Preparation and Applications of Nanomaterials

SESSION 1
January 9, 2018

Based on apresentation by
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Objectives

1. **Practice professional English in writing, listening and conversation.**
2. **Introduce the synthesis and processing of nanomaterials and nanostructures, which are the essential aspects of nanotechnology.**
3. **Study on the new physical properties and applications of nanomaterials and nanostructures.**

Text Books

Guozhong Cao, "Nanostructures and Nanomaterials – Synthesis , Properties & Applications" Imperial College Press, (2004)

Reference Book

Hornyak, Dutta, Tibbals, Rao, "Introduction to Nanoscience" CRC press (2008)

Reference Journals

1. Science ; Nature
2. Advanced Materials (Adv. Mater.)
3. Advanced Functional Materials (Adv. Fun. Mater.)
4. Applied Physics Letter (Appl. Phys. Lett.)
5. Chemistry of Materials (Chem. Mater.)
6. Journal Physics and Chemistry B . C. (J. Phys. Chem. B. C.)
7. Materials Research Bulletin (Mater. Res. Bull.)
8. Journal Applied Physics (J. Appl. Phys.)
9. Journal of American Ceramic Society (J. Amer. Ceram. Soc.)
10. Journal of Materials Chemistry (J. Mater. Chem)
11. Journal of Materials Research (J. Mater. Res.)
12. Journal Chemical Physics (J. Chem. Phys.)
13. Japanese Journal Applied Physics (J. J. Appl. Phys.)
14. Ceramic International (Ceram. Int.)
15. Journal of Ceramic Society Japan (J. Ceram. Soc. Jpn.)
16. Journal of European Ceramic Society (J. Eur. Ceram. Soc.)
17. Materials Chemistry and Physics (Mater. Chem. Phys.)
18. Journal of Sol-Gel Science and Technology (J. Sol-Gel Sci. Tech.)
19. Journal Non-Crystalline Solid (J. Non-Cryst. Solids)
20. Journal of Materials Science (J. Mater. Sci.)

Book Content

Chap. 1. Introduction: Definition and Introduction

Chap. 2. Physical Chemistry of Solid Surfaces

Chap. 3. Zero-Dimensional Nanostructures – Nanoparticles

Chap. 4. One-Dimensional Nanostructures – Nanowire, Nanorods.

Chap. 5. Two-Dimensional Nanostructures – Thin films.

Chap. 6. Special Nanomaterials

Chap. 7. Nanostructures Fabricated by Physical Techniques

Chap. 8. Characterization and Properties of Nanomaterials

Chap. 9. Applications of Nanomaterials

Syllabus

Before we start…….

Think…..

What we have from history..?

We have only one earth !

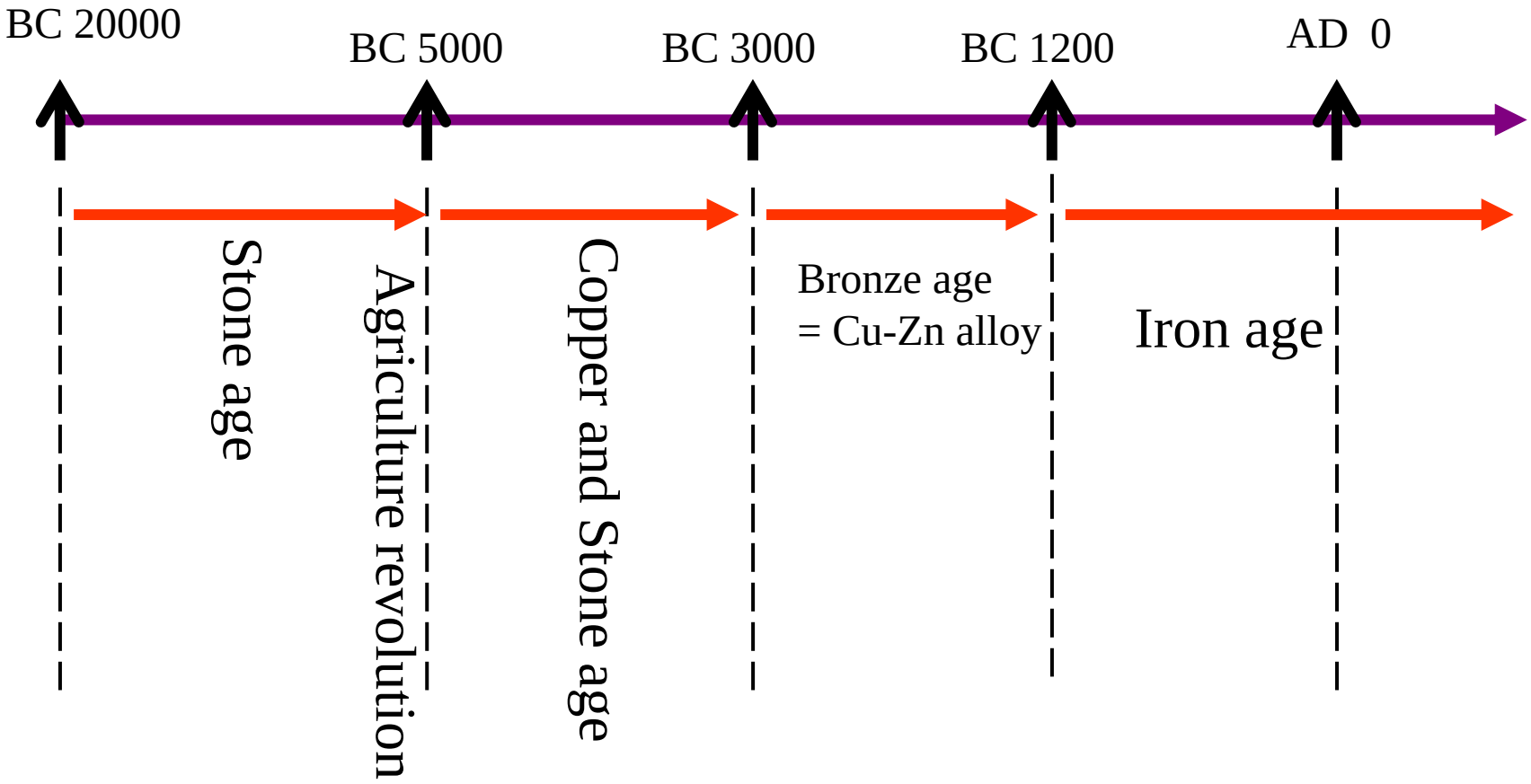
ABUNDANCE (WEIGHT PERCENT) AND DISTRIBUTION OF ELEMENTS ON EARTH[a]

Crust		Seawater		Atmosphere	
Oxygen	47	Oxygen	85.7	Nitrogen	79
Silicon	27	Hydrogen	10.8	Oxygen	19
Aluminum	8	Chlorine	1.9	Argon	2
Iron	5	Sodium	1.05	Carbon dioxide	0.04
Calcium	4	Magnesium	0.127		
Sodium	3	Sulfur	0.089		
Potassium	3	Calcium	0.040		
Magnesium	2	Potassium	0.038		
Titanium	0.4	Bromine	0.0065		
Hydrogen	0.1	Carbon	0.003		
Phosphorus	0.1	Strontium	0.0013		
Manganese	0.1	Boron	0.00046		
Fluorine	0.06				
Barium	0.04				
Strontium	0.04				
Sulfur	0.03				
Carbon	0.02				

