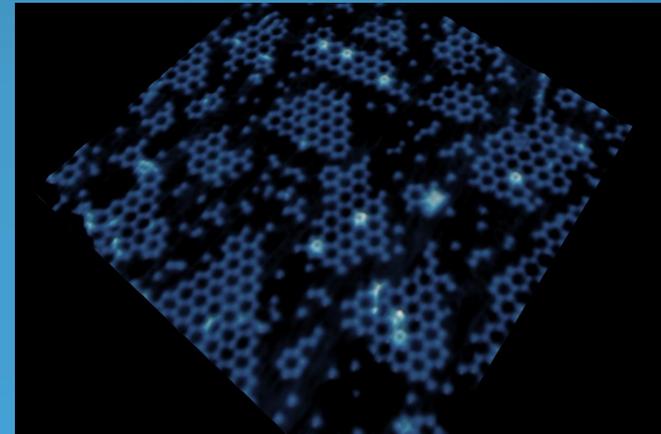
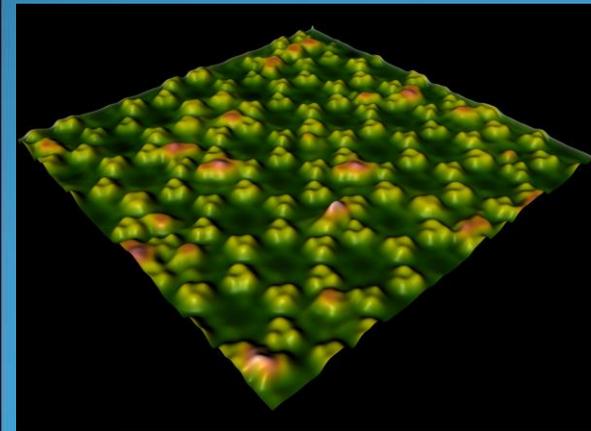


Nanotechnology : Changing the World at the Nanoscale

E. Yitamben

African School of Fundamental Physics



Outline



- What is nanotechnology?
- What is its current impact?
- What is its future impact?
- Nanotechnology in Africa



What is Nanotechnology?

- Exploring and exploiting unique phenomena occurring at the atomic, molecular, and supra-molecular scale to create materials, devices, and systems with new and useful properties and function.
- Scale → 1 – 100 nm
- Highly interdisciplinary
- Potentially disruptive technology.



10^7 meters



10^{-1} meters



10^{-9} meters

The Scale of Things – Nanometers and More

Things Natural



Dust mite
200 μm

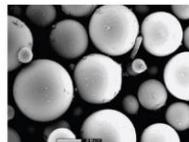


Human hair
~ 60-120 μm wide

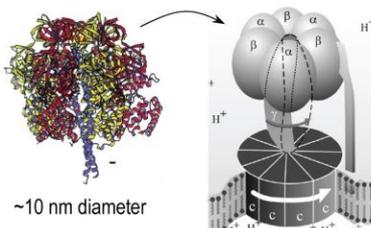
Red blood cells
(~7-8 μm)



Ant
~ 5 mm

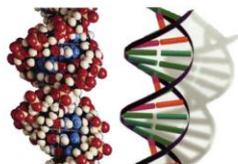


Fly ash
~ 10-20 μm

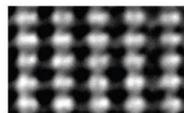


~10 nm diameter

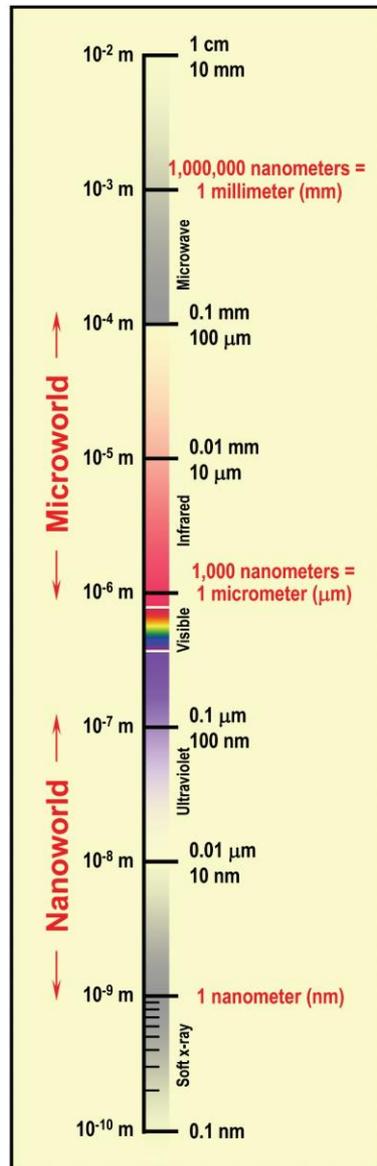
ATP synthase



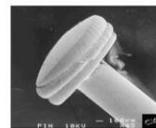
DNA
~2-1/2 nm diameter



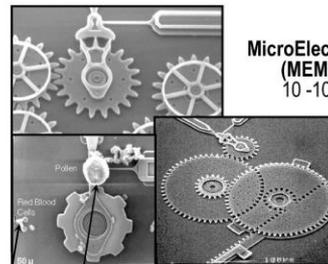
Atoms of silicon
spacing 0.078 nm



Things Manmade



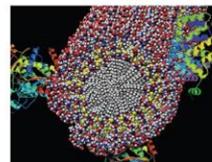
Head of a pin
1-2 mm



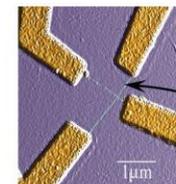
MicroElectroMechanical (MEMS) devices
10-100 μm wide

Pollen grain
Red blood cells

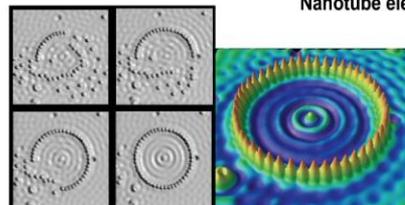
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



Self-assembled, Nature-inspired structure
Many 10s of nm

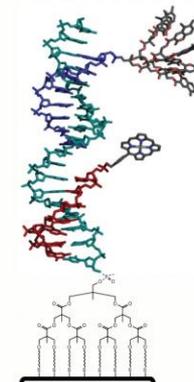


Nanotube electrode



Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm

The Challenge

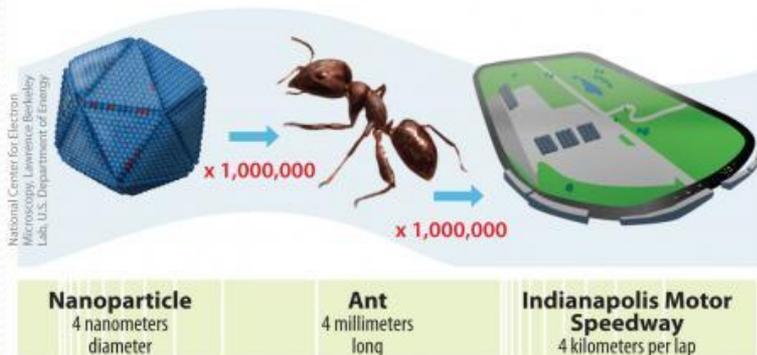
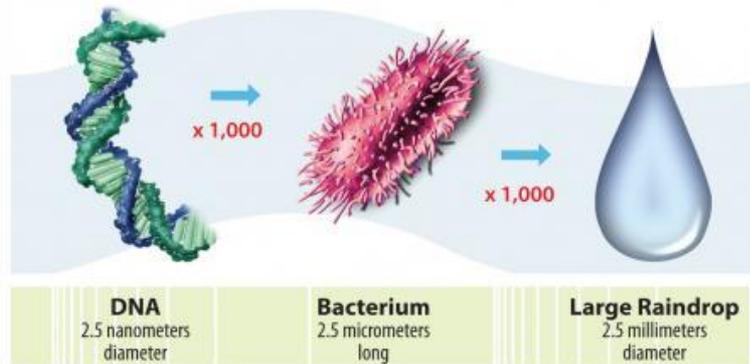


Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.



Carbon nanotube
~1.3 nm diameter

A Little More on the Scale of Things



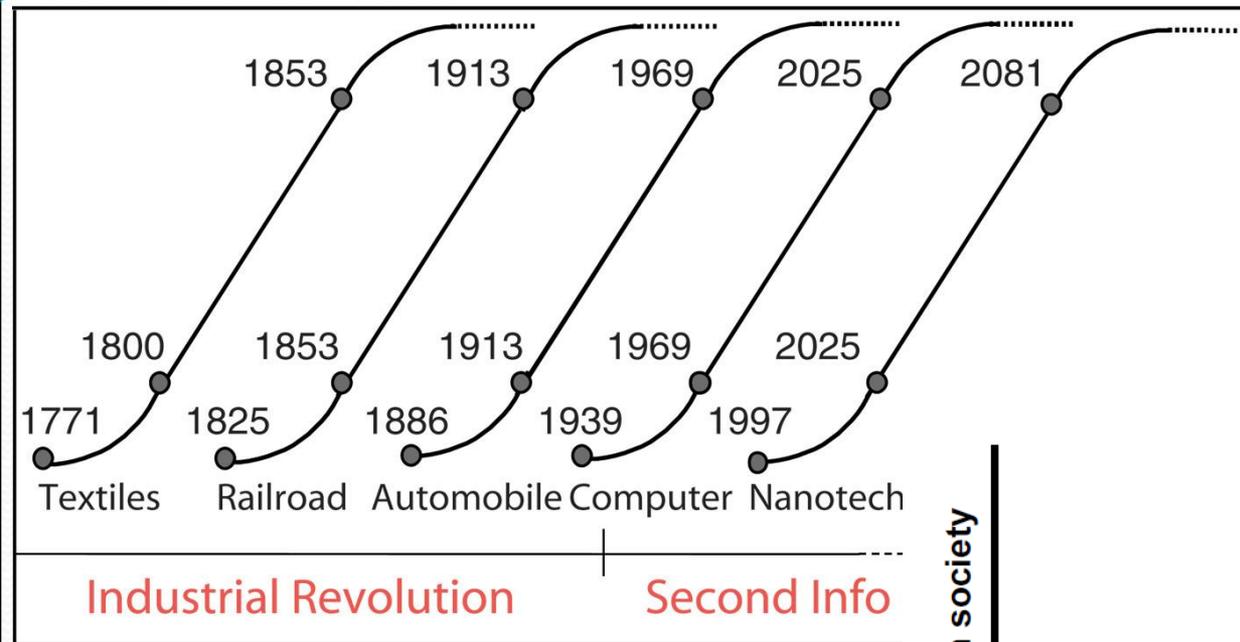
- A sheet of paper is ~ **100,000 nm** thick;
- A human hair is ~ **80,000 – 100,000 nm** wide;
- Hemoglobin, which carries oxygen through the bloodstream is **5 nm** in diameter;
- A strand of human DNA is ~ **2.5 nm** in diameter;
- A single gold atom is ~ **1/3 nm**;
- **1 nm** is approximately as long as your fingernail grows in **1s**.

Why is the Nanometer Scale Different?

- The **wavelike** properties of electrons inside matter are influenced by variations on the nanometer scale.
- The systematic organization of matter on the nanometer length scale is a key feature of biological systems.
- Nanoscale components have very high surface areas.
- The finite size of material entities, determine an increase of the relative importance of surface tension and local electromagnetic effects.
- The interaction wavelength scales of various external wave phenomena become comparable to the material entity size.
- Nanoscale materials and effect are found in nature all around us → many important functions of living organisms take place at the nanoscale.

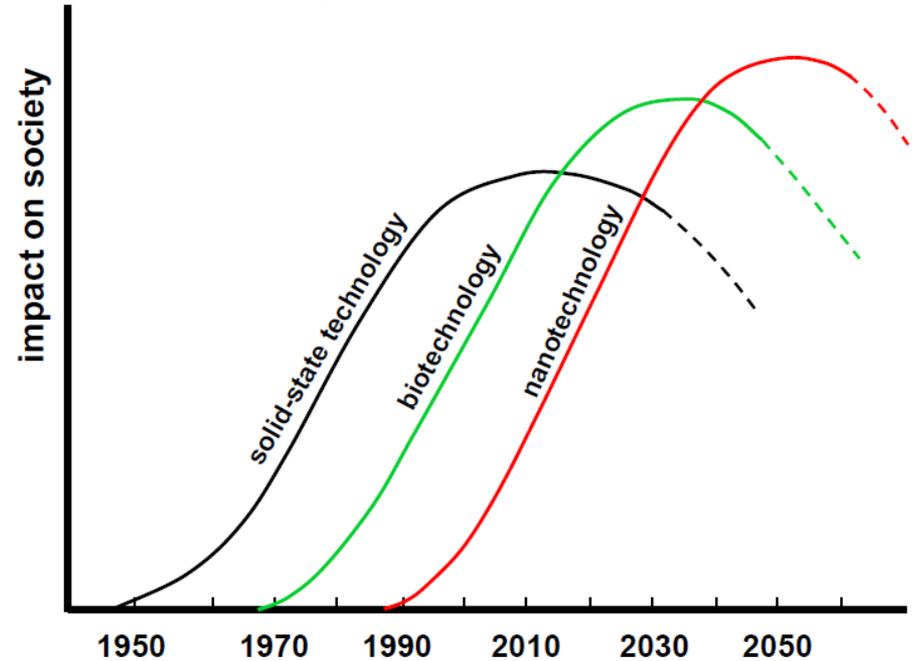
Nanotechnology Growth

Growth Innovations



Sources: Norman Poire, Merrill Lynch

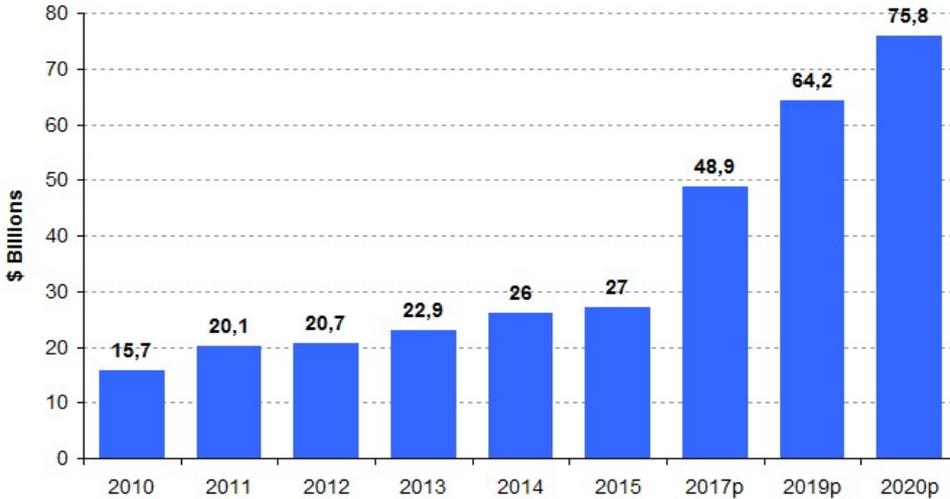
S. Milunovich, J. Roy. *United States Technology Strategy*. Merrill Lynch. 4



A. ten Wolde: "Nanotechnology; towards a molecular construction kit", Netherlands Study Centre for Technology Trends (STT). 1998

Predicted Global Market Growth

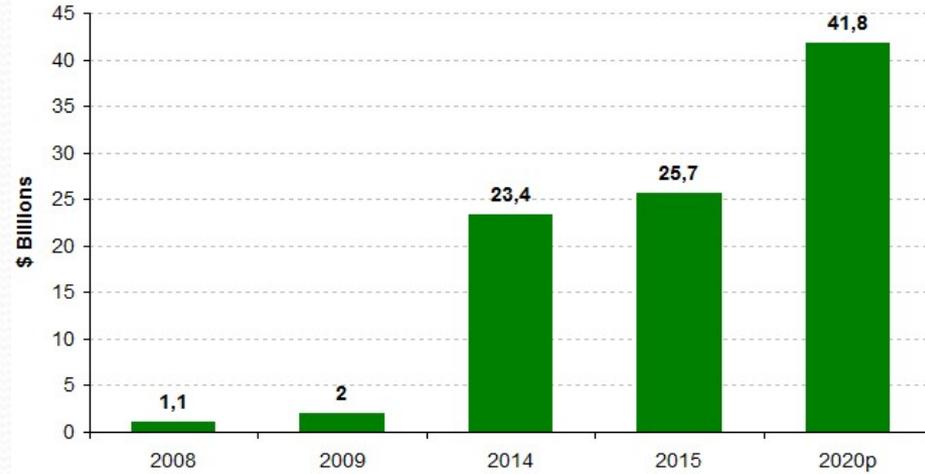
Global nanotechnology market, 2010-2020



p = projections

Sources : BCC Research, 2010, 2012, 2014 and 2015; Research and Markets, 2015.

