, roofs, and clothing**
  - ***Solar becomes a cheap energy alternative!***



Nano solar cell: Inorganic nanorods embedded in semiconducting polymer, sandwiched between two electrodes

Source: http://www.berkeley.edu/news/media/releases/2002/03/28_solar.html

Nanomedicine

Nanomedicine is the application of nanotechnology in medicine, including to cure diseases and repair damaged tissues such as bone, muscle, and nerve

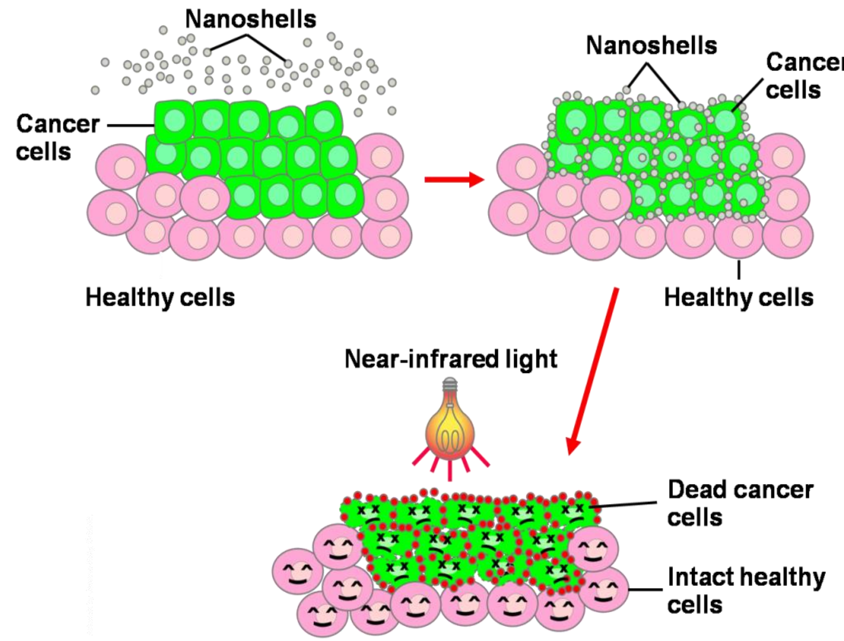
Key Goals for Nanomedicine

– To develop cure for traditionally incurable diseases (e.g. cancer) through the utilization of nanotechnology

– To provide more effective cure with fewer side effects by means of targeted drug delivery systems

Nanotechnology in Health Care

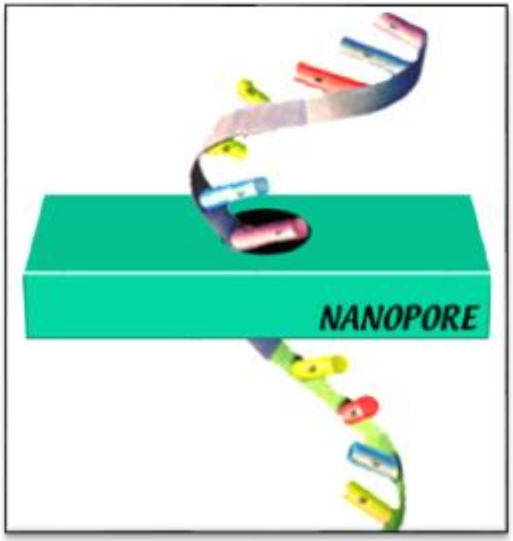
- **Thermal ablation of cancer cells**
  - Nanoshells have metallic outer layer and silica core
  - Selectively attracted to cancer shells either through a phenomena called enhanced permeation retention or due to some molecules coated on the shells
  - The nanoshells are heated with an external energy source killing the cancer cells