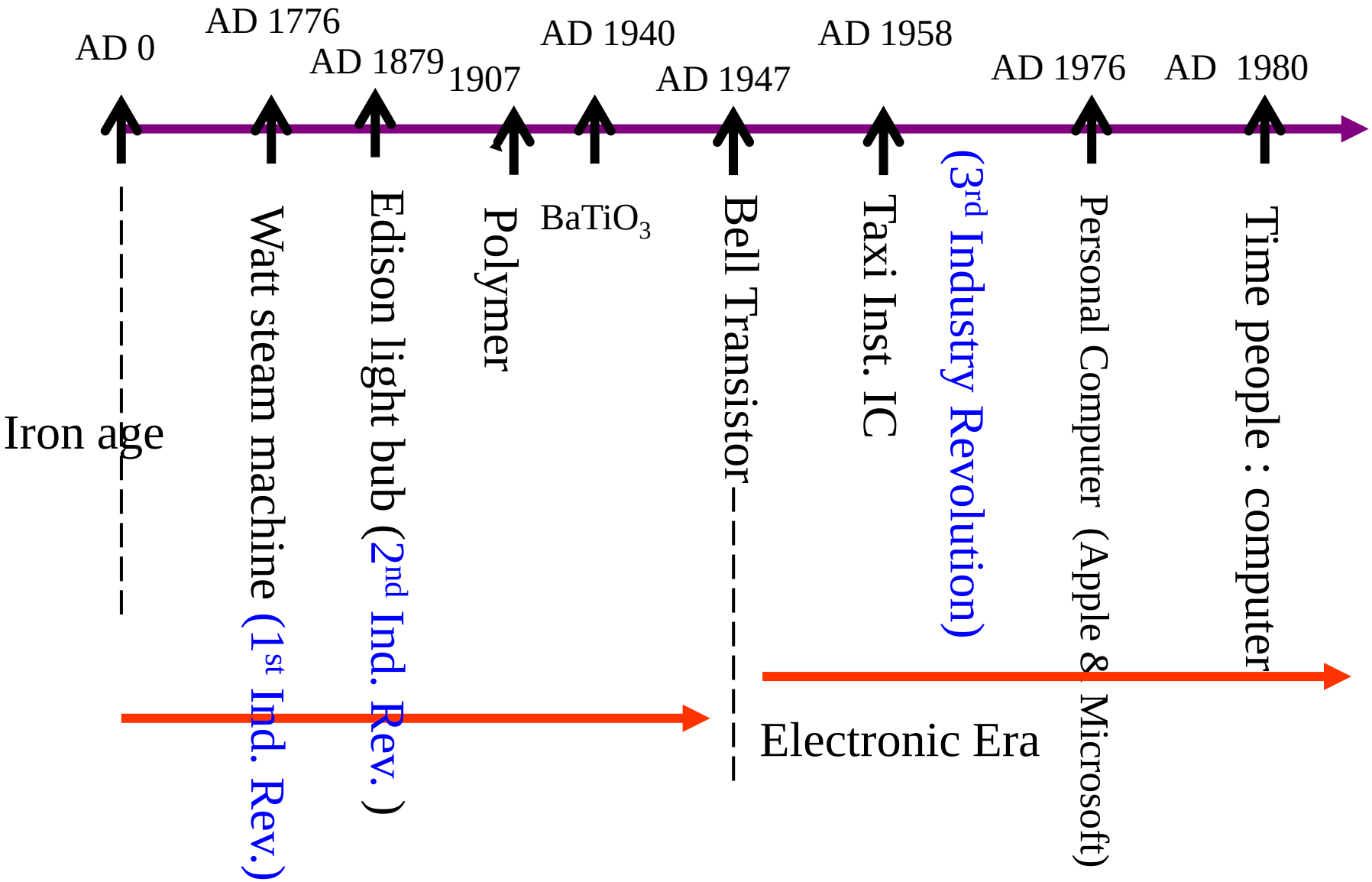
[a] The total mass of the crust to a depth of 1 km is 3×10^{21} kg; the mass of the oceans is 10^{20} kg; that of the atmosphere is 5×10^{18} kg.

From M. F. Ashby and D. R. Jones, *Engineering Materials 1: An Introduction to Their Properties and Applications*, Pergamon Press, Oxford (1980).

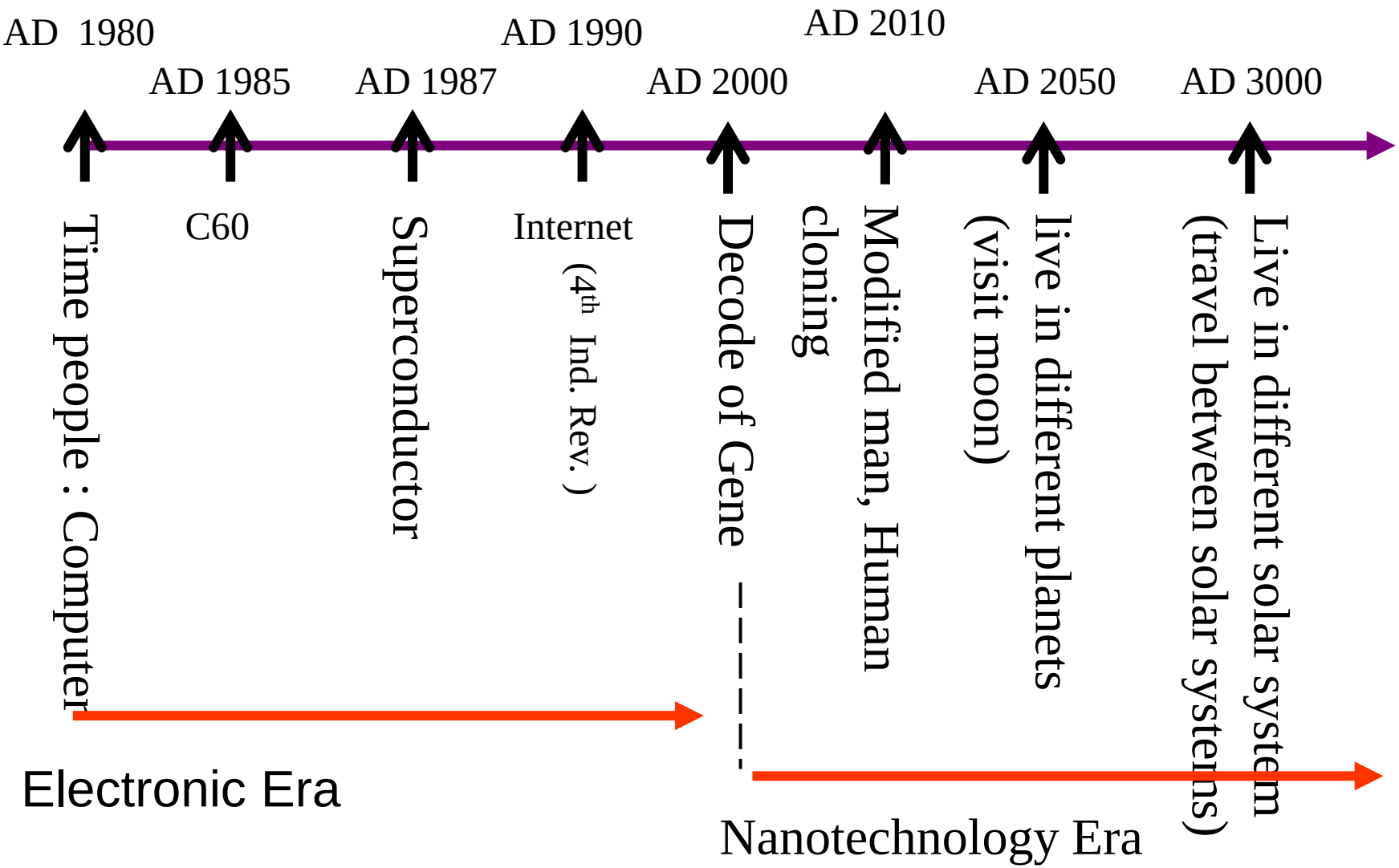
What history have given us



What history have given us



What history have given us



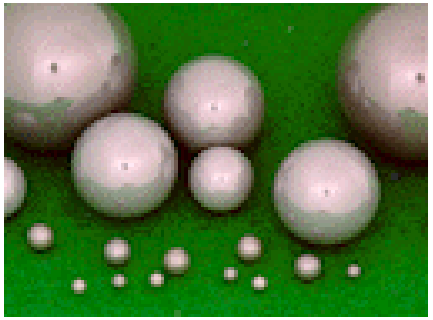
Groups of Materials

Metal	**Fe, Au, Ag, Cu, Al, Alloy….**
Ceramic	**Traditional ceramic: Refractory, china, clay-based** **Advanced ceramic:** **1. Structural ceramic – Al_2O_3, ZrO_2** **2. Electronic ceramic – $BaTiO_3$, PZT, YBaCuO** **3. Glass ceramic, optical fiber**
Polymer	**Plastic, rubber (elastomer), fiber, paint, adhesives**
Composite	**Metal-matrix composites (MMCs)** **Ceramic-matrix composites (CMCs)** **Polymer-matrix composites (PMCs)**
Semiconductor	**IC chip, Junction devices (diodes) transistor, by using Si wafer**
Biomaterials	**Stainless steel, Al_2O_3, $Ca(PO_4)_2$, $Ca_{10}(PO_4)_6(OH)_2$**