Global market for nanotechnology in environmental applications, 2008-2020



p = projections

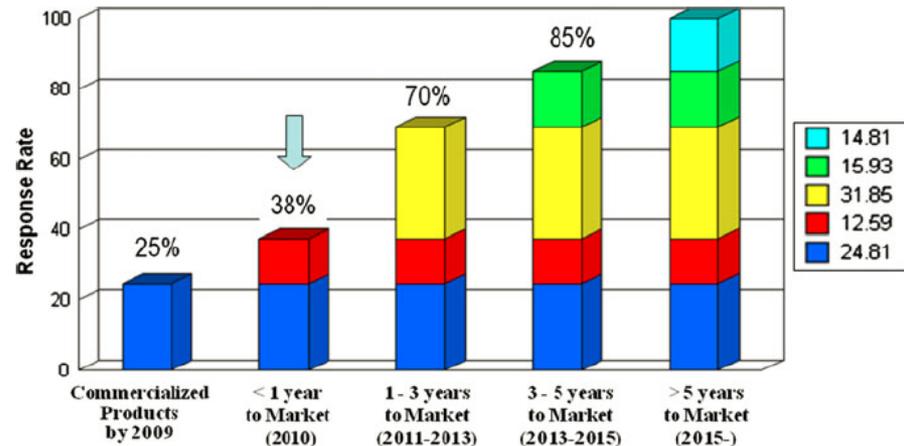
Sources : BCC Research, July 2009, September 2015 and November 2015.

2015 prediction: Global nanotechnology market outlook to reach US \$75.8 Billion by 2020

National Nanotechnology Initiative

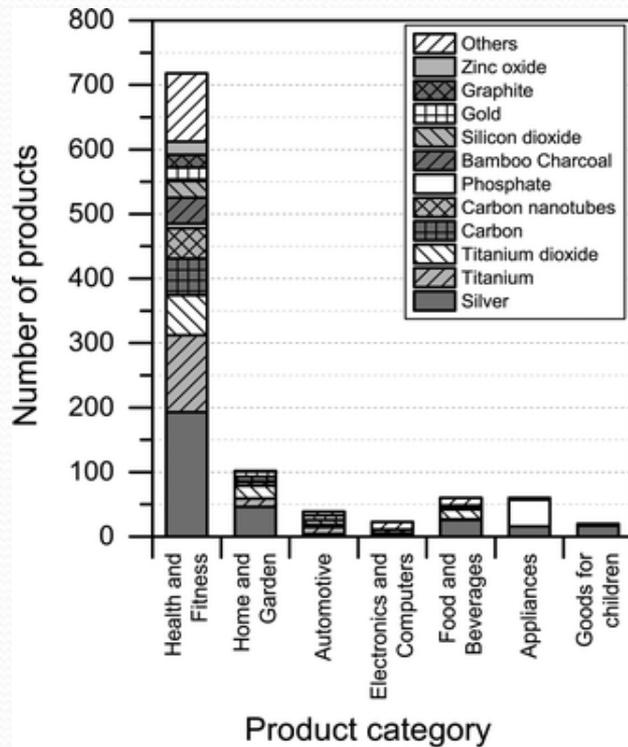
<http://www.nano.gov/nanotech-101/what/nano-size>

NanoInventory Growth as a function of time

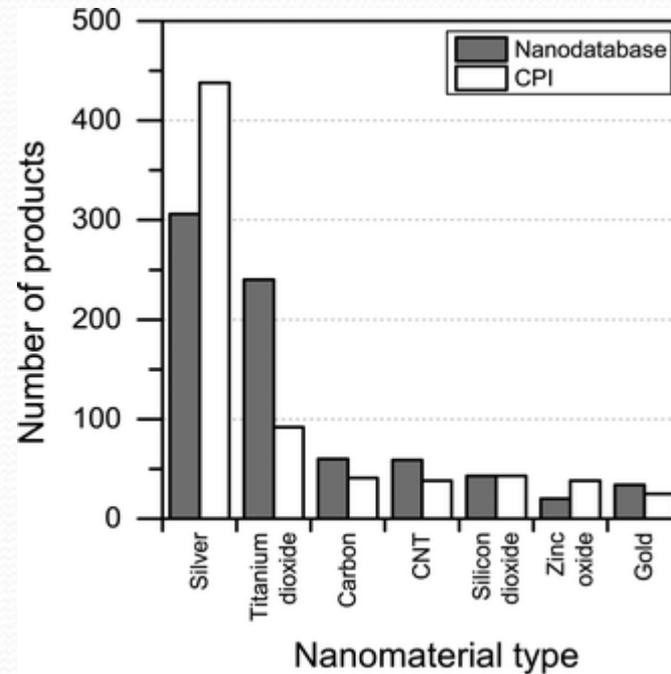


Roco, M., J. Nanopart. Res. 13, 427 (2011)

Materials in Use



Identity of nanomaterials claimed to be used in different product categories



Silver is a powerful anti-microbial agent and more than 300 products use nanoscale silver to make anti-bacterial surfaces, cosmetics, and clothing.

Hansen, S., et al., *Environ. Sci. Nano*, 2016, 3, 169-180

2015 prediction: Global nanotechnology market outlook to reach US \$75.8 Billion by 2020

Examples of the Use of NanoSilver: Almost Everywhere ...



Nano silver beauty soap



Nano silver hair shampoo



Nano silver body cleanser



Nano silver toothpaste



Nano silver hand sanitizer



Nano silver facial mask sheet



Nano silver skin care line



Nano silver makeup line



Nano silver wet wipes



Nano silver disinfectant spray



Nano silver toothbrush



Nanosilver hair conditioner



Nano silver wash dish & laundry detergent



Nano silver colloid



Nano silver antimicrobial masterbatch

Nanotechnology → Multidisciplinary

Chemical
engineering

Biology

Industrial
engineering

Physics

Electrical
engineering

Medicine

Chemistry

Materials Science

Forestry

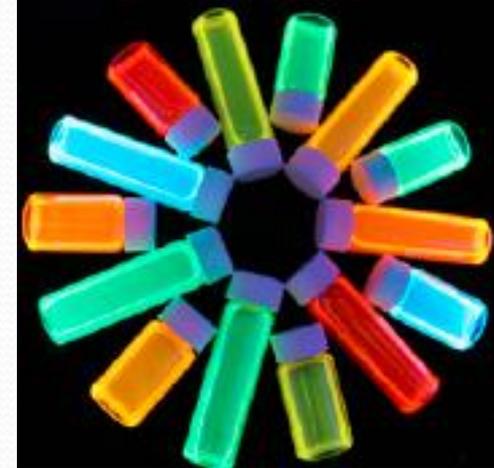
Mathematics

Food Science

Mechanical
Engineering

Nano → New Shapes, and New Shapes → New Properties – Good

- Optical properties
- Semiconductors' bandgap
- Magnetic properties
- Mechanical properties
- Surface reactivity
- Melting point
- Specific heat
- Conductivity
- Biocompatibility



Evident Technologies



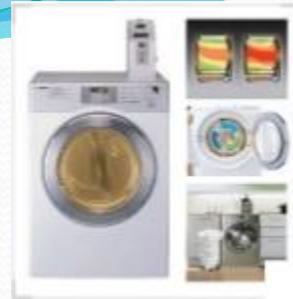
Maya warrior, The Cleveland Museum of Art, 250 – 900 AD

Potential Uses of Nanotechnology



1. Organic light emitting diodes (OLEDs) for displays;
2. Photovoltaic film that converts light into electricity;
3. Scratch proof coated windows that clean themselves with UV;
4. Fabrics coated to resist stains and control temperature;
5. Intelligent clothing measures pulse and respiration;
6. Bucky-tubeframe is light, but very strong;
7. Hipjoint made from biocompatible materials;
8. Nano-particle paint to prevent corrosion;
9. Thermo-chromic glass to regulate light;
10. Magnetic layers for compact data memory;
11. Carbon nanotube fuel cells to power electronics and vehicles;
12. Nano-engineered cochlear implant.

Consumer Products



- **Nanoelectronics** → XBOX One by Microsoft; Intel hard drives.
- **Nano air filters** → NanoBreeze Car Air Purifier by NanoTwin Technologies Inc.
- **Cosmetics** → TiO₂ or ZnO nanoparticles are used in sunscreens.
- **Clothing** → Swimsuits, rain jackets, body armor, stain-repellant fabric.
- **Nanochocolate** → Nanoceuticals Slim Shake Chocolate by RBC Life Sciences, Inc.
- **Nanocomposites** → BMC Racing Fourstroke FS01 (BMC Cycling); light tennis rackets; artificial muscles.
- **Targeted imaging probes** → CellTracks [Immunicon Corporation].



Nanotechnology and Medicine

➤ **Prevention and Control of Cancer**

Development of nanoscale devices to deliver cancer prevention agents and vaccines using nanoscale delivery vehicles

➤ **Early Detection and Proteomics**

Creating implantable molecular sensors that can detect cancer-associated biomarkers.

➤ **Imaging Diagnostics**

Designing “smart” injectable, targeted contrast agents that improve the resolution of cancer to the single cell level

➤ **Multifunctional Therapeutics**

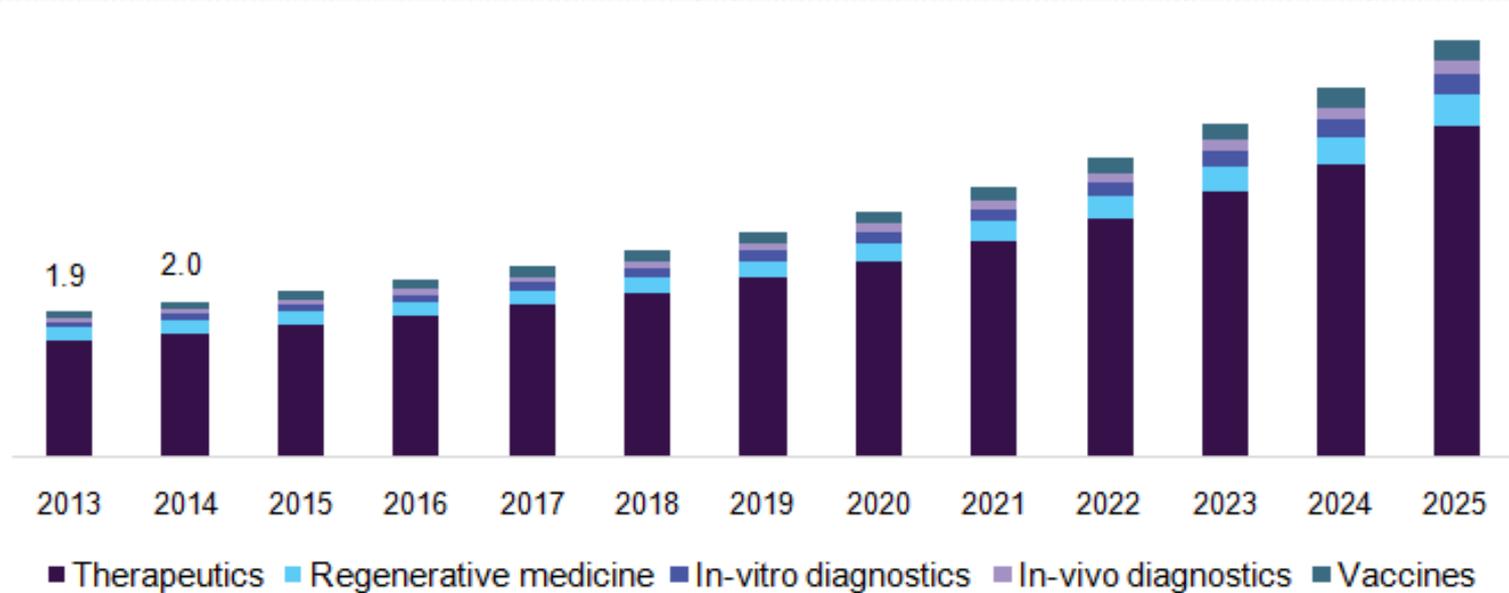
Developing nanoscale devices that integrate diagnostic and therapeutic functions

➤ **Interdisciplinary Training**

Coordinating efforts to provide cross-training in molecular and systems biology to nanotechnology engineers and in nanotechnology to cancer researchers

Growth of Nanomedicine

U.S. Nanomedicine market by products 2013 – 2025 (\$Billions)



Grand View Research, Market Research Report (2017)

Current Medical Applications

➤ Appetite control

- Megace® ES

➤ Bone replacement

- Vitoss
- Zirconium oxide

➤ Cancer

- Abraxane™
- Docil®
- Emend®

➤ Chemical substitute

- Neowater

➤ Cholesterol

- TriCor®

➤ Diagnostic tests

- CellTracks®
- NanoChip® Technology
- Microarrays



➤ Drug Development

- Controlled Flow Cavitation

➤ Hormone therapy

- Estrasorb™

➤ Imaging

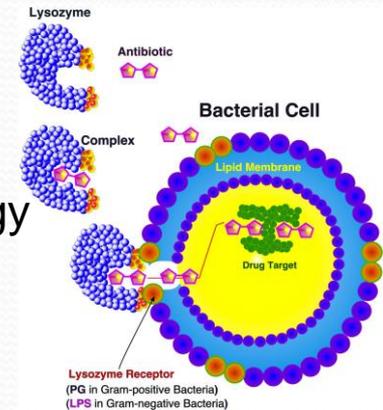
- Qdot nanocrystals
- TriLite™ Technology