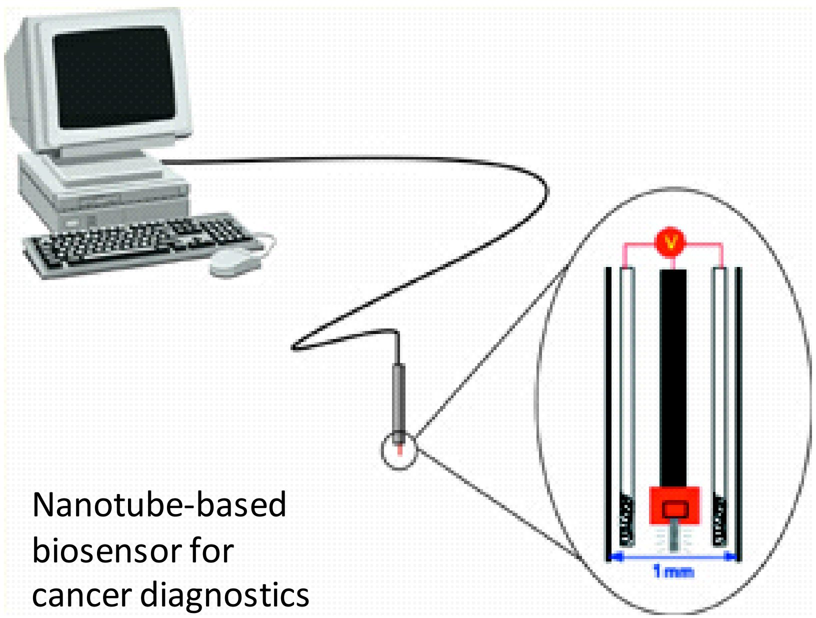


Thermal ablation of cancer cells assisted by nanoshells coated with metallic layer and an external energy source *– National Cancer Institute*

- Expanding ability to characterize genetic makeup will revolutionize the specificity of diagnostics and therapeutics -Nanodevices can make gene sequencing more efficient

- Effective and less expensive health care using remote and in-vivo devices





Nanotube-based biosensor for cancer diagnostics

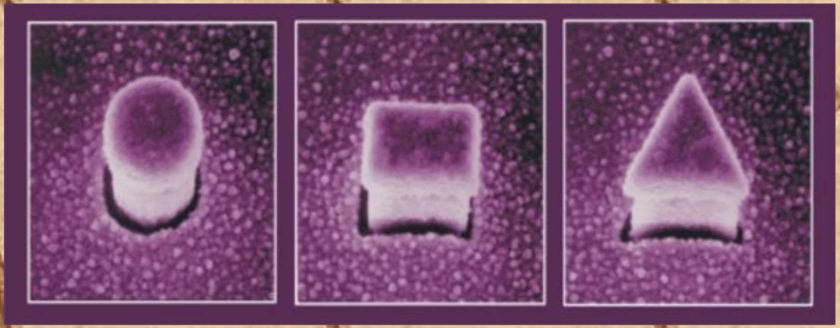
- New formulations and routes for drug delivery, optimal drug usage

- More durable, rejection-resistant artificial tissues and organs

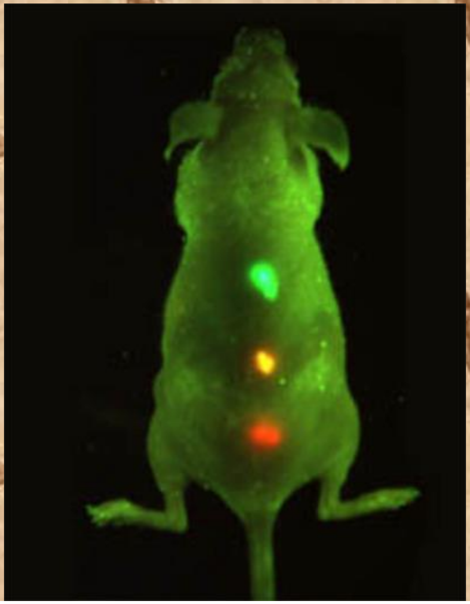
- Sensors for early detection and prevention

Detecting Diseases Earlier

- Quantum dots glow in UV light
  - Injected in mice, collect in tumors
  - Could locate as few as 10 to 100 cancer cells



Quantum Dots: Nanometer-sized crystals that contain free electrons and emit photons when submitted to UV light