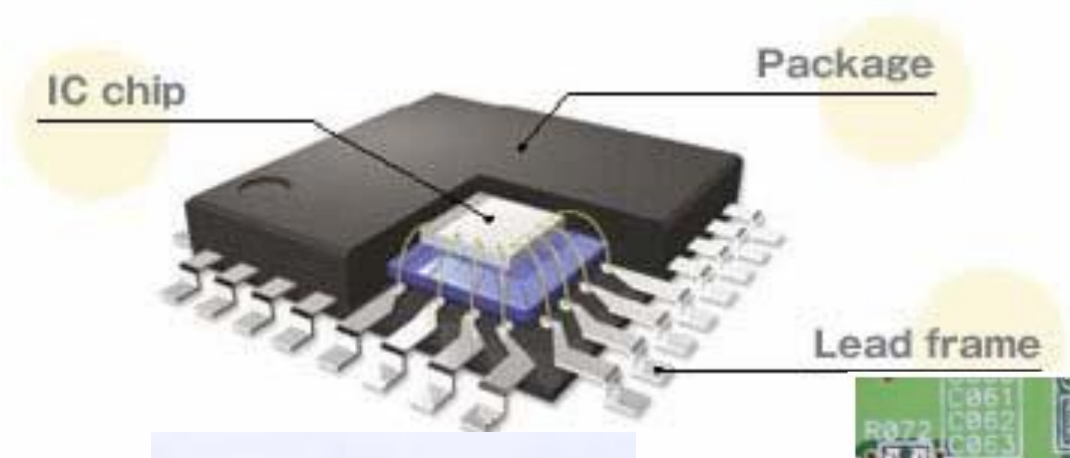
Application of metals

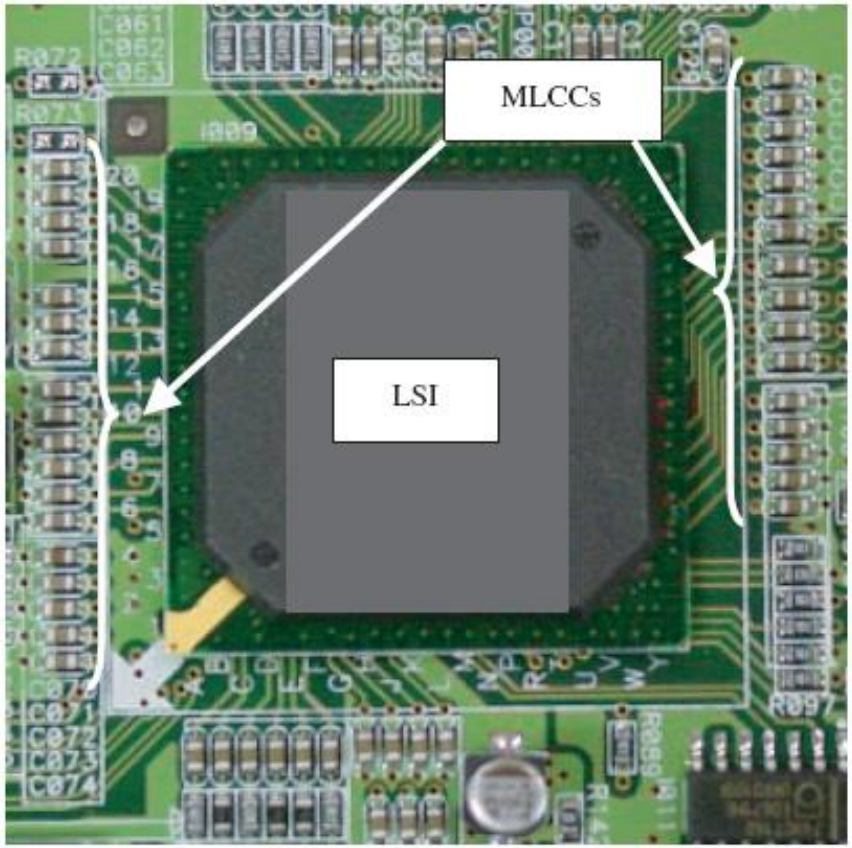
Applications of Ceramics

Pyrolytic
Boron Nitride (PBN)