➤ Immunosuppressant

- Rapamune®

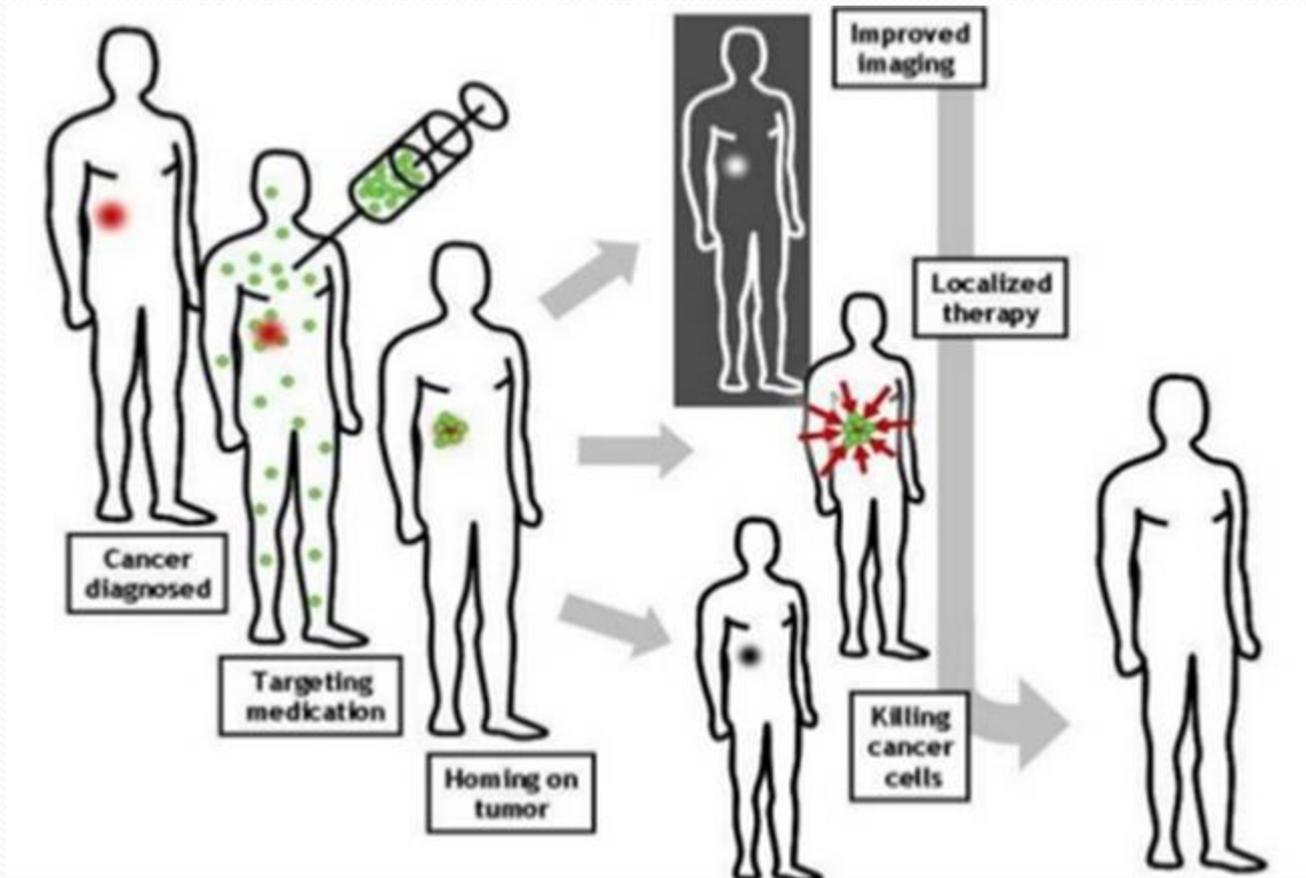
➤ Medical tools

- EnSeal Laparoscopic Vessel Fusion System
- TiMESH
- Acticoat®
- SilvaGard™ Technology



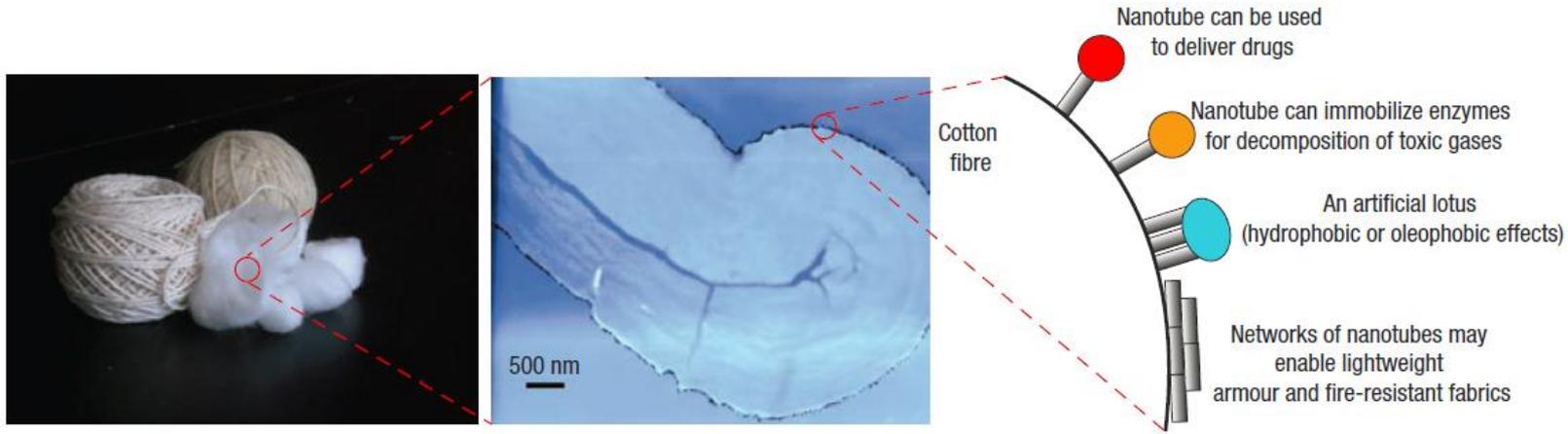
H. Ibrahim,
<http://chem.agri.kagoshi-ma-u.ac.jp/~hishamri/>

Example of Medical Application: Molecular Imaging and Therapy



Wikipedia

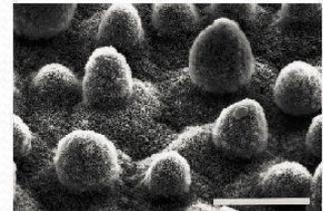
Nanotechnology in Textiles



Possible applications of cotton: CNT coatings on the cotton fibre can be modified in different ways

A. Avila et al., Nature Nanotechnology 3, 458 (2008)

Lotus Effect



- Use of **the lotus effect**: microscopic “bumps” on lotus leaves reduce friction causing a hydrophobic self-cleaning surface (droplets of water just roll off)
- Surface texture of products can be optimized for various applications (glass, textiles, electronics, machines, cars) by adhering nanoparticles with specific properties
- Particle size is much smaller than the wavelength of visible light, so particles are transparent.



Toyota Center, home of the NBA Houston Rockets, nanotechnology-treated upholstery for stain-resistance and easy cleaning

M. Gurian, Upholstery Journal Feb/Mar(2009)



The intelligent knee sleeve is a bio-feedback device monitoring the knee joint



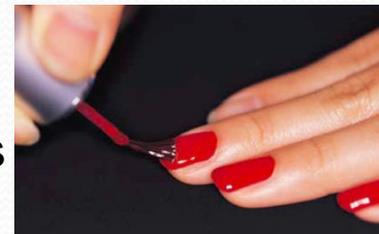
Lumalive textile from Philips features flexible arrays of colored LED fully integrated to the clothes

S. Coyle et al. MRS Bulletin 32, 434 (2007)

In Essence, Nanotechnology in Textiles ...



Nanotechnology in Cosmetics



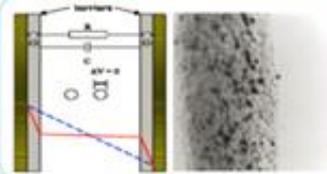
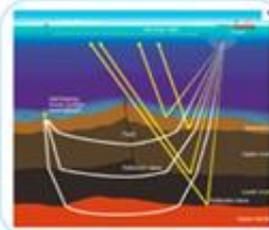
- Improved aesthetics
 - Better spreadability / softer feeling
 - Transparency glow
- Deeper skin penetration for delivery of therapeutic components
- Increase skin hydration and smoothness
- Do not cause wash-out of active ingredients
- Reduces permeability of skin

Nanotechnology and the Oil Industry

Nanotechnology for enhanced oil recovery

SEISMIC SURVEYING

- New seismic survey that provides information about the fracturing of the oil reservoir
- Development of impulsive source elements for marine seismic surveying



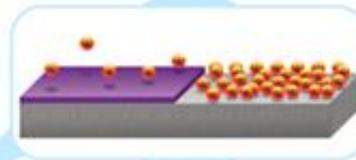
ELECTROCOALESCENCE

- Water/Oil separation by electric field



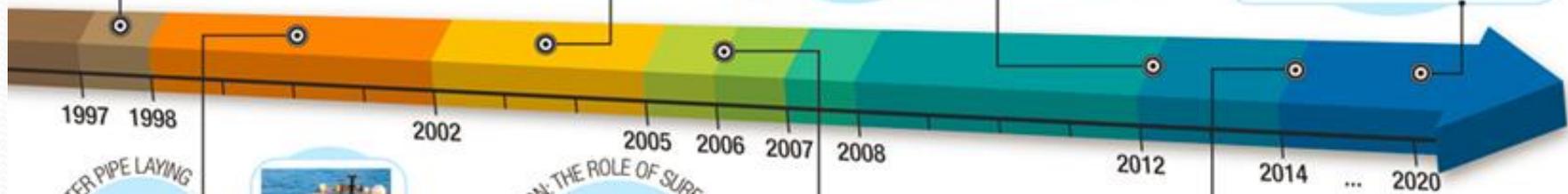
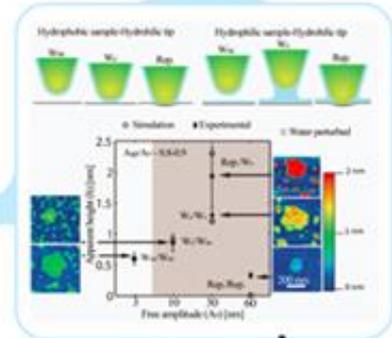
NANOCOATING

- Anti-fouling coatings
- Thermal coatings
- Lubricant coatings
- Anticorrosion coatings



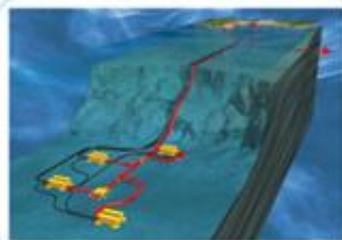
CAPILLARY INTERACTIONS

- Microwave excitation of the oil reservoir for EOR



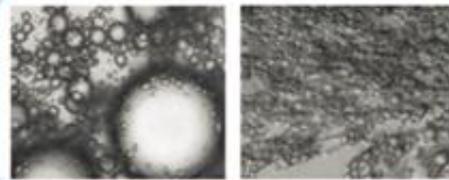
DEEP WATER PIPE LAYING

- Linking advanced fracture model to structural analysis



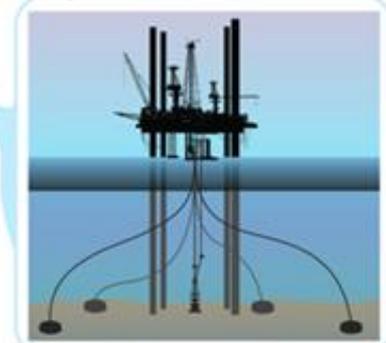
WATER/OIL SEPARATION: THE ROLE OF SURFACE SCIENCE

- Understanding surface chemistry of oil and water, knowledge inherited to LENS from previous industrial experience



RESERVOIR SURVEILLANCE

- Nanoparticle injection to monitor water breakthrough



NanoProducts

Where is it used?



Future use?

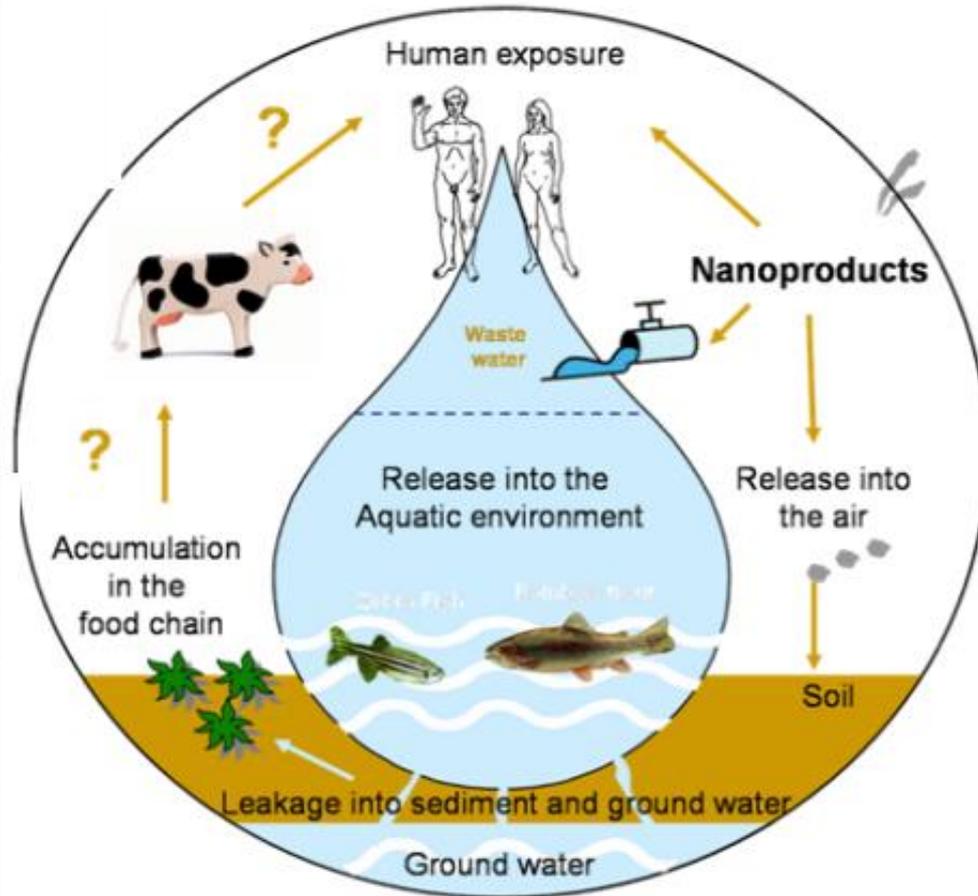


How do you dispose of it?