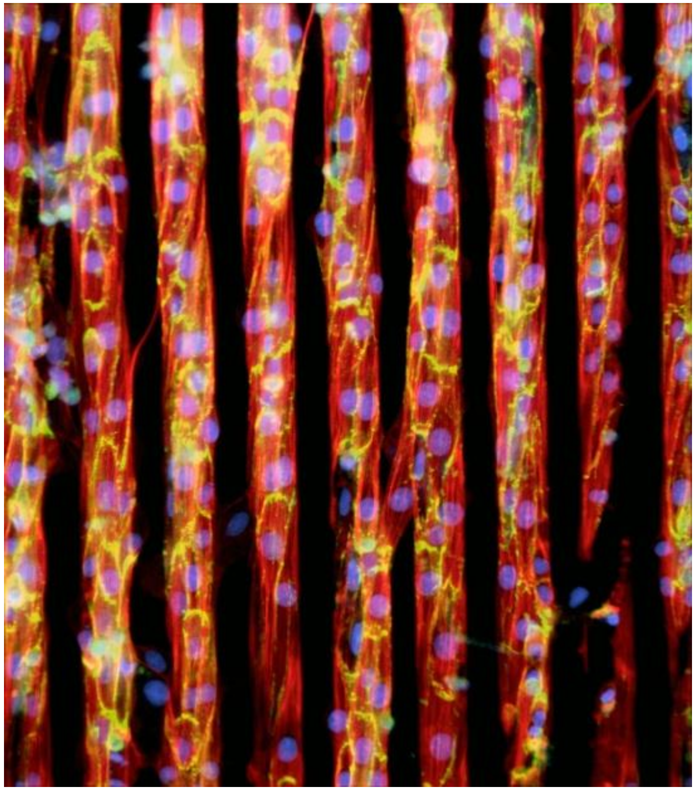


Early tumor detection, studied in mice

Sources: http://vortex.tn.tudelft.nl/grkouwen/qdotsite.html
http://www.whitaker.org/news/nie2.html

Growing Tissue to Repair Hearts

- Growing cardiac muscle tissue is an area of current research
  - Grown in the lab now, but the fibers grow in random directions
  - With the help of nanofiber filaments, it grows in an orderly way
- Could be used to replace worn out or damaged heart tissue



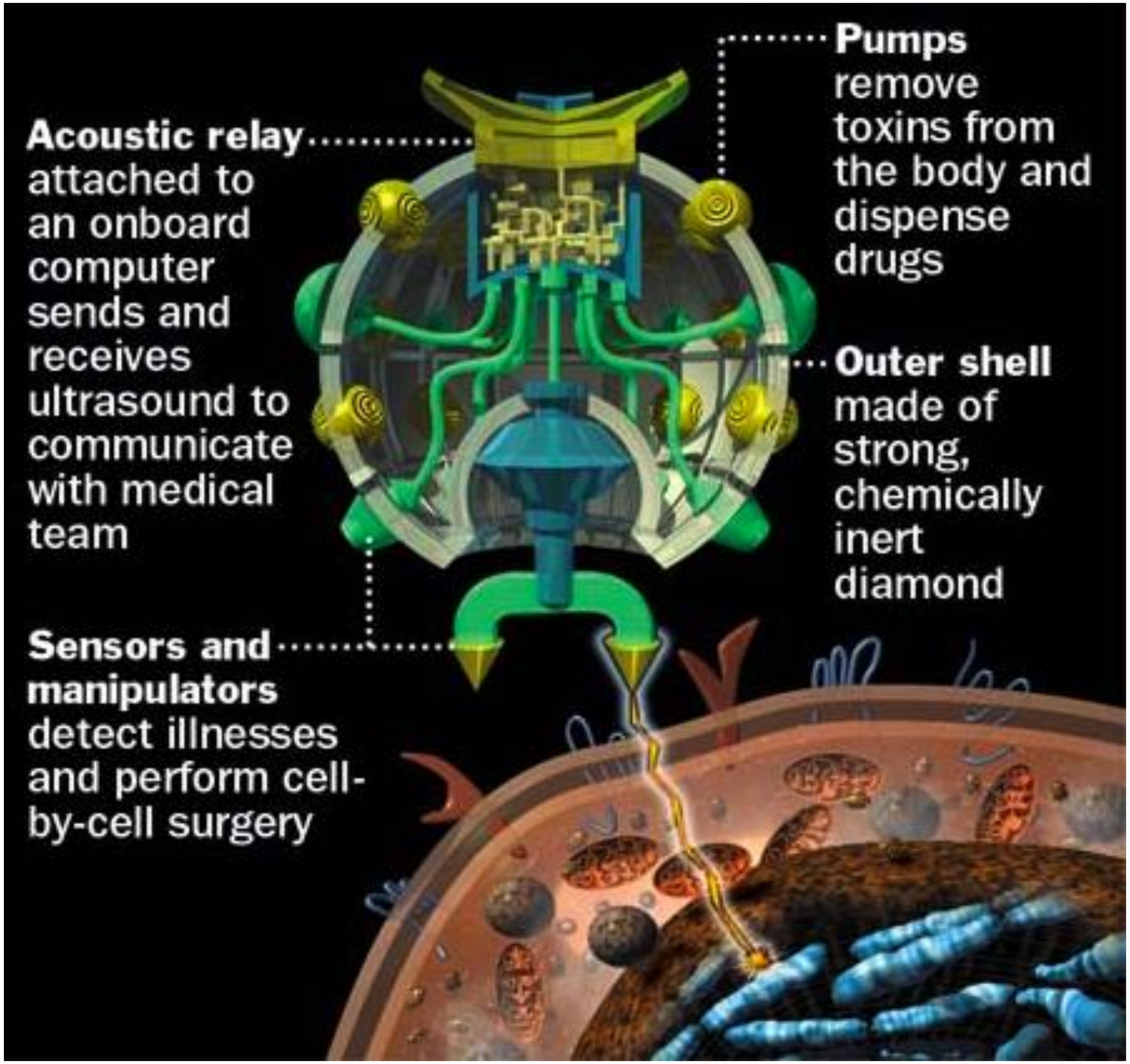
Cardiac tissue grown with the help of nanofiber filaments