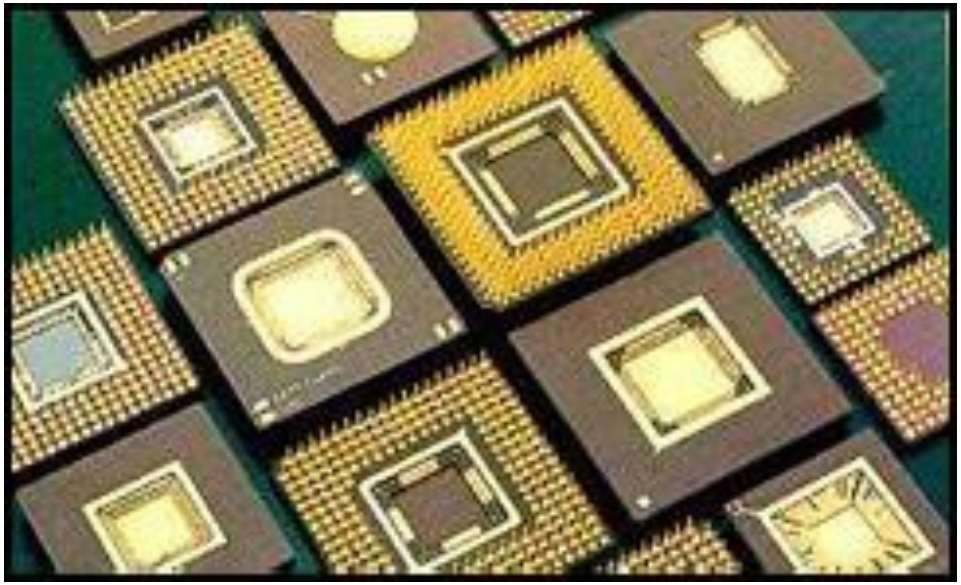


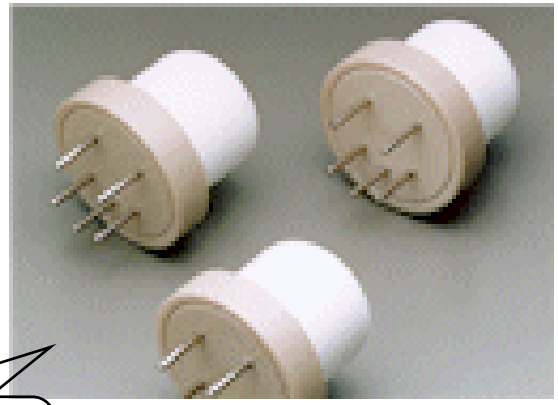
Applications of Ceramics





Applications of Ceramics

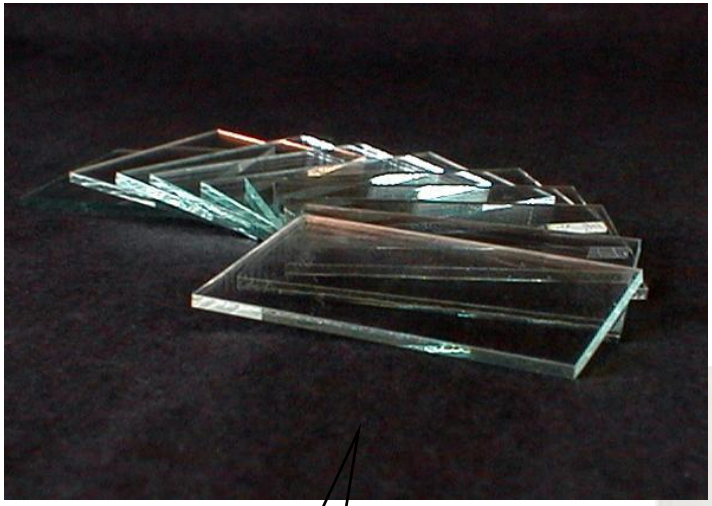




Oxygen Sensor

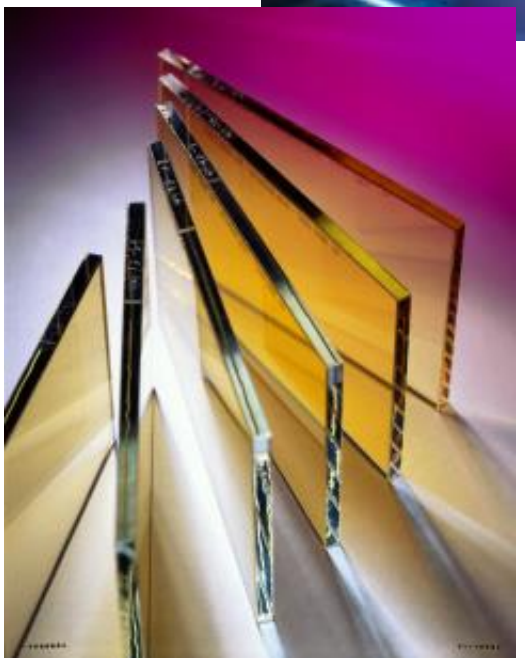
Microwave Dielectric Resonator

Applications of Glass

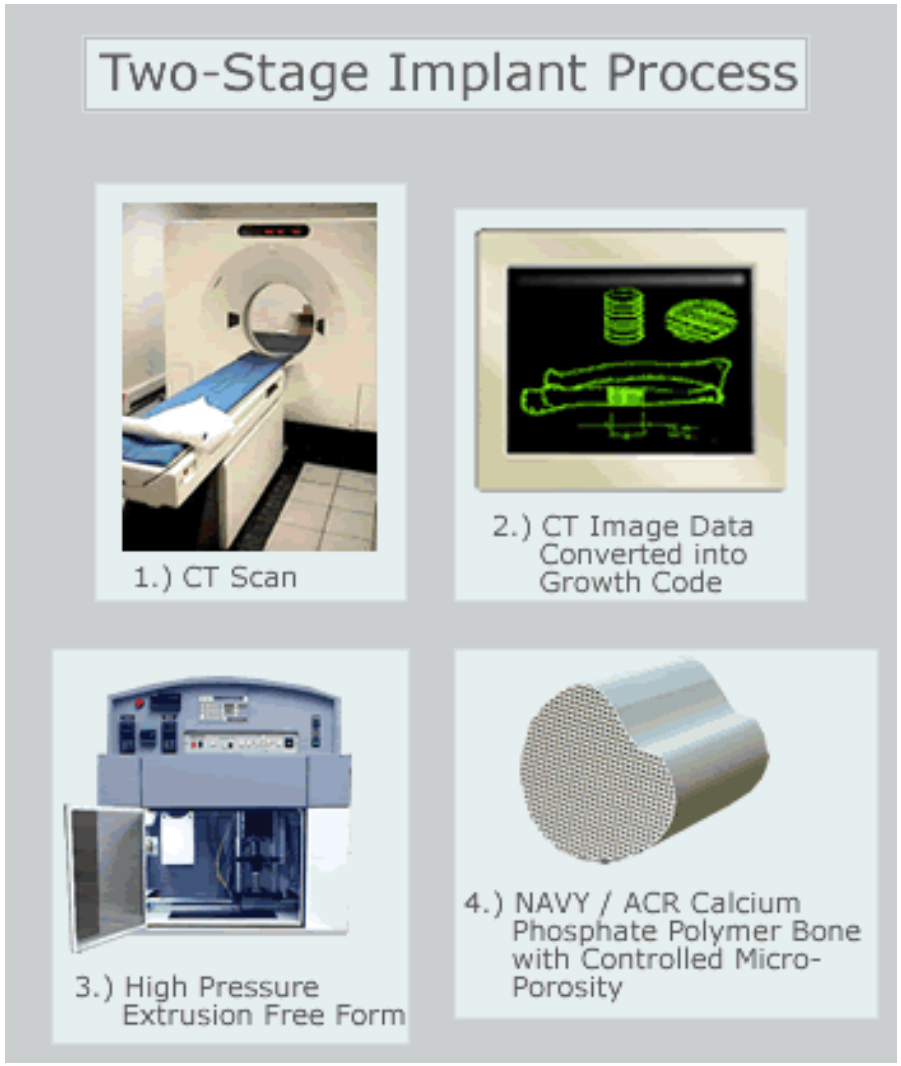


ITO
Glass

Applications of Ceramics: Optical Fiber, Glass-Ceramics



Applications of Biomaterials



Application of Polymers

- How about double the performance and half in price ?

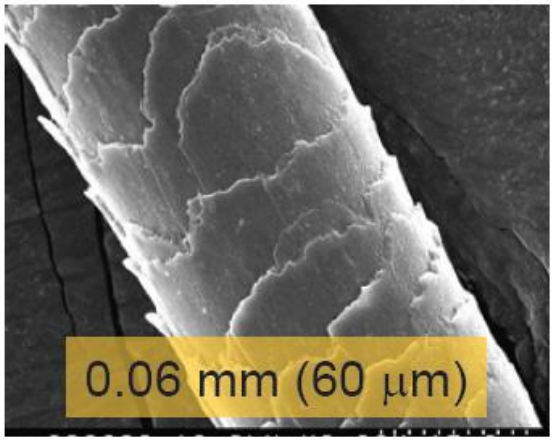
1.1. Introduction

- Define of Nanotechnology
  - Fabrication and processing technologies for nanomaterials.
- Define of nanomaterials
  - Materials with its size down to where the quantum effects take place, usually sub-nanometer to 100 nm.
- Technologies to fabricate nanomaterials:
  - Nanoparticles
  - Nanorods or nanowires
  - Thin Films
  - Bulk materials

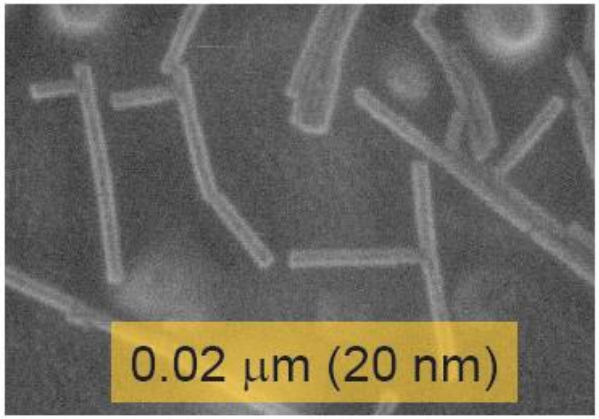
1.1. Introduction

How small is NANO?

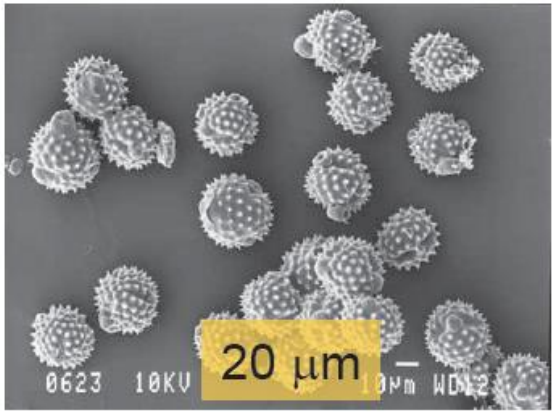
human hair



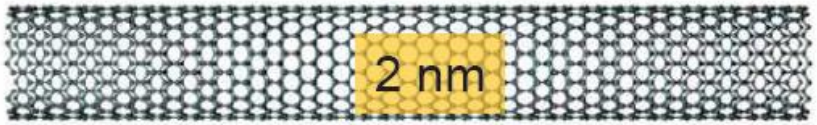
virus



pollen grain



carbon nanotube



1.1. Introduction

- One nanometer = 1 nm = 10^{-9} m
- Nanomaterials could be metals, ceramics, and polymers.
- Types of nanomaterials :
  - 0-D, nanoparticles, quantum dots.
  - 1-D, nanorods, nanowires, quantum wire.
  - 2-D, thin films, quantum well.

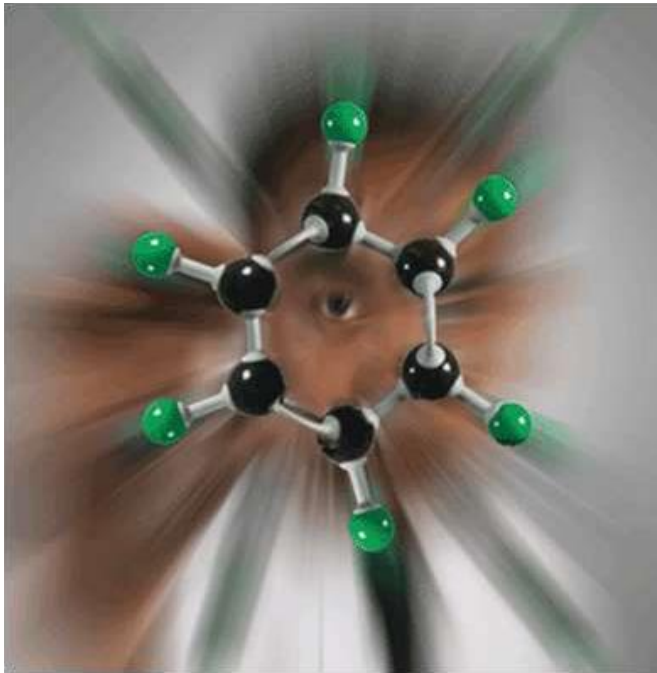
Q1: What is nanomaterials ?