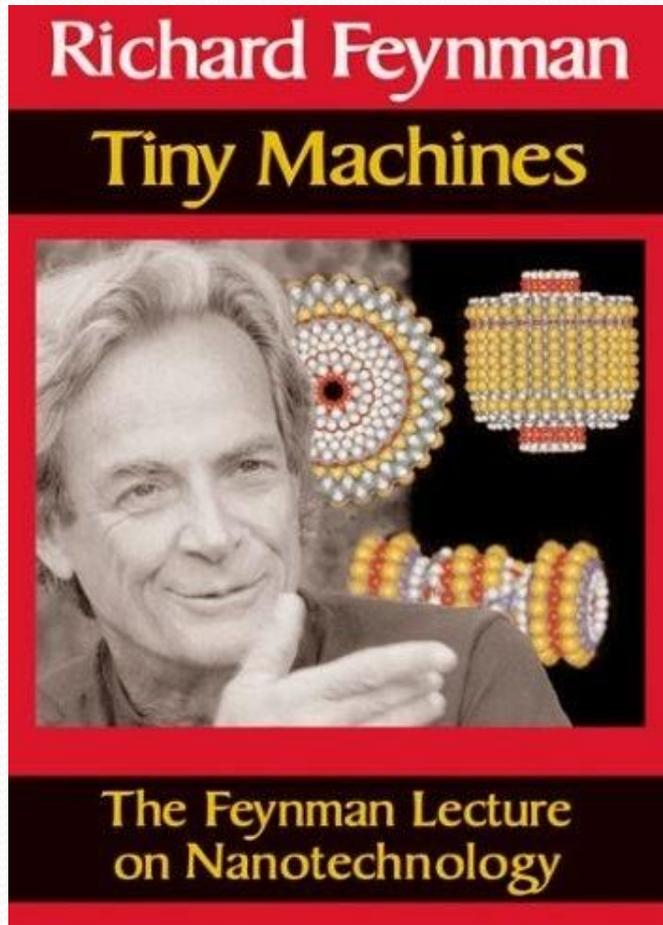
Risks: Toxicity, Assessment, Exposure

- Exposure routes in humans
 - **Inhalation**, ingestion, skin, mouth, eyes.
- Not well-understood yet
 - Reaction with the environment.
 - Toxicity
- Environmental fate and transport uncertain if materials enter environment at the end of their life.
 - (some intentionally released) e.g. TiO₂ in Water.
- Primary issues
 - Not firmly attached to a particular surface / unbound
 - There could be new toxicological properties not observed in bulk material.
- Detection techniques inadequate.



Solutions ... for now: Administrative controls, Mechanical controls, PPE, Monitoring equipment, Medical monitoring, Proper waste disposal.

Where it all started: "There's plenty of room at the bottom."



"There's Plenty of Room at the Bottom" was a lecture given by physicist Richard Feynman at an American Physical Society (APS) meeting at Caltech on December 29, 1959. This talk inspired the conceptual beginnings of the field decades later.



On the Basic Concept of 'Nano-Technology'

Norio TANIGUCHI
Tokyo Science University
Noda-shi, Chiba-ken, 278 Japan

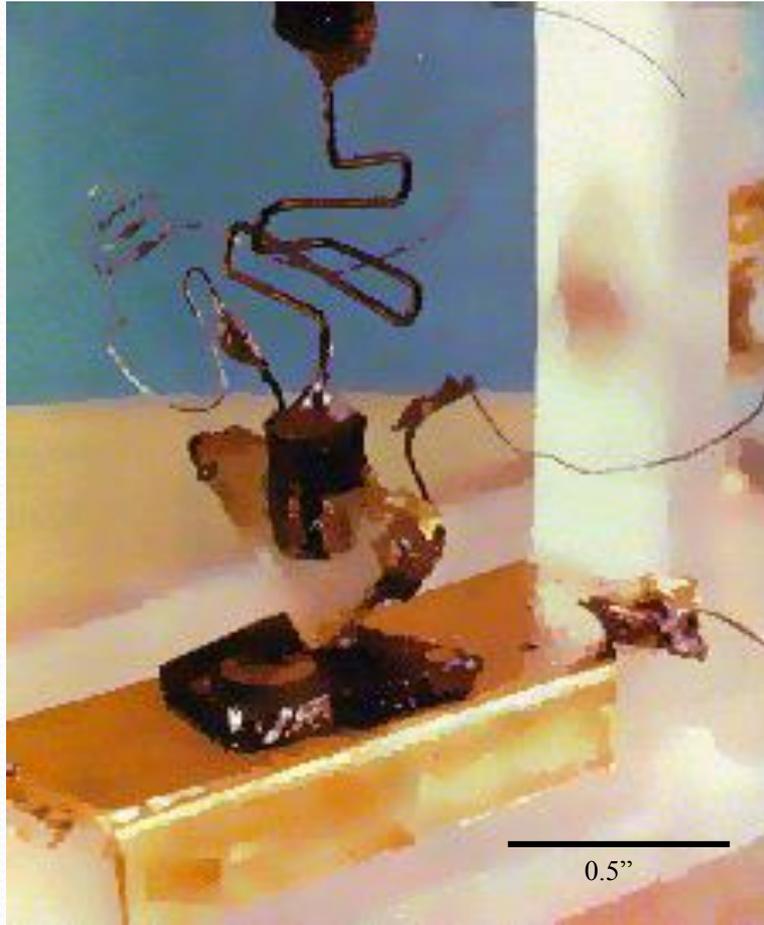
Abstract

'Nano-technology' is the production technology to get the extra high accuracy and ultra fine dimensions, i.e. the preciseness and fineness of the order of 1 nm (nanometer), 10^{-9} m in length. The name of 'Nano-technology' originates from this nanometer. In the processing of materials, the smallest bit size of stock removal, accretion or flow of materials is probably of one atom or one molecule, namely 0.1~0.2 nm in length. Therefore, the expected limit size of fineness would be of the order of 1 nm. Accordingly, 'Nano-technology' mainly consists of the processing of separation, consolidation and deformation of materials by one atom or one molecule. Needless to say, the measurement and control techniques to assure the preciseness and fineness of 1 nm play very important role in this technology.

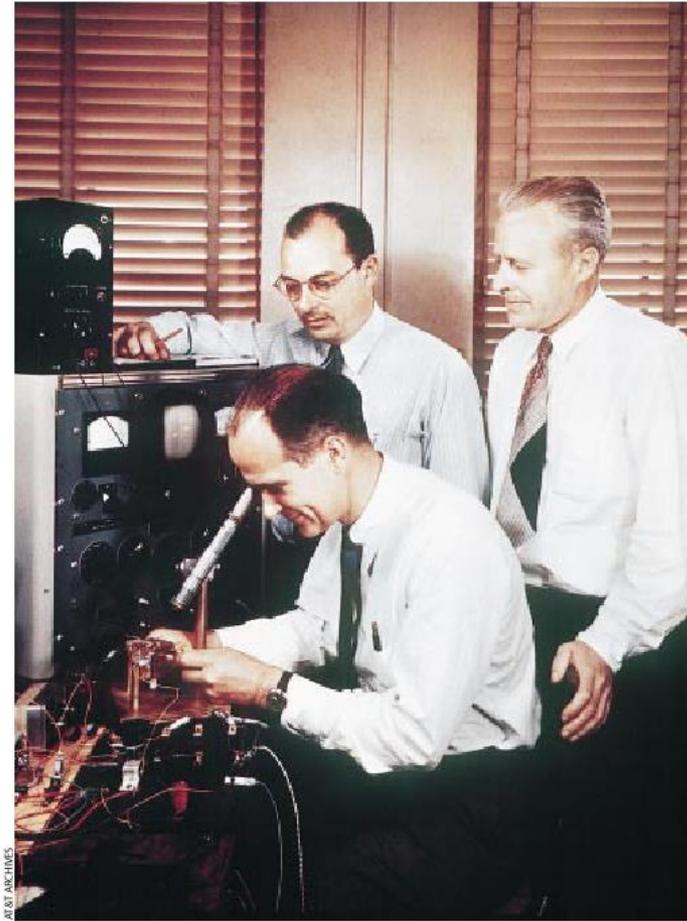
In the present paper, the basic concept of 'Nano-technology' in materials processing is discussed on the basis of microscopic behaviour of materials and as a result the ion sputter-machining is introduced as the most promising process for the technology.

Norio Taniguchi first termed the word "Nanotechnology" in 1974, in his paper on ion sputtering: *N. Taniguchi, Proc. Intl. Conf. Prod. Eng. Tokyo Part II, Japan Society of Precision Engineering, 1974, pp 18-23.*

The Beginning: At Bell Labs in 1947



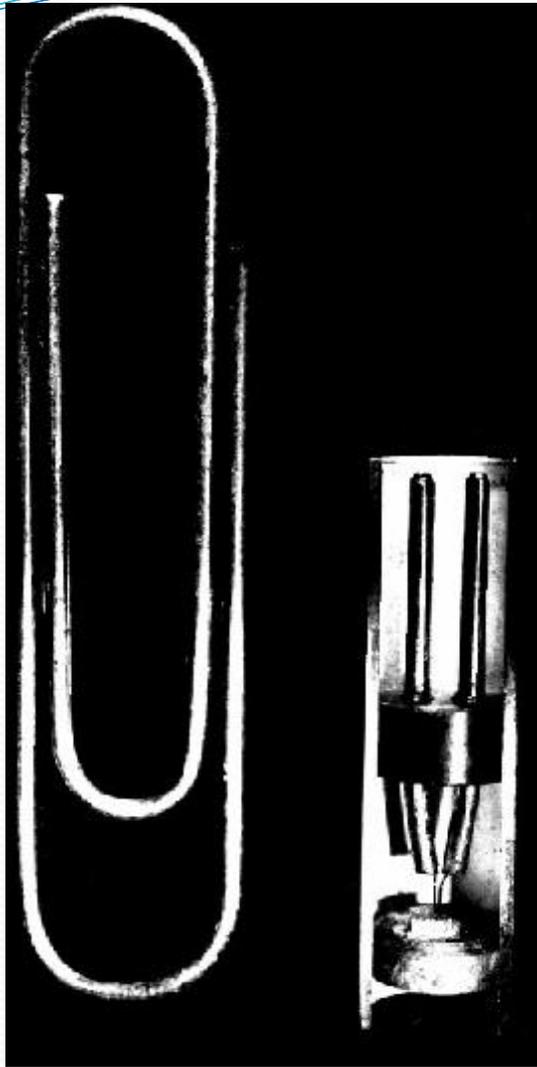
the first transistor made of Germanium



INVENTORS Shockley (*seated*), Bardeen (*left*) and Brattain (*right*) were the first to demonstrate a solid-state amplifier (*opposite page*).

AT&T Archives

In 1956, Schockley, Bardeen, and Brattain were awarded the Nobel Prize in Physics, "for their researches on semiconductors and their discovery of the transistor effect"



Point Contact Transistor

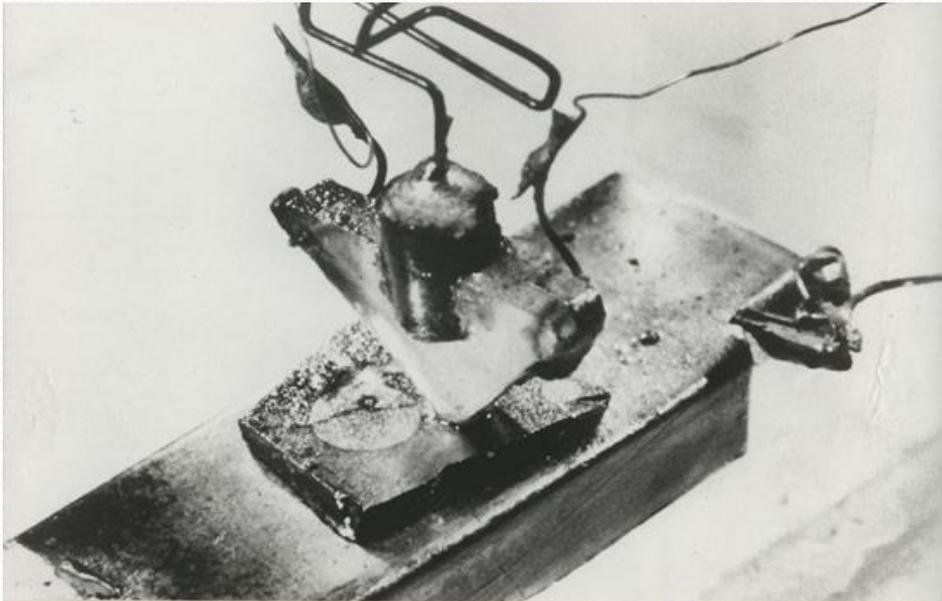
THE TRANSISTOR

Basic research in the electrical properties of solids has opened up an entirely new way of manipulating electrons to do useful work

by Frank H. Rockett

*this article, Scientific American, Sep. 1948,
offers the earliest survey of transistor technology*

Comparison: The Old vs. the New Transistor

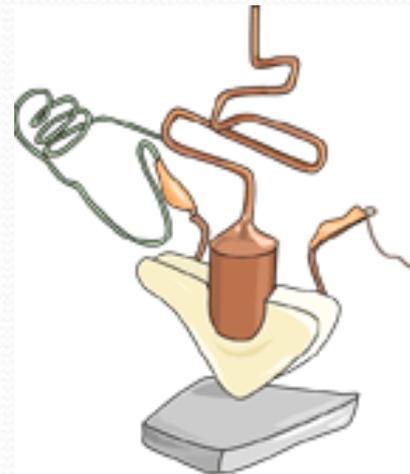


THE FIRST TRANSISTOR AS IT WAS PATENTED BY THREE NOBEL PRIZE-WINNING BELL LABORATORIES SCIENTISTS

The first transistor made use of the semiconductor germanium. Paper clips and razor blades were used to make the device.