Source: http://www.washington.edu/admin/finmgmt/annrpt/mcdevitt.htm

Making Repairs to the Body

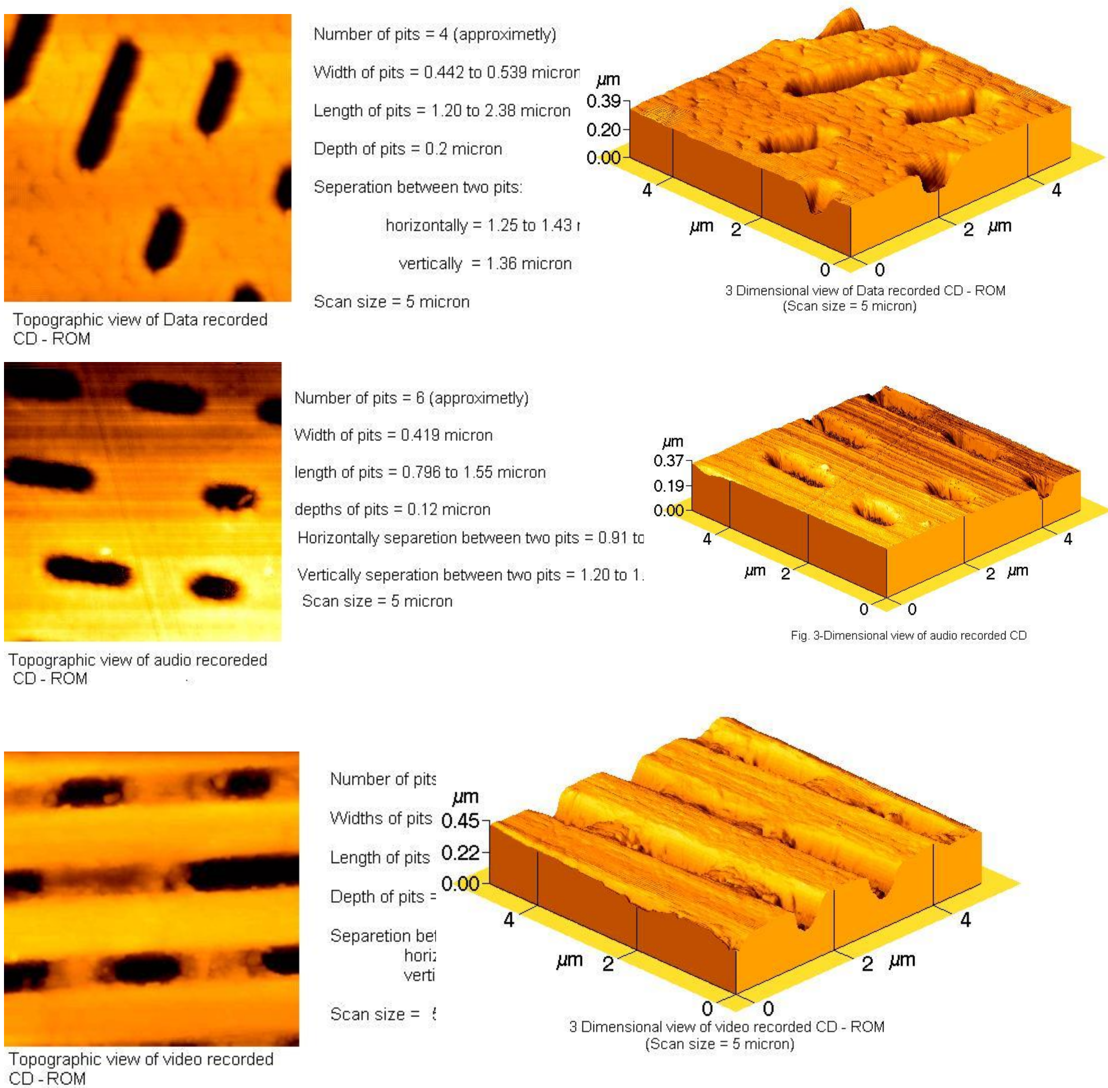
Nanorobots are imaginary, but nanosized delivery systems could…