What Is Nanotechnology

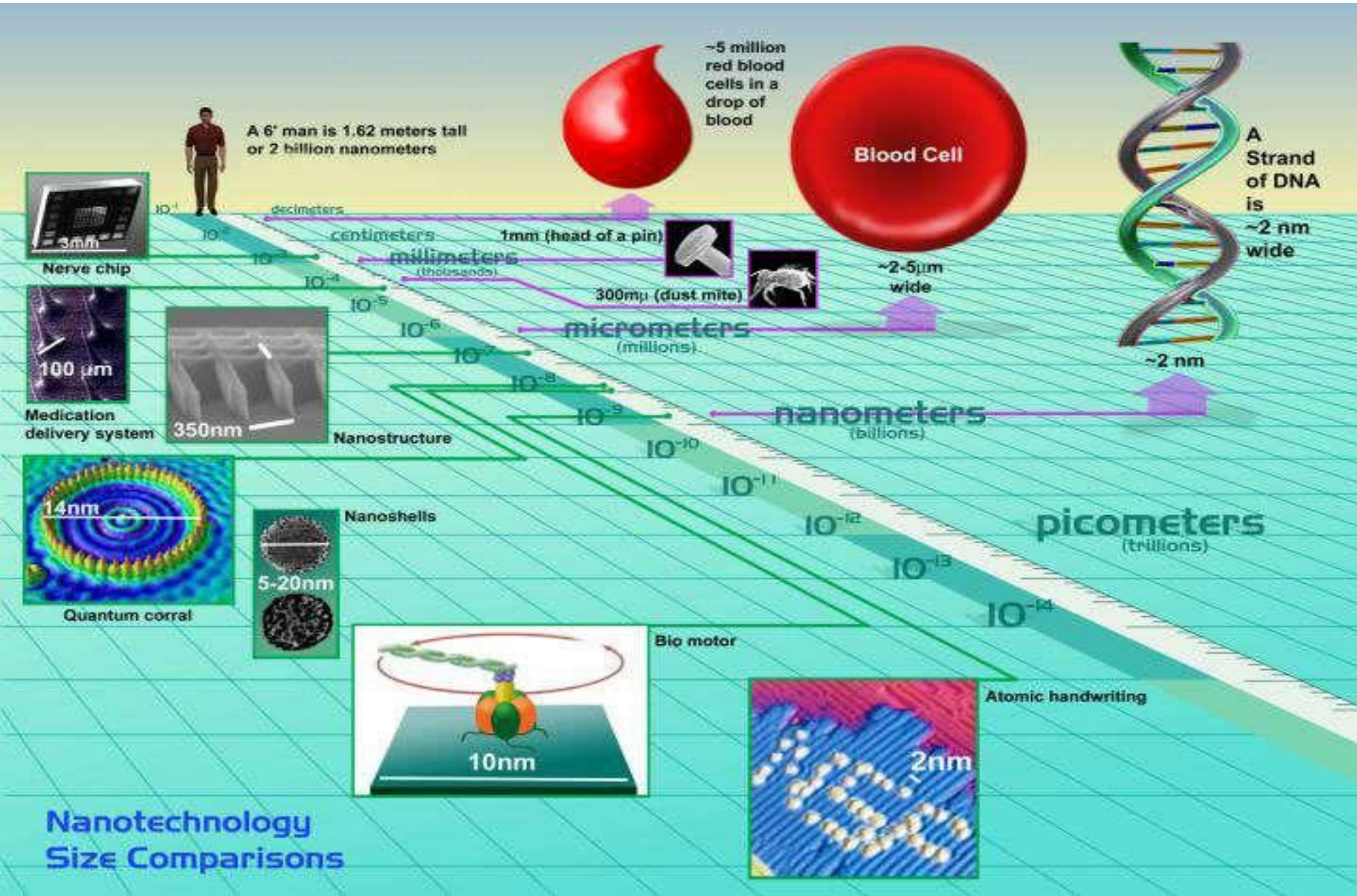
“Nanotechnology is the art and science of manipulating matter at the nanoscale”

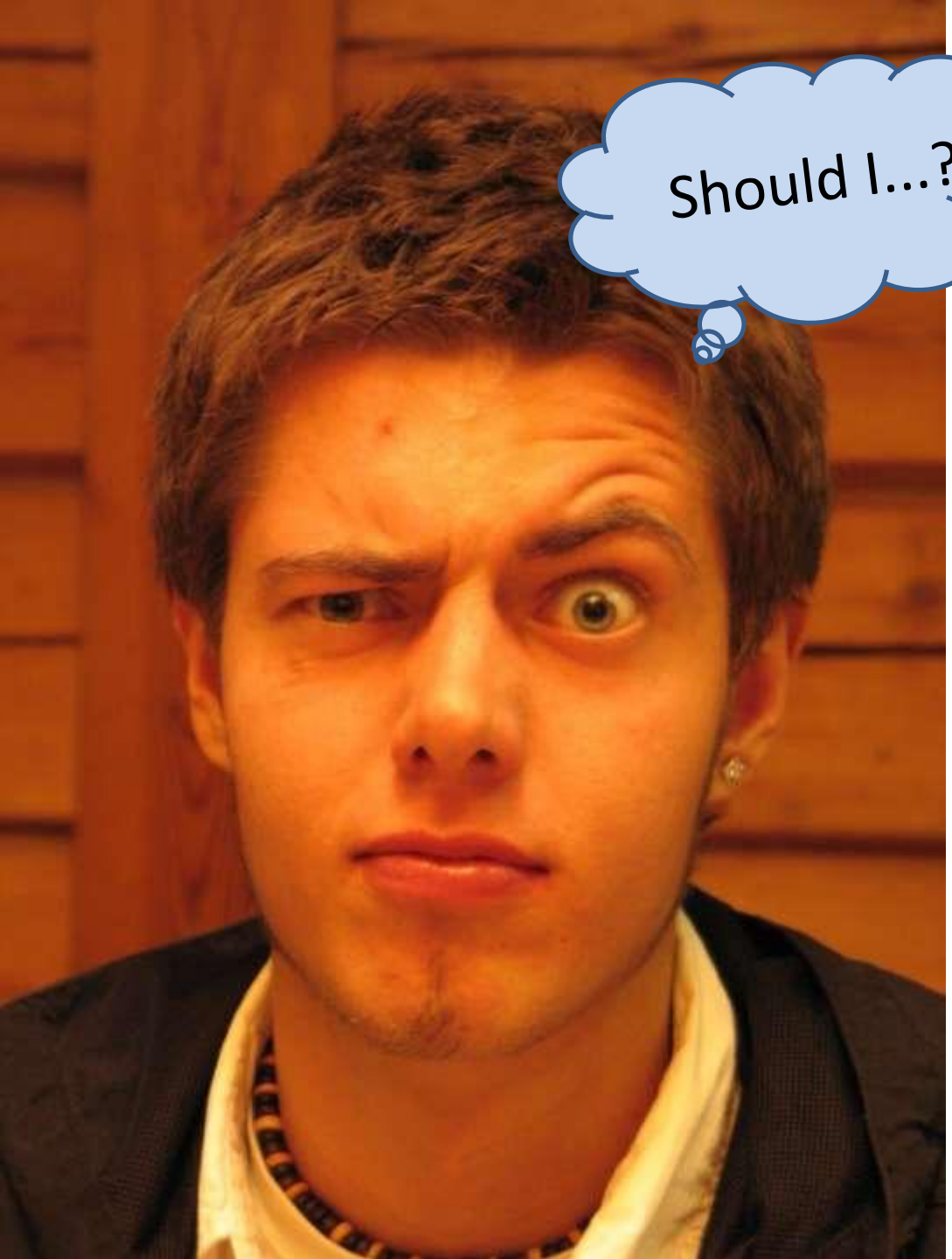
The term "nanotechnology" was defined by Tokyo University of Science Professor Norio Taniguchi in a 1974 paper as follows:

> "'*Nano-technology' mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule*."