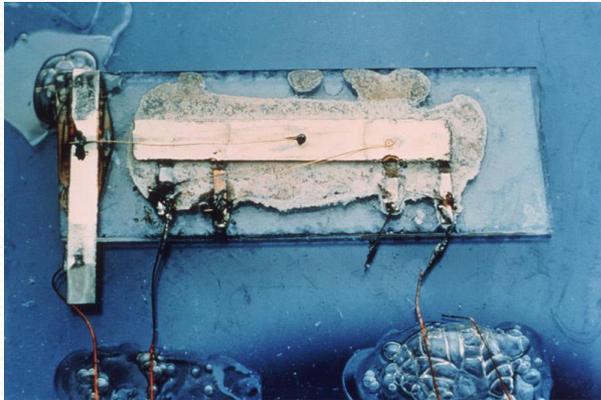


Wikipedia.org



The Integrated Circuit

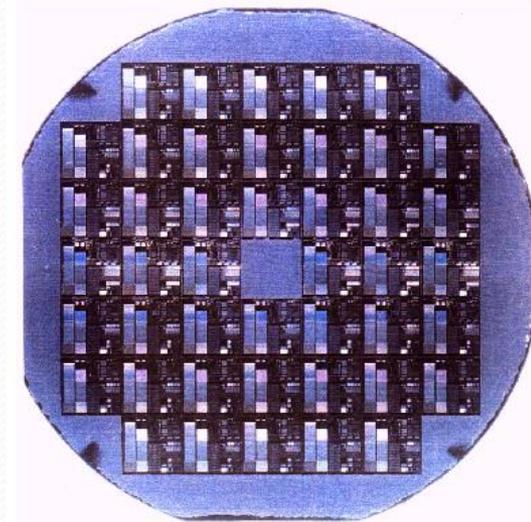
Stacking many transistors and complex circuits on single substrate



1st integrated circuit made by
Texas Instruments

1958 - Jack Kilby and Robert
Noyce

<http://www.ti.com/corp/docs/kilbyctr/downloadphotos.shtml>



modern integrated circuit

each chip contains many millions [transistors](#)

Nobel Prize in Physics 2000

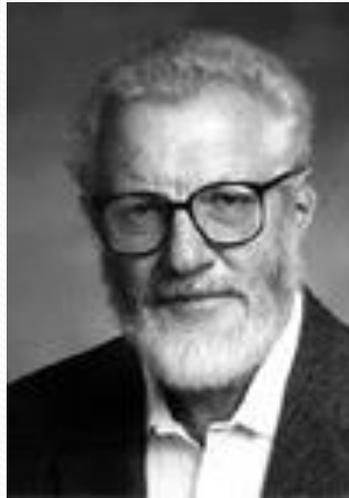


"for basic work on information and communication technology"

"for developing semiconductor heterostructures used in high-speed and optoelectronics"



**Zhores I
Alferov**



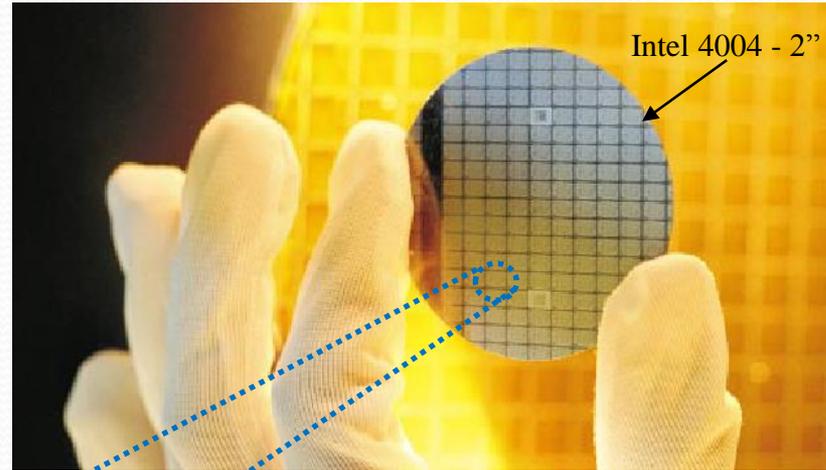
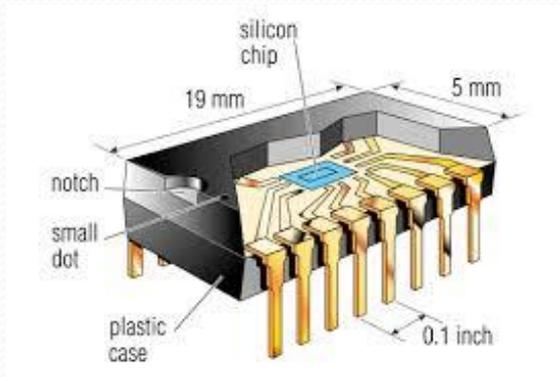
**Herbert
Kroemer**



**Jack S.
Kilby**

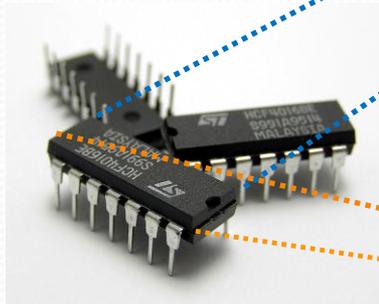
"for his part in the invention of the integrated circuit"

Integrated circuits: The heart of the computer



Intel.com

today's wafers-12''



Wikipedia.org

Three 14-pin (DIP14)
plastic dual in-line
packages containing IC
chips packaged chip

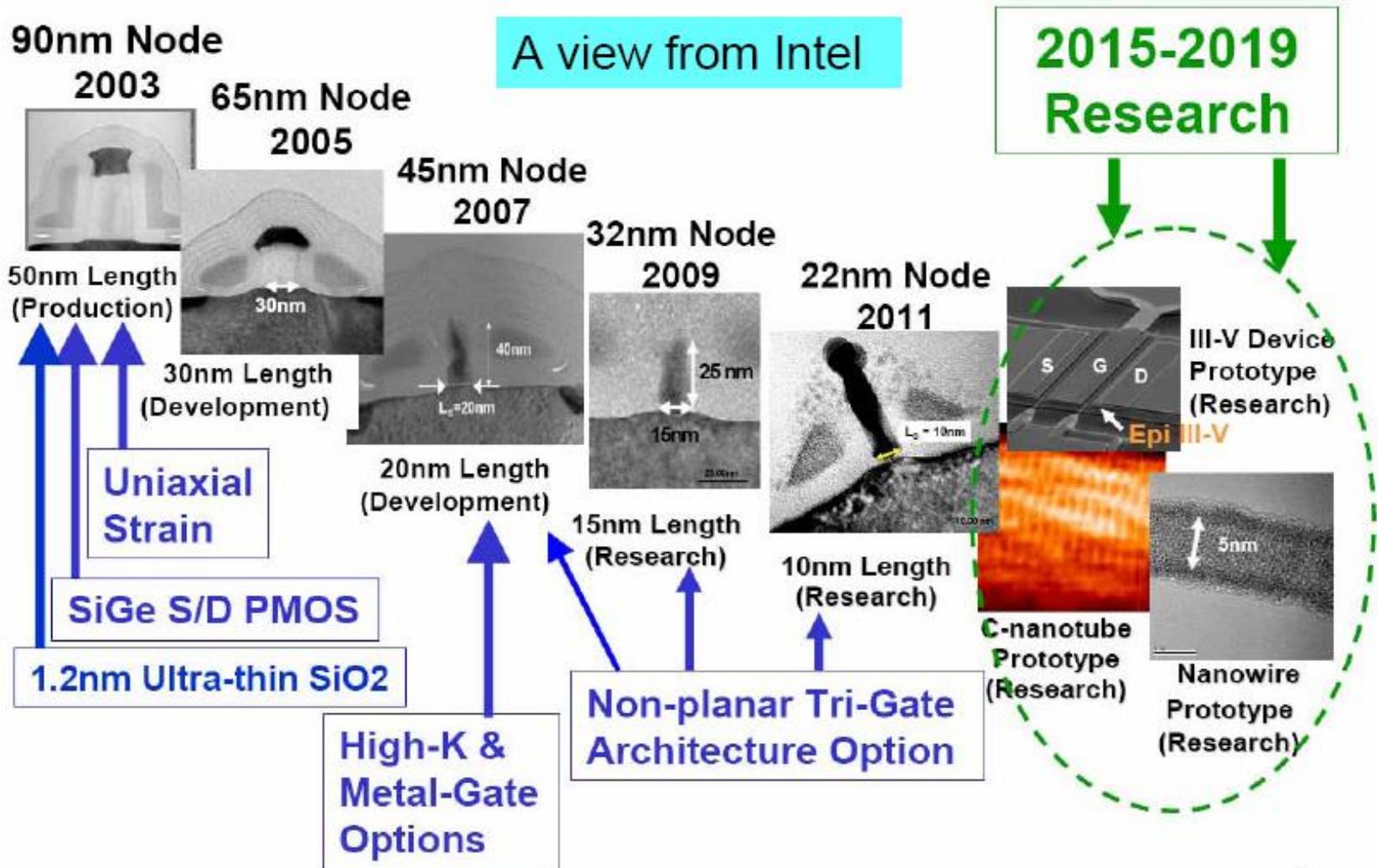


modern pc

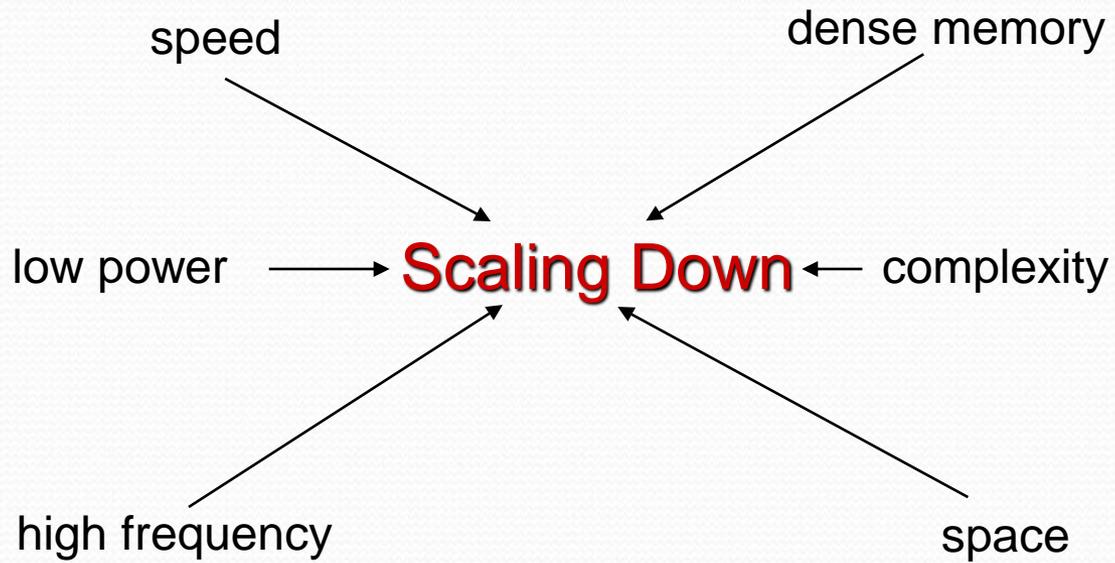


Scalability / Miniaturization

From the Age of Microelectronics to Nanoelectronics



Drive for ...

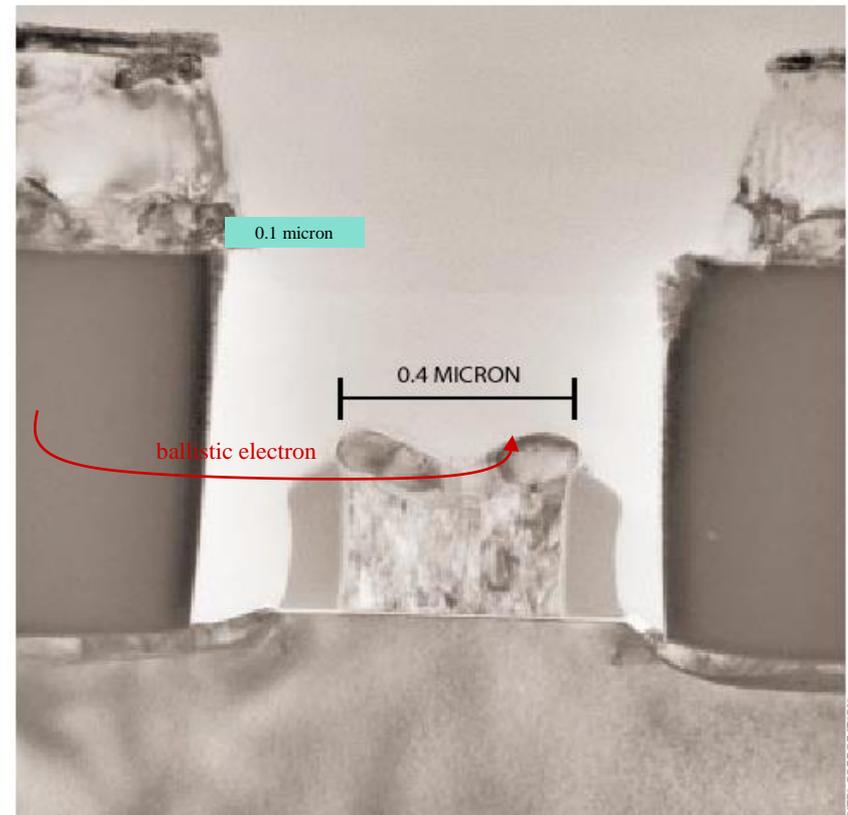
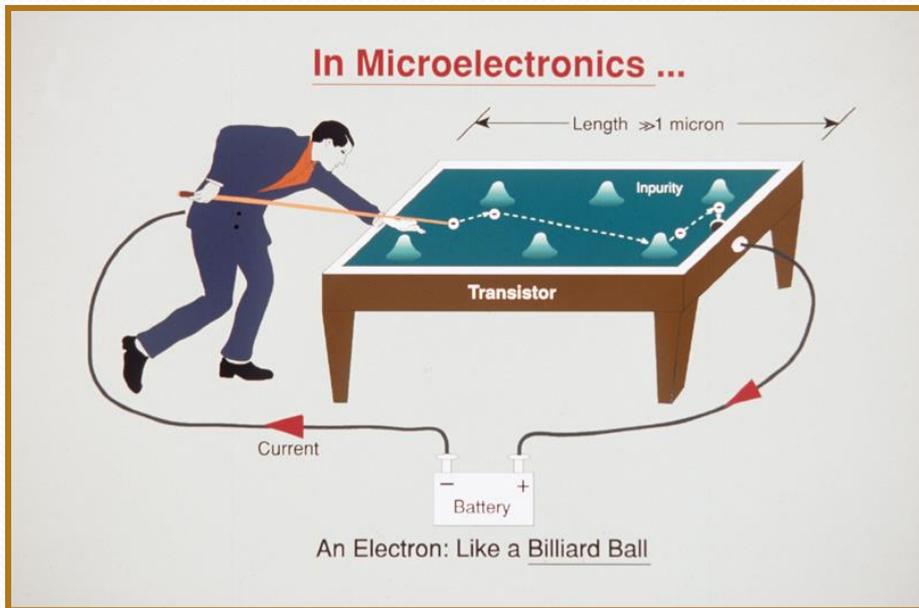