- Break apart kidney stones, clear plaque from blood vessels, ferry drugs to tumor cells



Source: http://www.genomenewsnetwork.org/articles/2004/08/19/nanorobots.php

CD Technology:

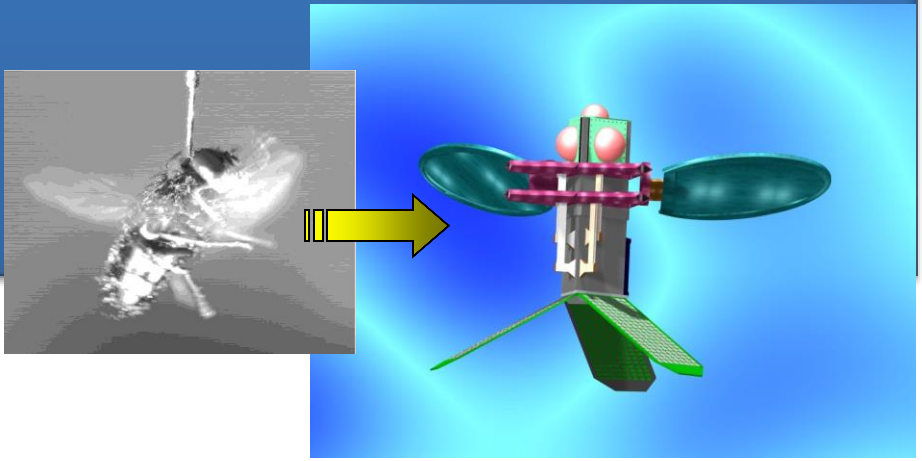


- Current CD and DVD media have storage scale in *micrometers*
- New nanomedia (made when gold self-assembles into strips on silicon) has a storage scale in *nanometers*

Challenges facing Nanotechnology

- Lots of nanoscience now, some nice nanotechnology; more emphasis on technology development and participation from engineering communities are needed
- People do not buy technology; they buy products
  - Robust product development is critical to realize the potential
  - Early and periodic wins, a must to keep investor confidence high
- Recognition of nano-micro-macro hierarchy in product development