How Small Is Nanoscale

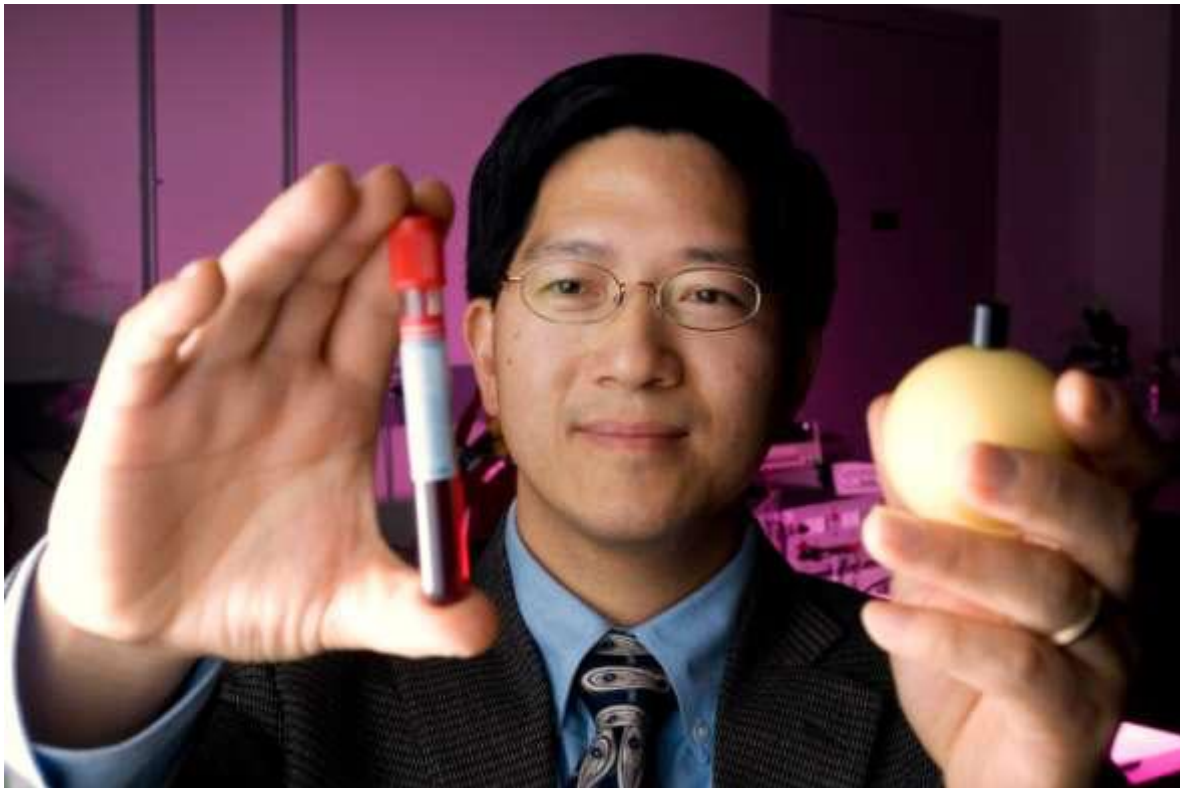

A 6' man is 1.62 meters tall or 2 billion nanometers
~5 million red blood cells in a drop of blood
Blood Cell
A Strand of DNA is ~2 nm wide
3mm
Nerve chip
decimeters
centimeters
millimeters
(thousands)
1mm (head of a pin)
300mμ (dust mite)
~2-5μm wide
micrometers
(millions)
~2 nm
100 μm
Medication delivery system
350nm
Nanostructure
nanometers
(billions)
14nm
Quantum corral
Nanoshells
5-20nm
picometers
(trillions)
Bio motor
10nm
Atomic handwriting
2nm
Nanotechnology
Size Comparisons

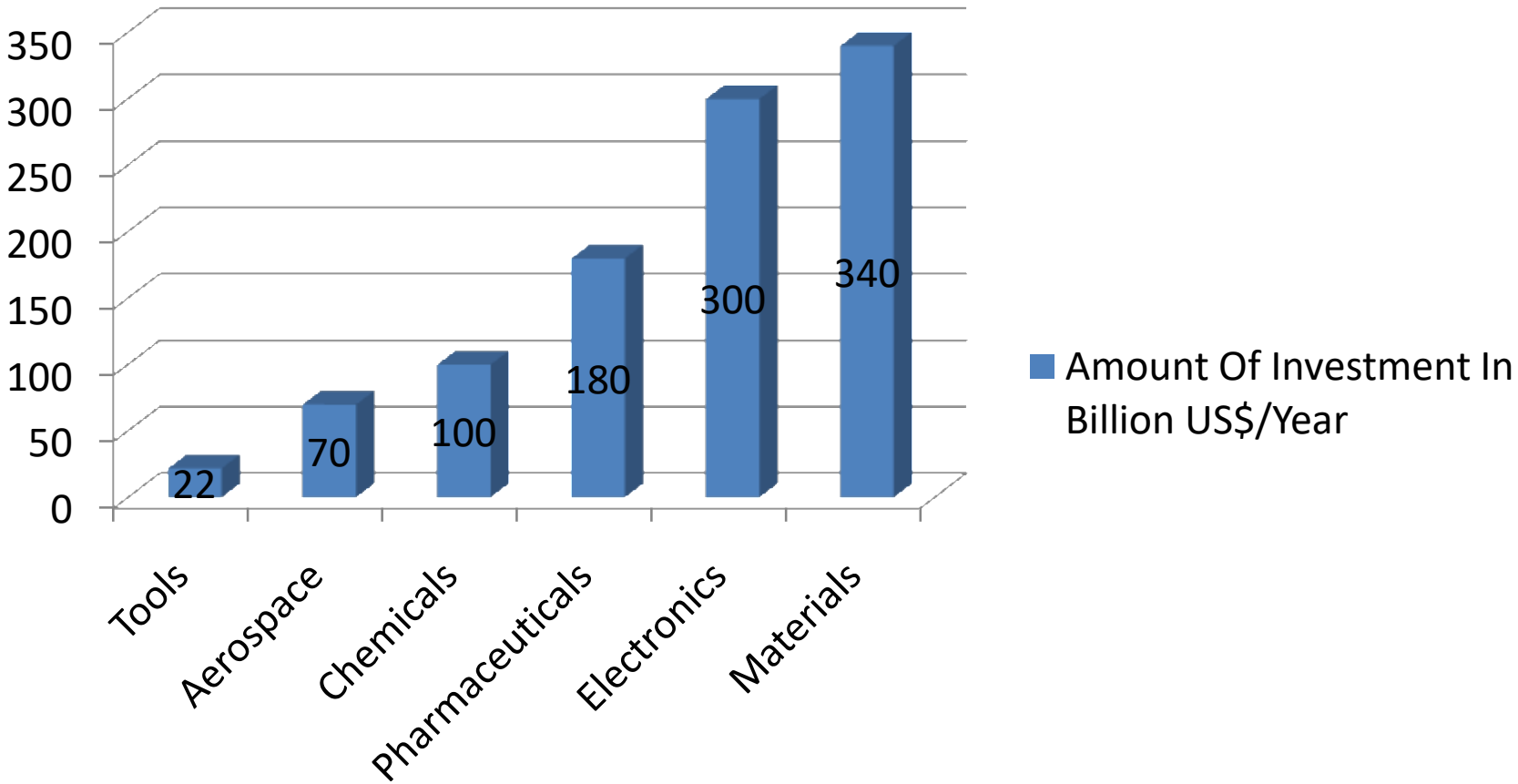


Who Cares About Nanotechnology

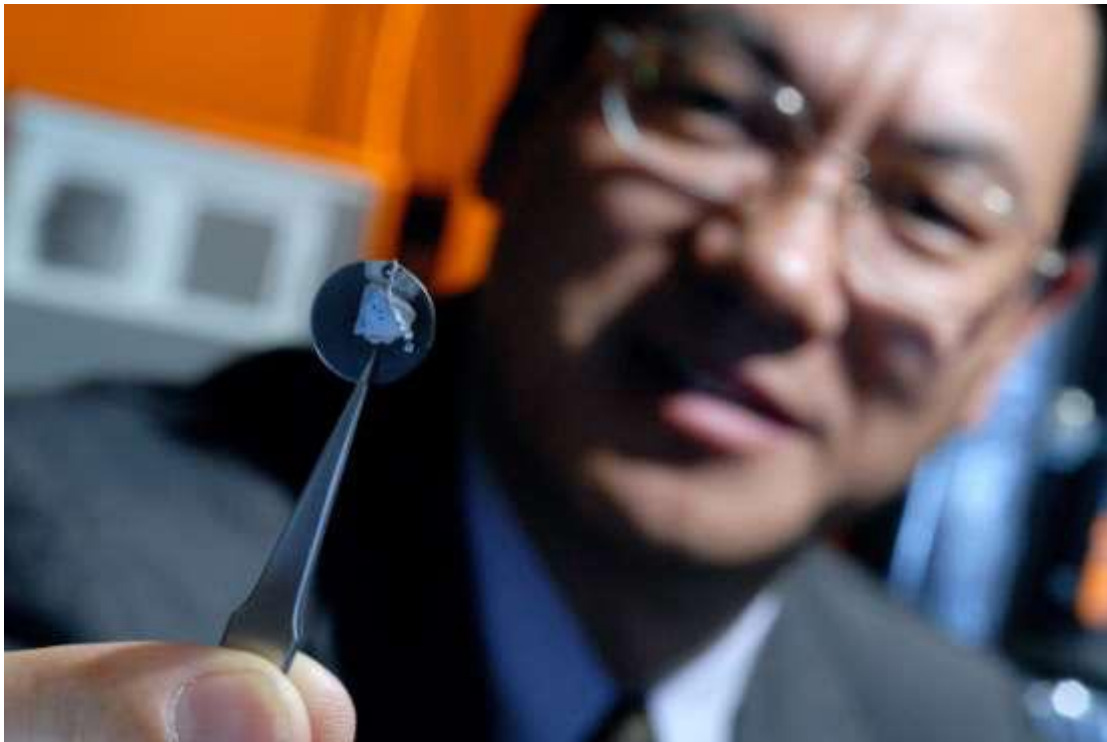
We All Should Care!

- Because it can bring revolution in the current industrialization and manufacturing processes.