**What happens when
transistors
get smaller and smaller?**

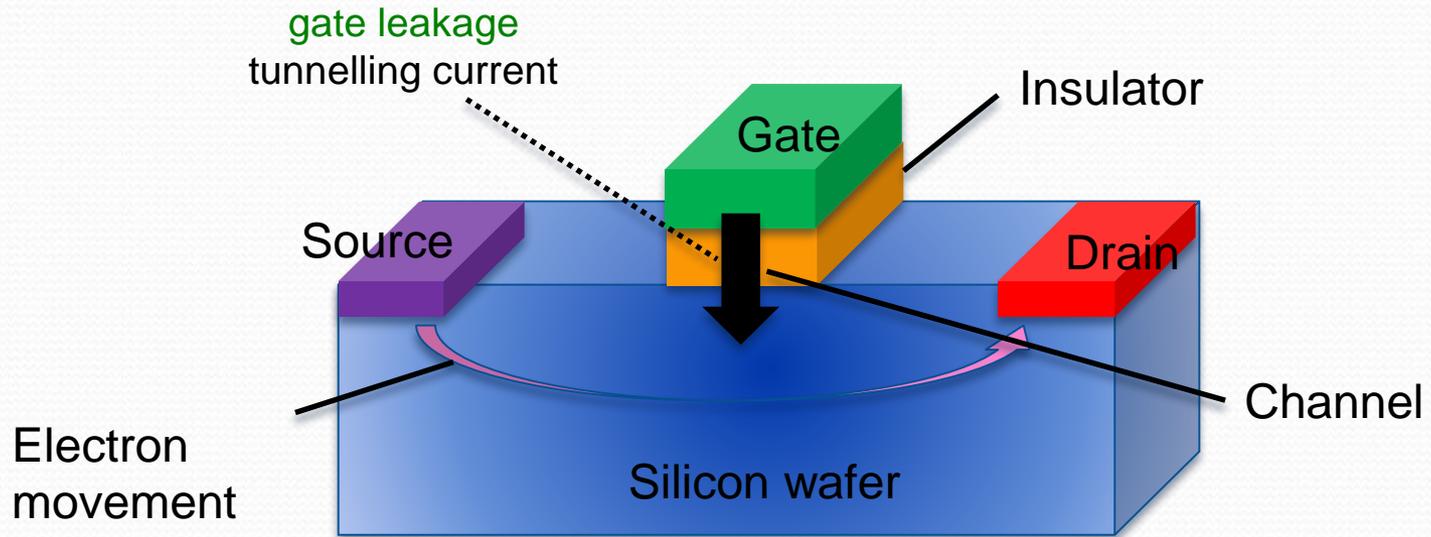
From many impurities to very few

Intel - 2004



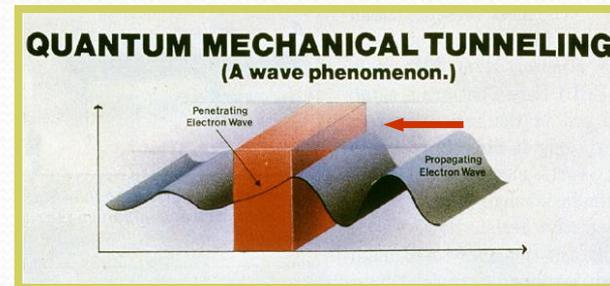
moving without collisions

Tunneling: Limiting Device Miniaturization



Another amazing effect of the *wave nature* of electrons

TUNNELING



Nobel Prize in Physics 1973



"for their experimental discoveries regarding **tunneling phenomena** in semiconductors and superconductors, respectively"

"for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects"



Leo Esaki

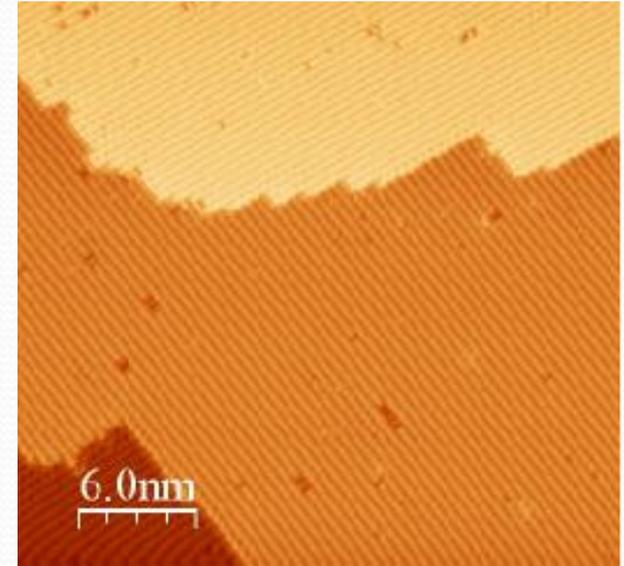
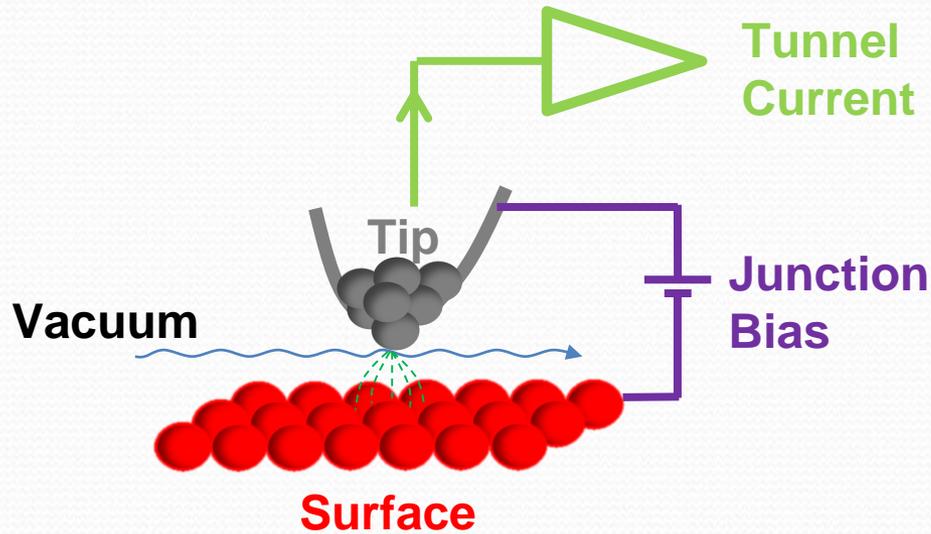


**Ivar
Giaever**

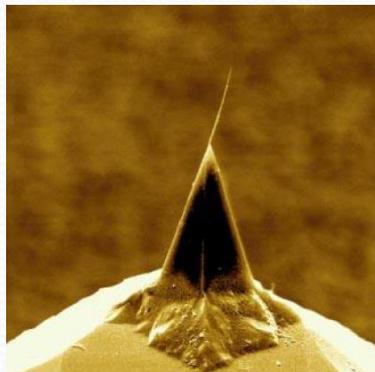


**Brian David
Josephson**

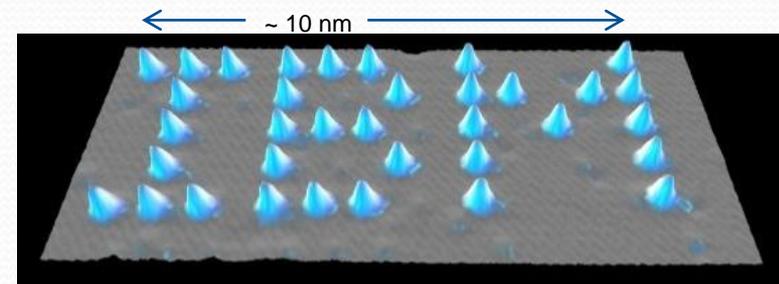
Scanning Tunneling Microscopy: A Revolution for Tunneling



Imaging



STM tip



Eigler, D., Nature 344, 524 (1990)

Atomic manipulation

Nobel Prize in Physics 1986



"for his fundamental work in electron optics, and for the design of the first electron microscope"

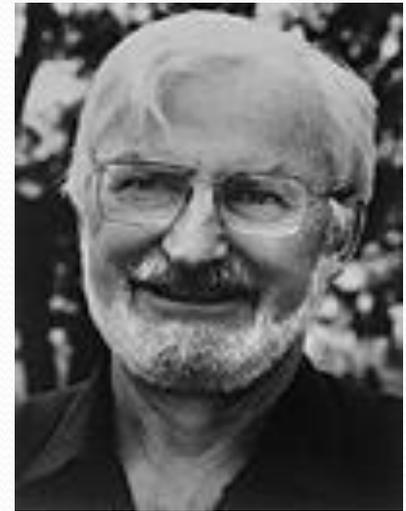
"for their design of the **scanning tunneling microscope**"



Ernst Ruska



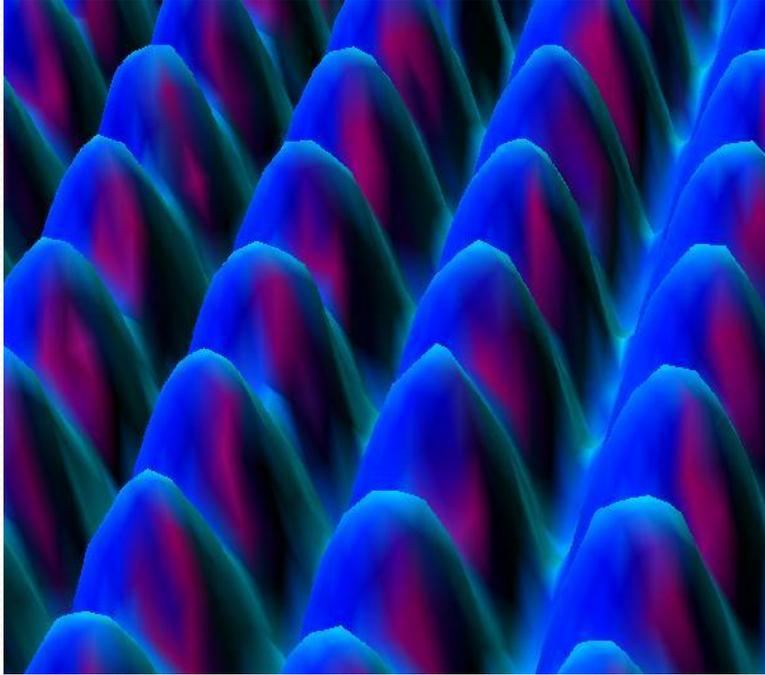
Gerd Binnig



Heinrich Rohrer

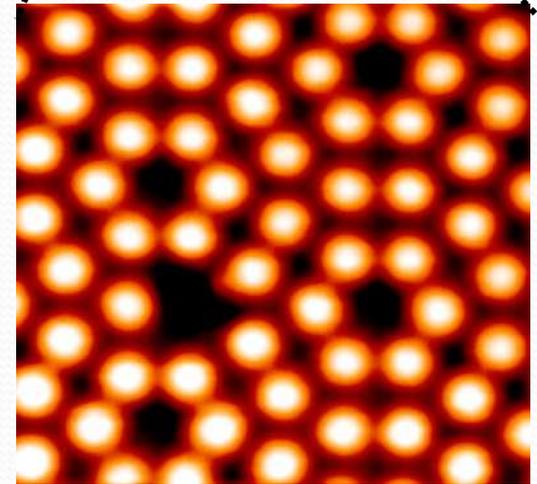
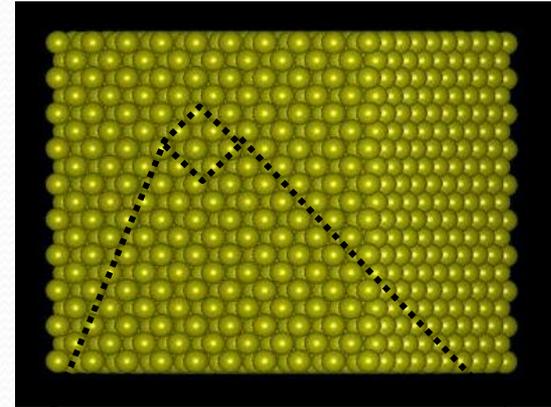
STM observing surfaces

Nickel



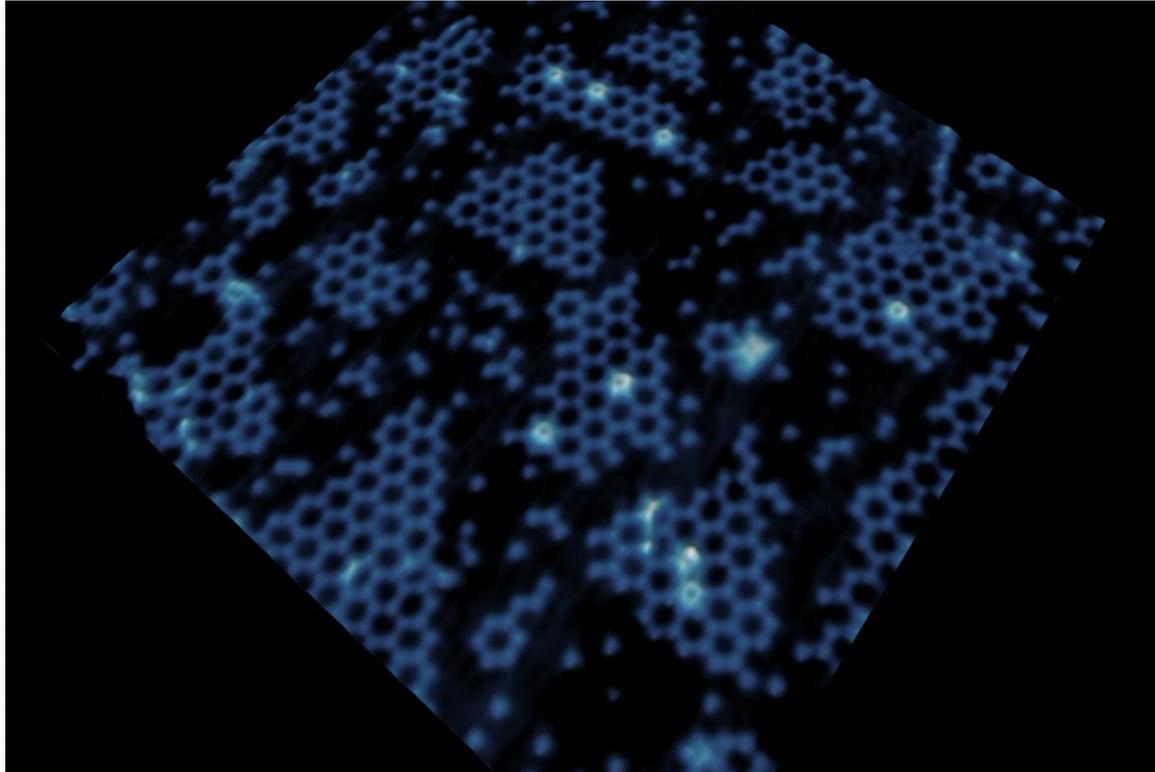
↔
3 Angstroms = 0.3 nm

Silicon



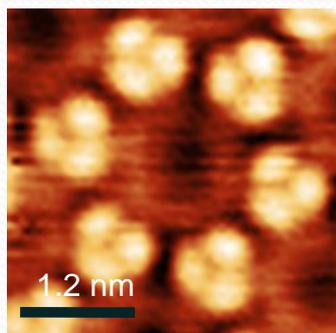
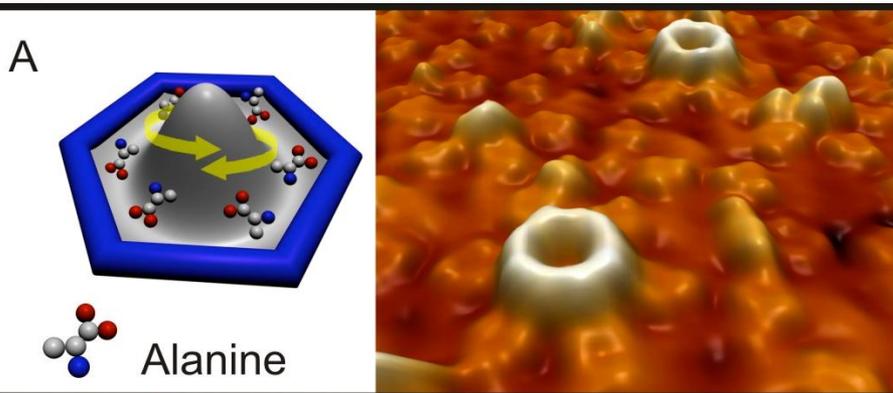
STM of Si(111) 7 x 7 reconstruction

Looking at Amino Acids with STM

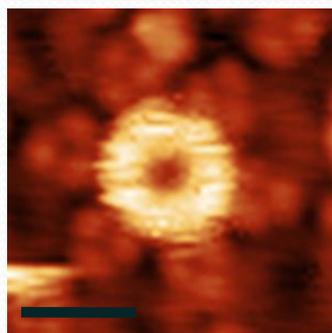


- Alanine molecules self-organize to create an extended chiral hexagonal molecular superstructure on Cu(111).
- Excess molecules can be seen spinning inside the hexagonal pores.