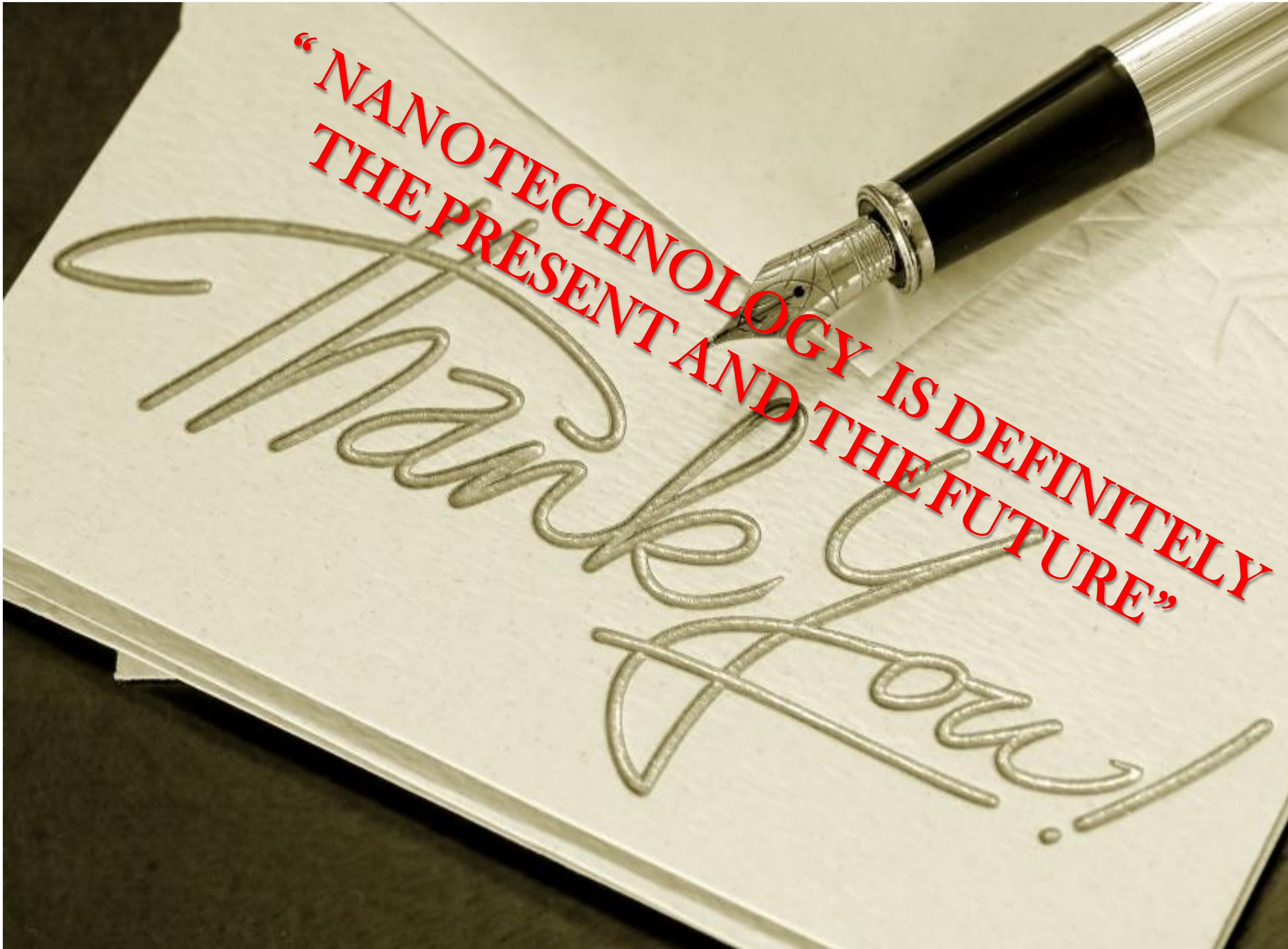
Source: UC Berkeley



- **Given the long term nature of the technology and payoffs in terms of job creation and economic returns,**

- **Venture community behavior will determine the fate**
  - **Lack of patience will hurt the startup activities**
  - **Indiscriminate investment**

- **Educating future generation scientists and engineers**


“ NANOTECHNOLOGY IS DEFINITELY
THE PRESENT AND THE FUTURE”
Thank You!