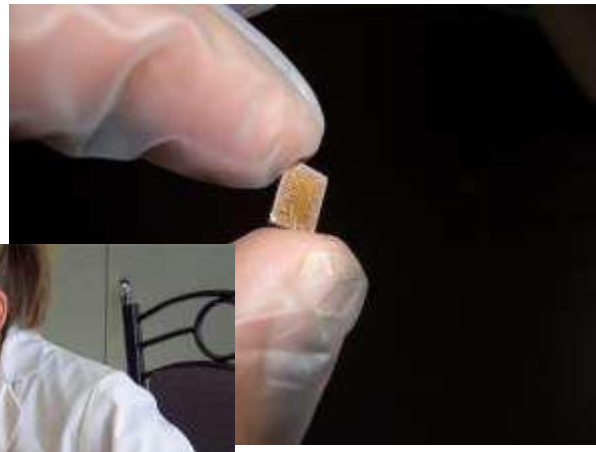

350
300
250
200
150
100
50
0
22
70
100
180
300
340
Tools
Aerospace
Chemicals
Pharmaceuticals
Electronics
Materials
Amount Of Investment In Billion US$/Year

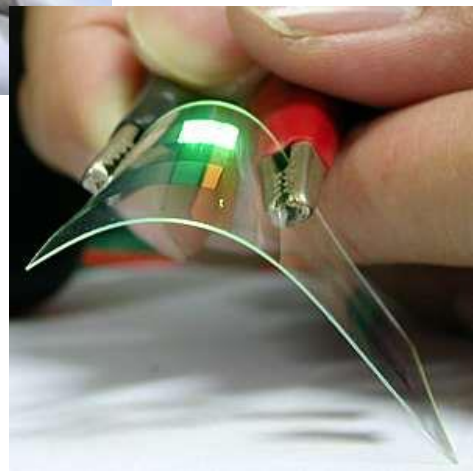
Applications Of Nanotechnology



Applications Of Nanotechnology

- **Electronics:**
  - Nano Transistors
  - Nano Diodes
  - OLED (Organic Light Emitting Diode)

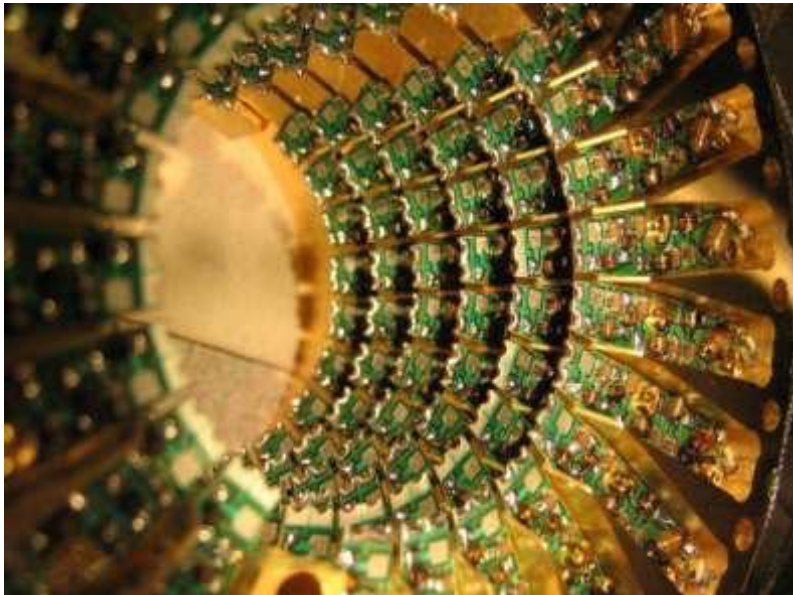




Electronics(contd.)

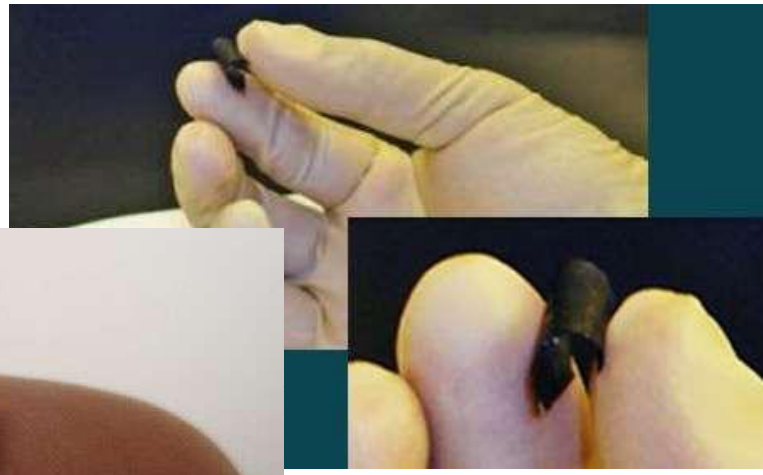
– Plasma Displays

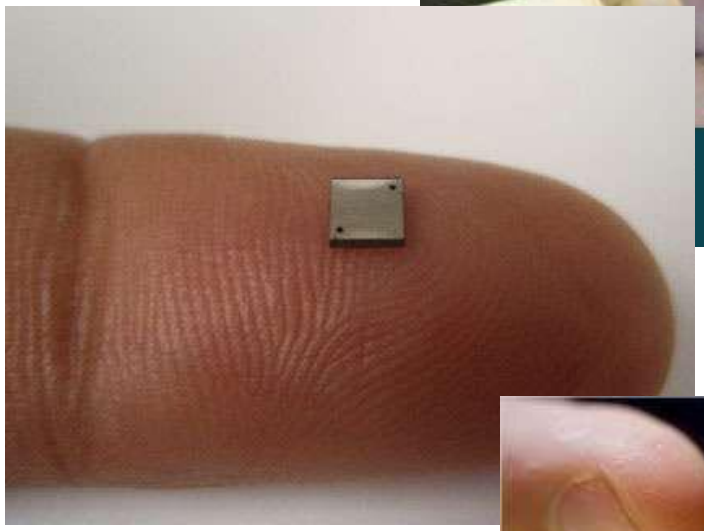
– Quantum Computers



Applications Of Nanotechnology

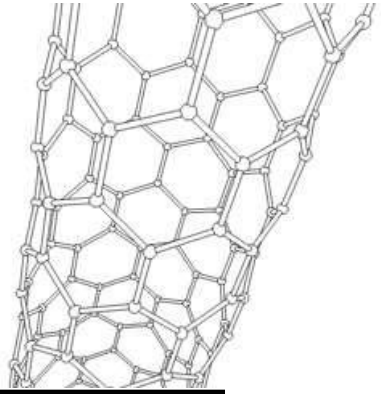
- **Energy:**
  - Batteries
  - Fuel Cells
  - Solar Cells





❑Materials:

– Nano Tubes

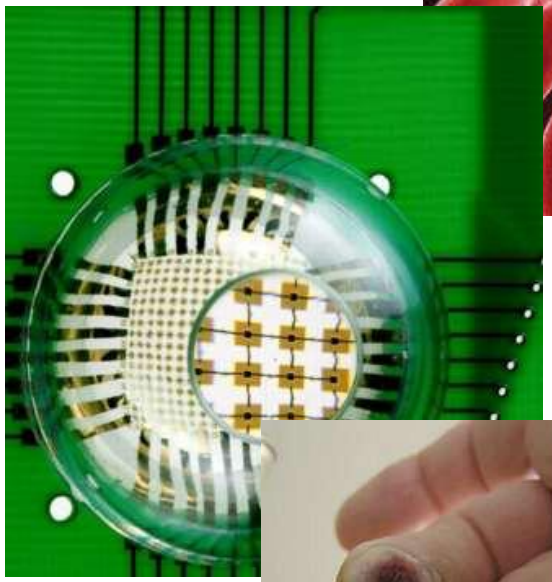


– Aerogel

– Nano Particles

Applications Of Nanotechnology

- **Life Sciences:**
  - Targeted Drug Delivery
  - Artificial Retina
  - Tissue Regeneration



Advantages

Advantages

❑Material

With NT, we can create unique materials and products which are:

- Stronger
- Lighter
- Cheaper
- Durable
- Precise

Advantages

- **Industrial**
  - Computers can become a billion times faster and a million times smaller
  - Automatic Pollution Cleanup
  - Manufacturing at almost no cost

Advantages

❑Medical

- End of Illnesses (i.e. cancer, heart disease)
- Universal Immunity (i.e. aids, flu)
- Body Sculpting
  (i.e. change your appearance)

Disadvantages

- Loss of jobs (in manufacturing, farming, etc)
- Carbon Nanotubes could cause infection of lungs
- Oil & Diamonds could become worthless
- Atomic weapons could be more accessible and destructive