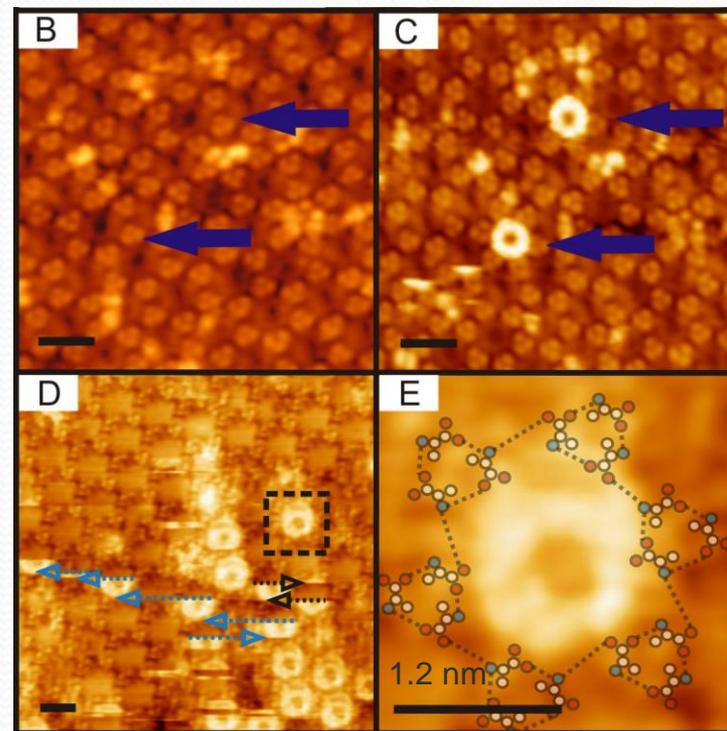
Observation of Molecular Motion



Empty corral



Corral with molecule

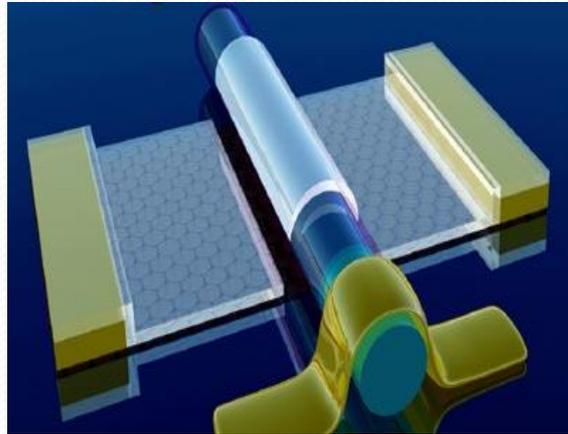
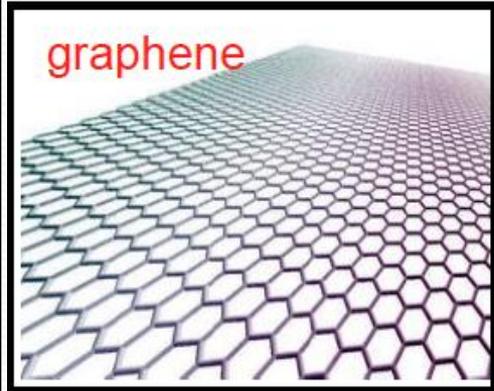


- Periodic motion confined to quantum corral;
- Adsorbate Tip can move the adsorbate across the hexagonal network kicking one from one corral to the other.



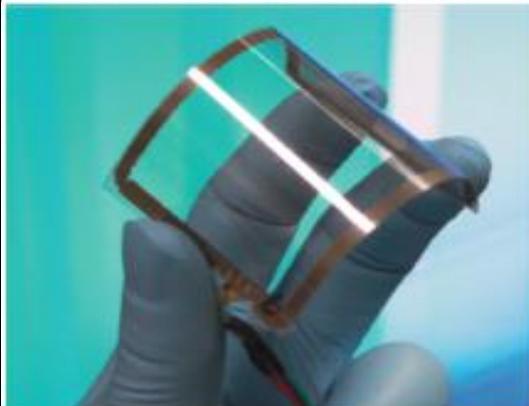
Today & Future

Graphene and the World of Nanotubes



Graphene transistor

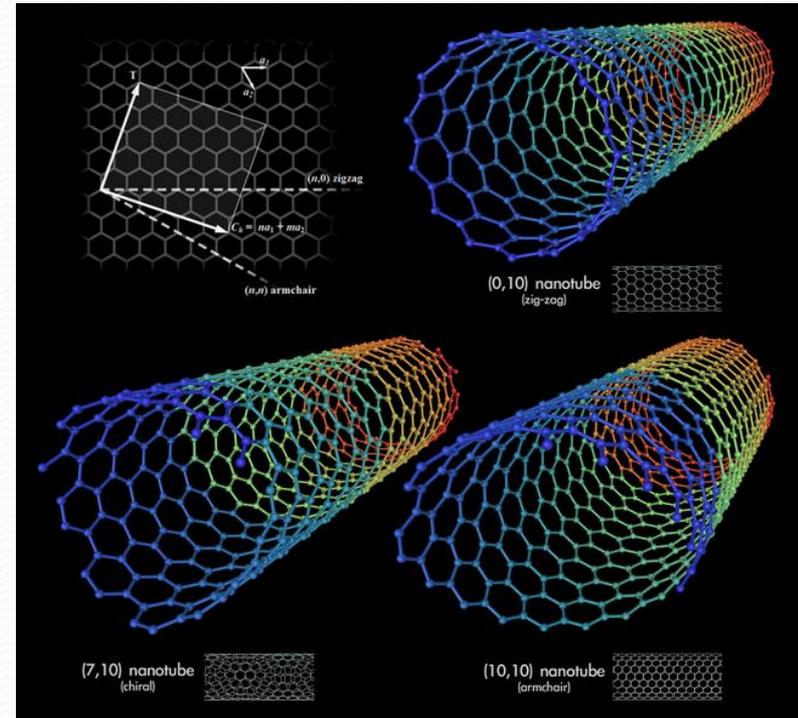
Physicsworld.com



Roll-to-roll production of transparent graphene

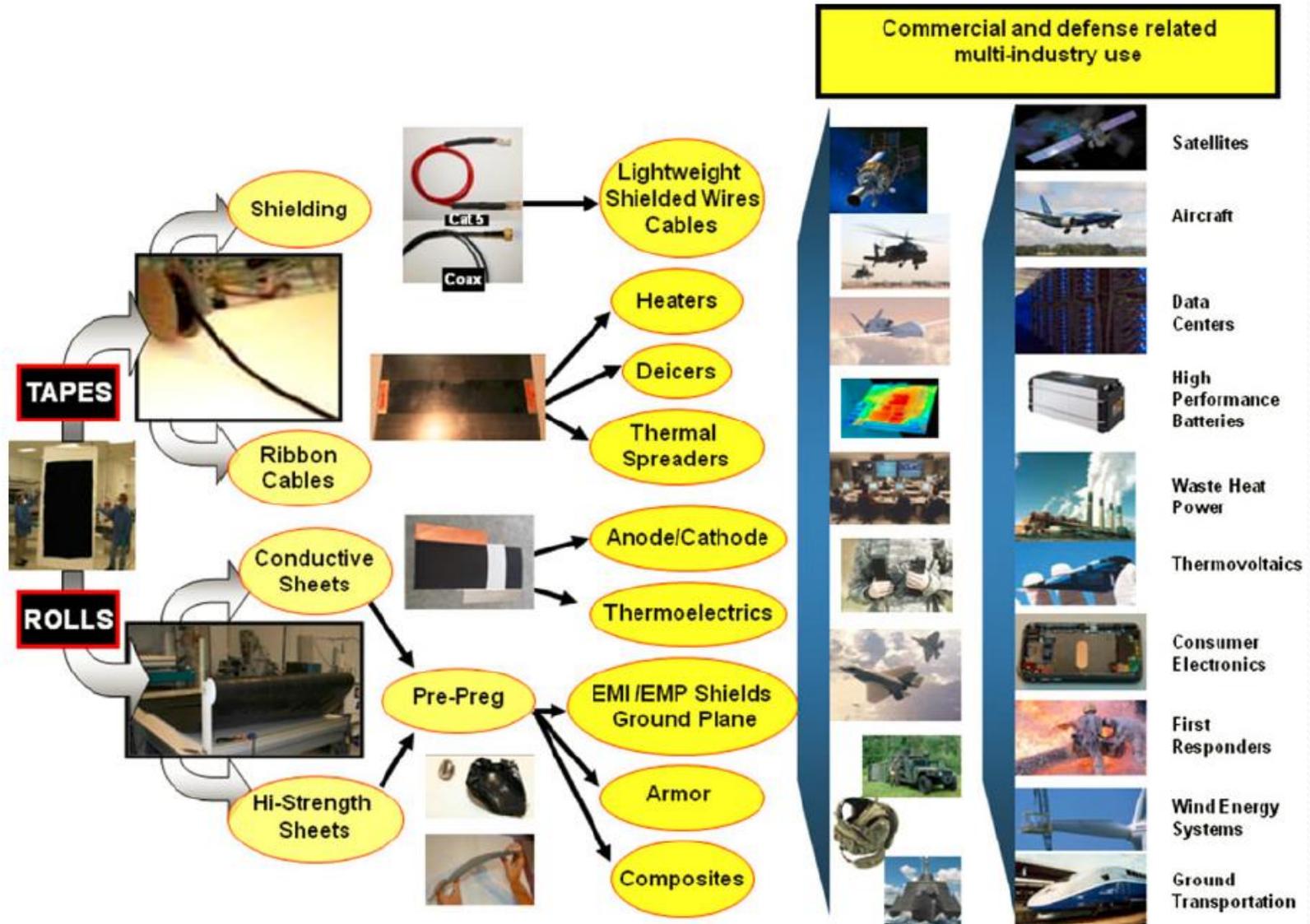
Bae, S. et al., Nature Nanotechnology 5, 574 (2010)

Carbon



Wikipedia.org

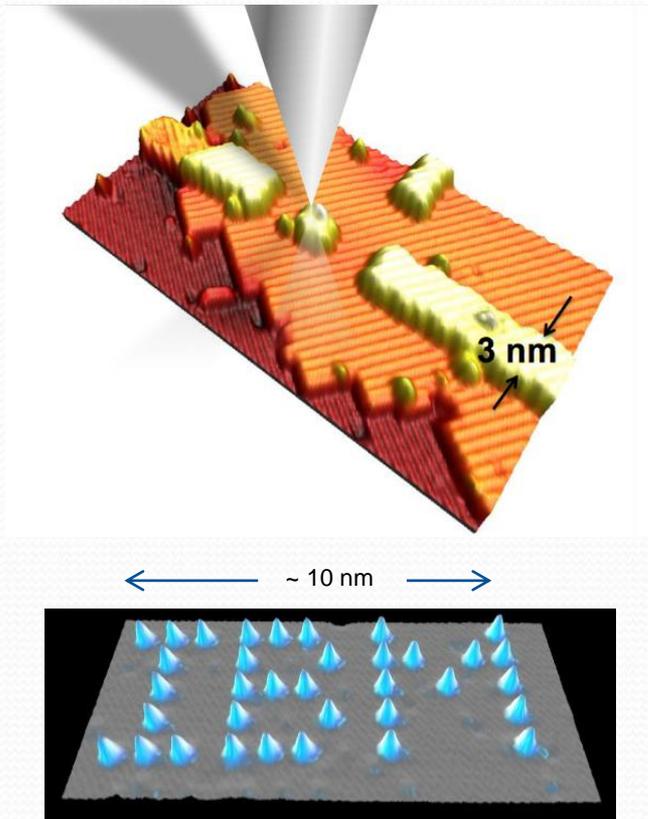
Carbon Nanotubes and Applications



Nanofabrication: Writing Devices

Pick and Place

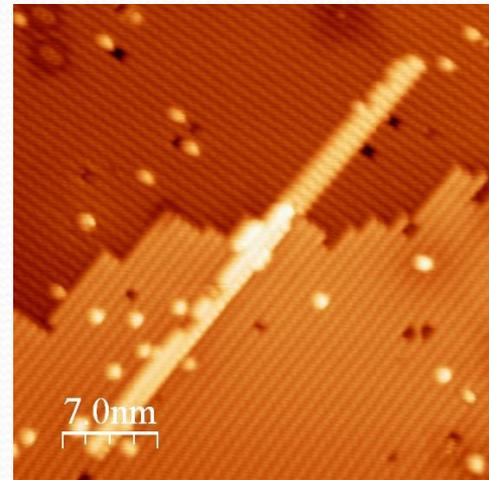
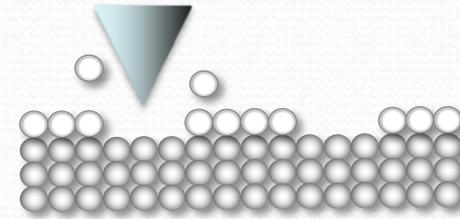
STM assisted nanofabrication



Eigler, D., Nature 344, 524 (1990)

Atomic manipulation

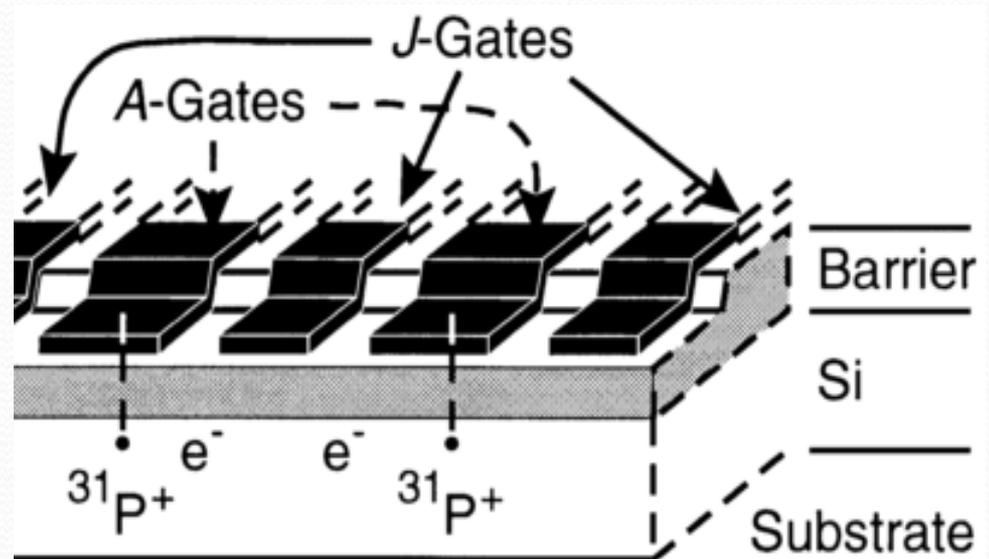
Write ...



Quantum Computing

Quantum mechanics + stored program computers =
Quantum Computing and Quantum Information Theory

- A **quantum computer** is: a computer design which operates using the principles of quantum mechanics to increase the computational power beyond what is attainable by a traditional computer.
- A quantum computer stores information as a quantum superposition of two states. Such a "quantum bit," is called a **qubit**.



Kane, B., Nature 393, 133 (1998)

Discussion Points

- What will be the impact of nanotechnology in Africa?
 - What areas will be impacted?
- Where will nanotechnology have its biggest impact 20 years from now?





Nanotechnology & Africa

Nanotechnology in Africa

Synthesis of nanoparticles

Nanophase catalysts
and electro-catalysts

Development of better and
cheaper solar cells

Synthesis of
quantum dots

Fuel cell
development

Synthesis of
nanotubes

Composites
development

Human and
animal health

Nanotechnology
and occupational
health

Water purification

Nutrition

Nanotechnology in Africa

- In **Kenya**, activities in nanotechnology research have concentrated on energy storage, production and conversion, agricultural productivity enhancement, agrochemical delivery, water treatment and purification, nanomedicine and nanobiotechnology.
- In **Ethiopia**, the main focus areas include electromagnetic properties of nanomaterials, solar energy and single-walled carbon nanotubes.
- Activities in **Sudan** include the synthesis and characterization of nanomaterials and drug delivery systems.
- In **Tanzania**, research revolves around nanotechnology for human and animal health, and nanobiotechnology.
- In **Nigeria**, the main themes of nanotechnology and nanoscience include nanomedicine (drug delivery methods, the treatment of diseases such as HIV, malaria, and cancer, and the biocompatibility of medical implants), nutrition, applications in electronics – optoelectronics, LEDs and MEMS devices and catalysis.
- In **Cameroon**, universities are involved in the synthesis and characterization of nanomaterials (nanocomposite thin films) and water purification and treatment.

Nanotechnology in Africa

- **Senegal** has been involved in the area of **synthesis, characterization** and **applications of nanomaterials**.
- **South Africa**, **nanoparticles** are produced by universities and other research groups, **small emerging companies**, and established **major international organizations**. The formation of lobby groups like the **South African Nanotechnology Initiative (SANi)**, the development of an enabling policy (South African Nanotechnology Strategy) combined with **investment** by the South African government has led to a surge in nanotechnology research activities in the country.



African Newsletter on Occupational Health and Safety, 22, 3 (2012)

Water Purification

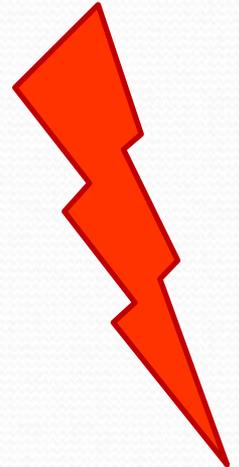


Mining



wikipedia.org

Effects on
population



Low-cost and effective solution to provide clean water to millions of people.
Opportunity to reduce the steps, materials, and energy needed to purify water.

Applications:

- Nanofiltration membranes → applied for removal of dissolved salts from salty water, water softening, removal of micro pollutants, and wastewater treatment.
- Nanocatalysts and magnetic nanoparticles → chemically degrade pollutants
- Nanosensors → for detection of chemical or biochemical parameters in water.

How Nanotechnology saved a Contaminated Lake in Peru

El Cascajo Wetlands in Peru were cleaned using micro nano bubbling system and a biofilter

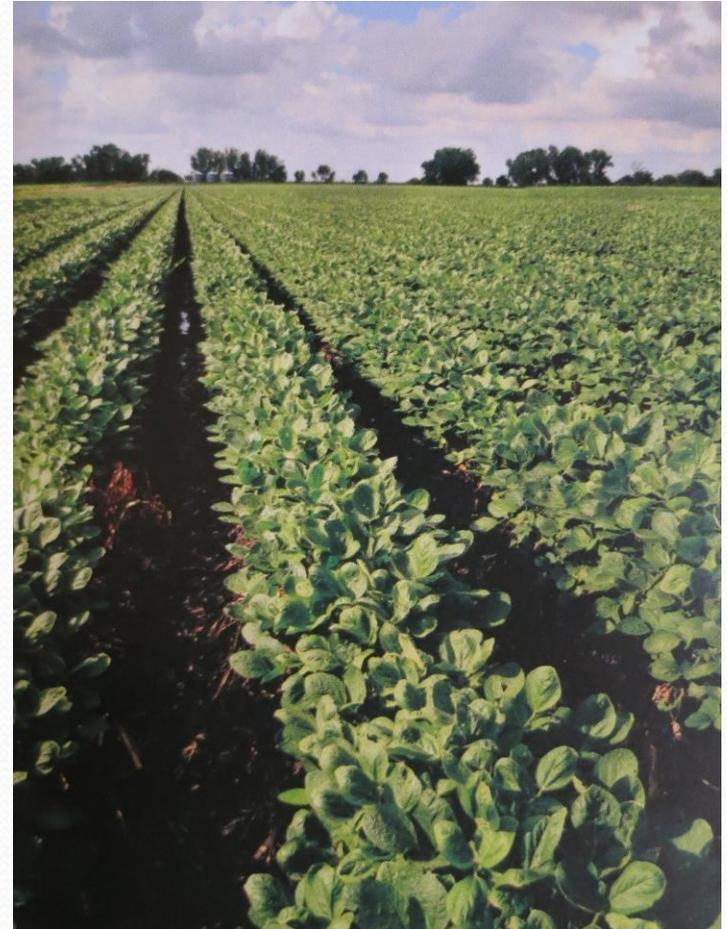


Marino Morikawa

<http://www.tea-after-twelve.com/all-issues/issue-02/issue-02-overview/chapter3/the-nanotechnology-miracle/#>

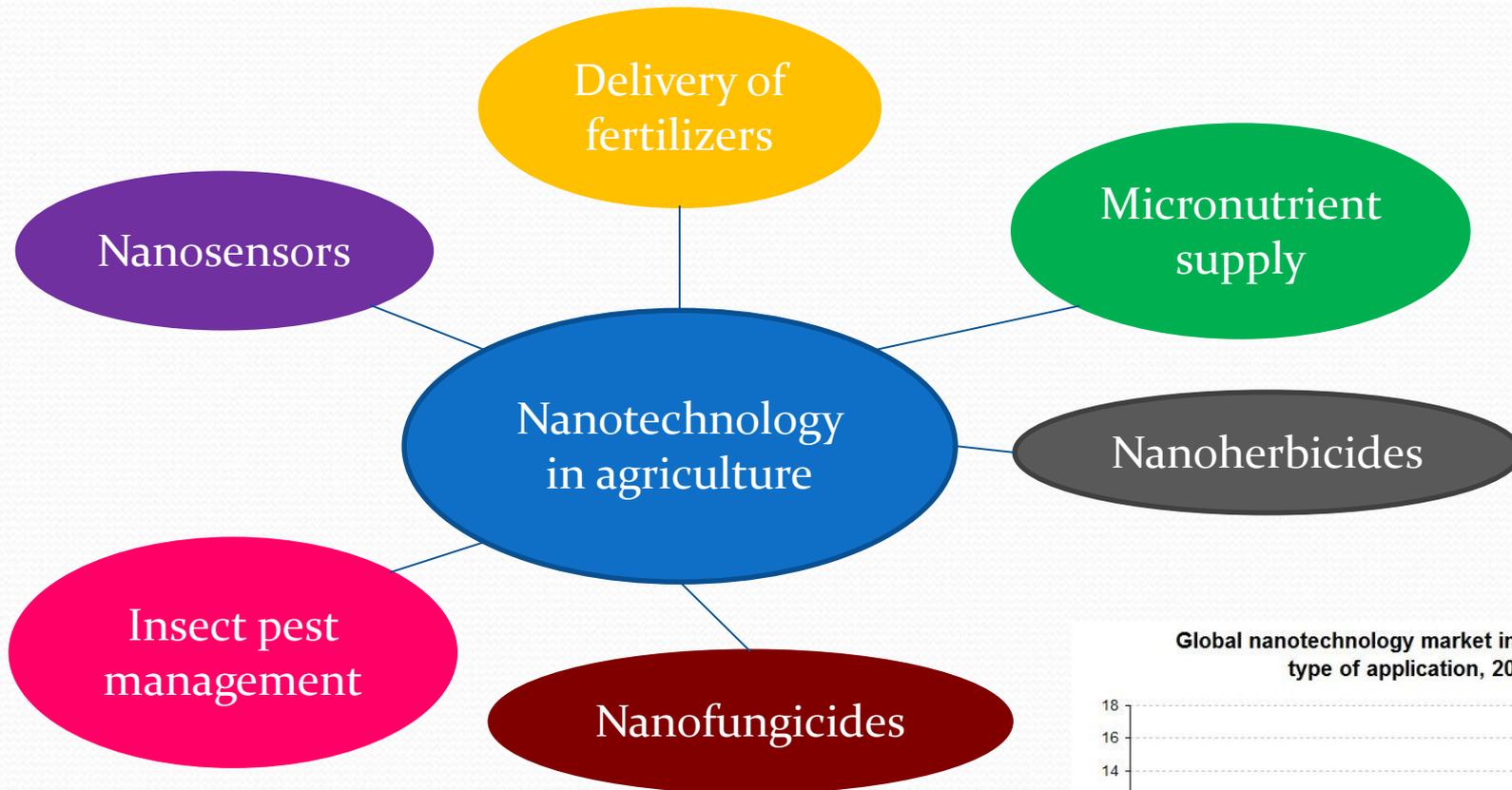
Agriculture & Forestry

Tracking & conservation & preservation & prevention

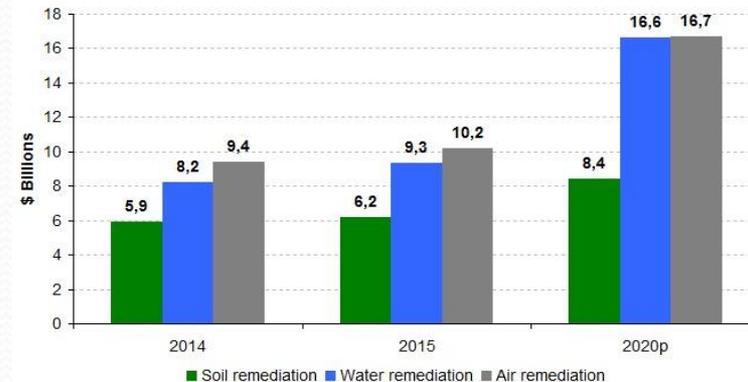


- Plant treatments
- Nano-scaled reformulations of pesticides, fungicides
- Nanosensors can be used to monitor various diseases

Nanotechnology and Agriculture



Global nanotechnology market in environmental, by type of application, 2014-2020



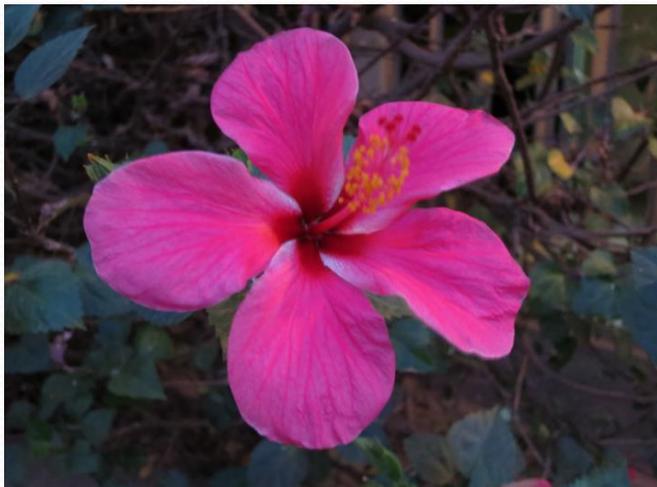
p = projections

Sources : BCC Research, July 2009 and November 2015.

Natural Extracts

Using green chemistry only → no harsh acids / no harsh bases

Pr. Malik Maaza, South Africa



Hibiscus flowers
Extraction of nano CeO_2 via natural extracts for cosmetics



Callistemon viminalis →
CuO nano fluids used in car industry for engine oil



Use of Agathosma betulina (buchu), high crystallinity



Nano gold from Alfalfa natural extract
 Eu^{3+} nano – phosphors

Other Plants?



Eucalyptus



Lantana



Calendula

Moringa oleifera



What if I am a Theorist?

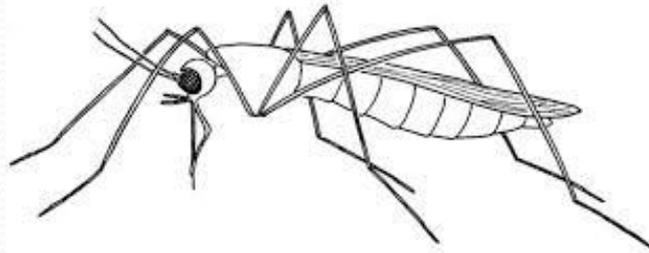
Paper battery



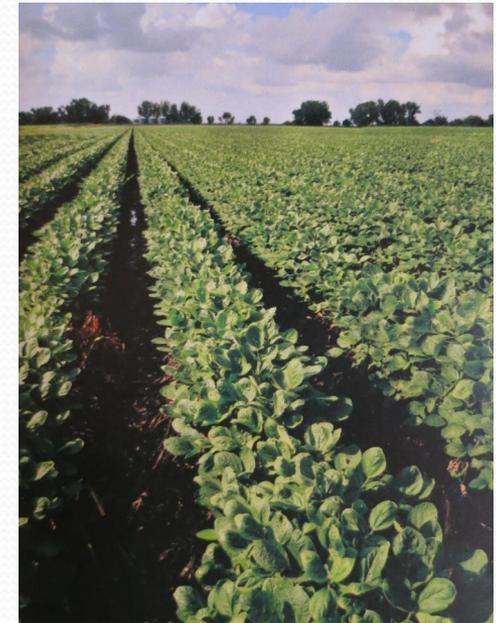
Solar energy



TB or malaria detection?



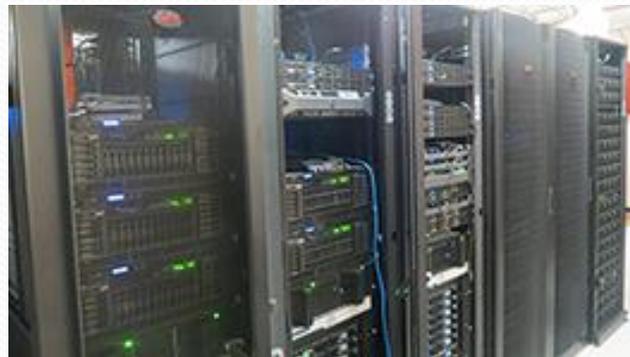
Air quality



Precision farming



Graphene



Lengau - Africa's fastest computer

Thank you for your attention