Future of Nanotechnology

Nanotechnology in future everyday life

Nano-particle paint to prevent corrosion

Thermo-chromic glass to regulate the influx of light

Organic Light Emitting Diodes (OLEDs) for displays

Photovoltaic film that converts light into electricity

LEDs are now powerful enough to compete with light bulbs

Scratchproof, coated windowpanes using the lotus effect

Menu card made of electronic cardboard

Nanotubes for new notebook displays

Fabrics coated to resist stains

Piezomats prevent annoying vibrations

Hip joints made from biocompatible materials

The helmet maintains contact with the wearer

Intelligent clothing measures pulse and respiration

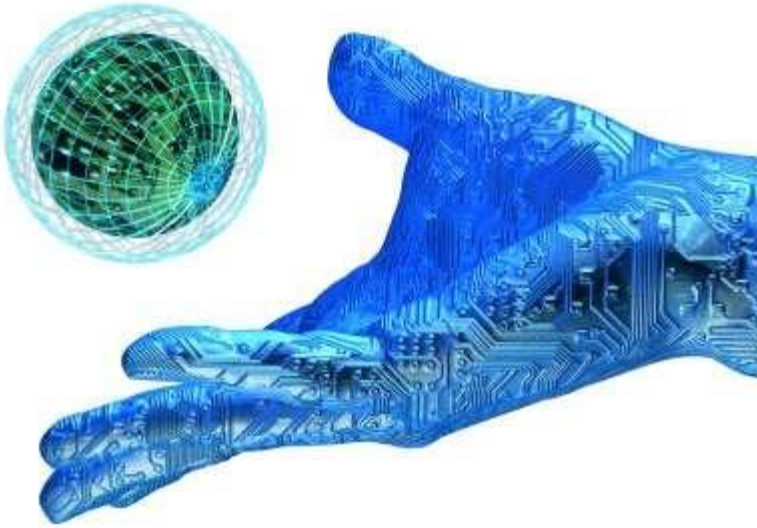
The Bucky-tube frame is as light as a feather, yet strong

Fuel cells provide power for mobile phones and vehicles

Magnetic layers for compact data memory

National Science and Technology Council (USA) claims that:

“Nanotechnology is an enabling technology that will change the nature of almost every human-made object in the next century.”



References

- Morph: Nokia's Nanotechnology Concept Phone

  http://tini.us/morph

- Wikipedia NT Portal

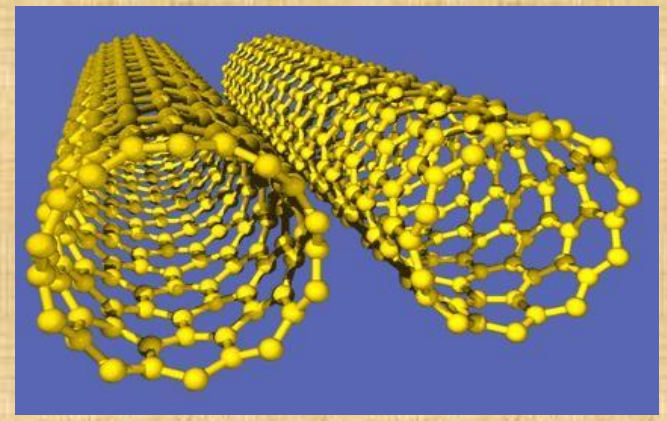
  http://tini.us/nano

- Image Credits

  http://sxc.hu/

HISTORY OF NANO-TECHNOLOGY

- In 1980 researchers reported the discovery of “Bucky Ball” a round molecule of 60 atoms of carbons. This led in turn to the 1991 discovery of a related molecular shape known as “**Carbon Nanotubes**”



Carbon NanoTubes are molecular-scale tubes of graphitic carbon with outstanding properties

- Nanotechnology is ubiquitous and pervasive. It is an emerging field in all areas of science, engineering and technology.
- NanoTechnology is seem to have greatest impact in our daily life. It had improved and helped in many field of science.

By

Abu Bakar Amanullah

FUNDAMENTALS CONCEPTS

- **Larger to smaller**: a materials perspective
  - A number of physical phenomena become pronounced as the size of the system decreases. These include statistical mechanical effects, as well as quantum mechanical effects
- **Simple to complex:** a molecular perspective
  - Modern synthetic chemistry has reached the point where it is possible to prepare small molecules to almost any structure. These methods are used today to manufacture a wide variety of useful chemicals such as pharmaceuticals or commercial polymers.
- **Molecular nanotechnology:** a long-term view
  - Molecular nanotechnology, sometimes called molecular manufacturing, describes engineered nanosystems (nanoscale machines) operating on the molecular scale. Molecular nanotechnology is especially associated with the molecular assembler, a machine that can produce a desired structure or device atom-by-atom using the principles of mechanosynthesis .

By

Abu Bakar Amanullah

TYPES

Nanotechnology is ubiquitous and pervasive. It is and emerging field in all areas of science, engineering and technology. Some are as given.

- Nano-Material.
- Nano-Electronic.
- Nano-Robotics.
- Molecular mechanics
- Nanoengineering
- Nanobiotechnology
- Nanofluidics
- Nanohub
- Nanometrology
- Nanoscale networks

By

Abu Bakar Amanullah

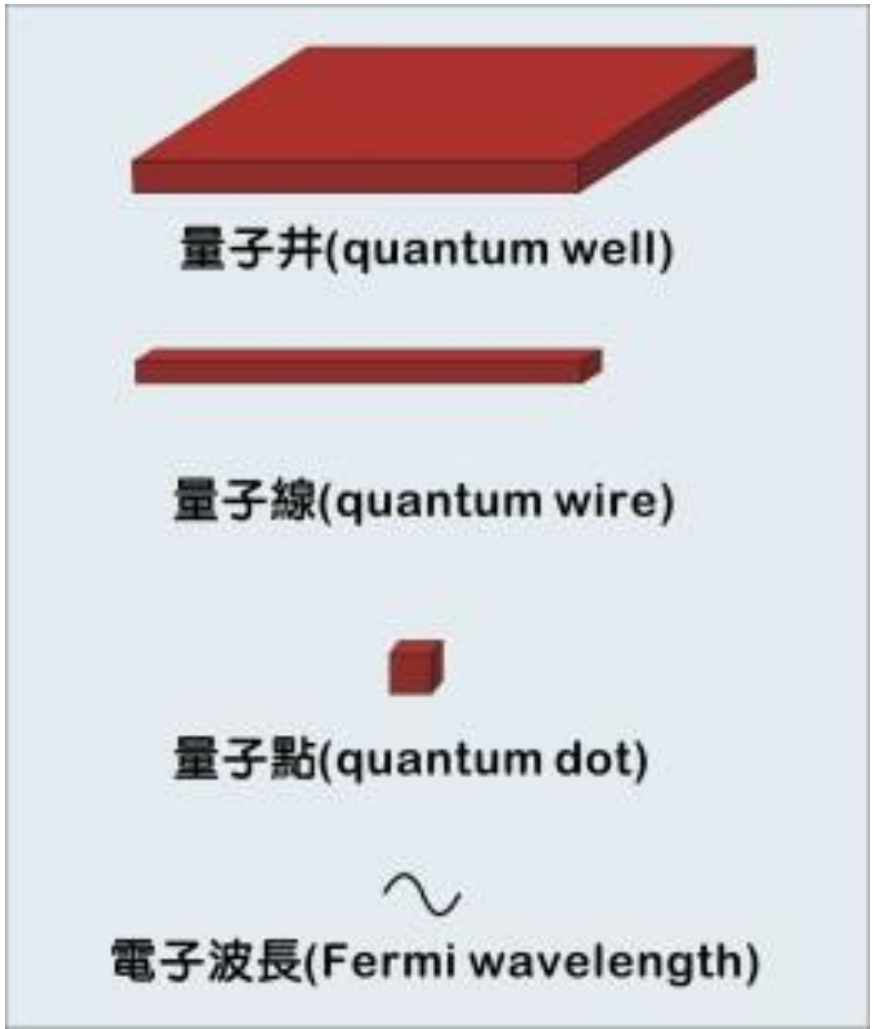
NANO-MATERIALS

- The nanomaterials field includes subfields which develop or study materials having unique properties arising from their nanoscale dimensions.
- Interface and colloid science has given rise to many materials which may be useful in nanotechnology, such as carbon nanotubes and other fullerenes, and various nanoparticles and nanorods. Nanomaterials with fast ion transport are related also to nanoionics and nanoelectronics.
- Nanoscale materials can also be used for bulk applications; most present commercial applications of nanotechnology are of this flavor.
- Progress has been made in using these materials for medical applications; see Nanomedicine.
- Nanoscale materials are sometimes used in solar cells which combats the cost of traditional Silicon solar cells
- Development of applications incorporating semiconductor nanoparticles to be used in the next generation of products, such as display technology, lighting, solar cells and biological imaging; see quantum dots.

By

Abu Bakar Amanullah

Quantum well, quantum wire, and quantum dot
= Thin film, nanowire, nanoparticle



1.2. Emergence of Nanotechnology

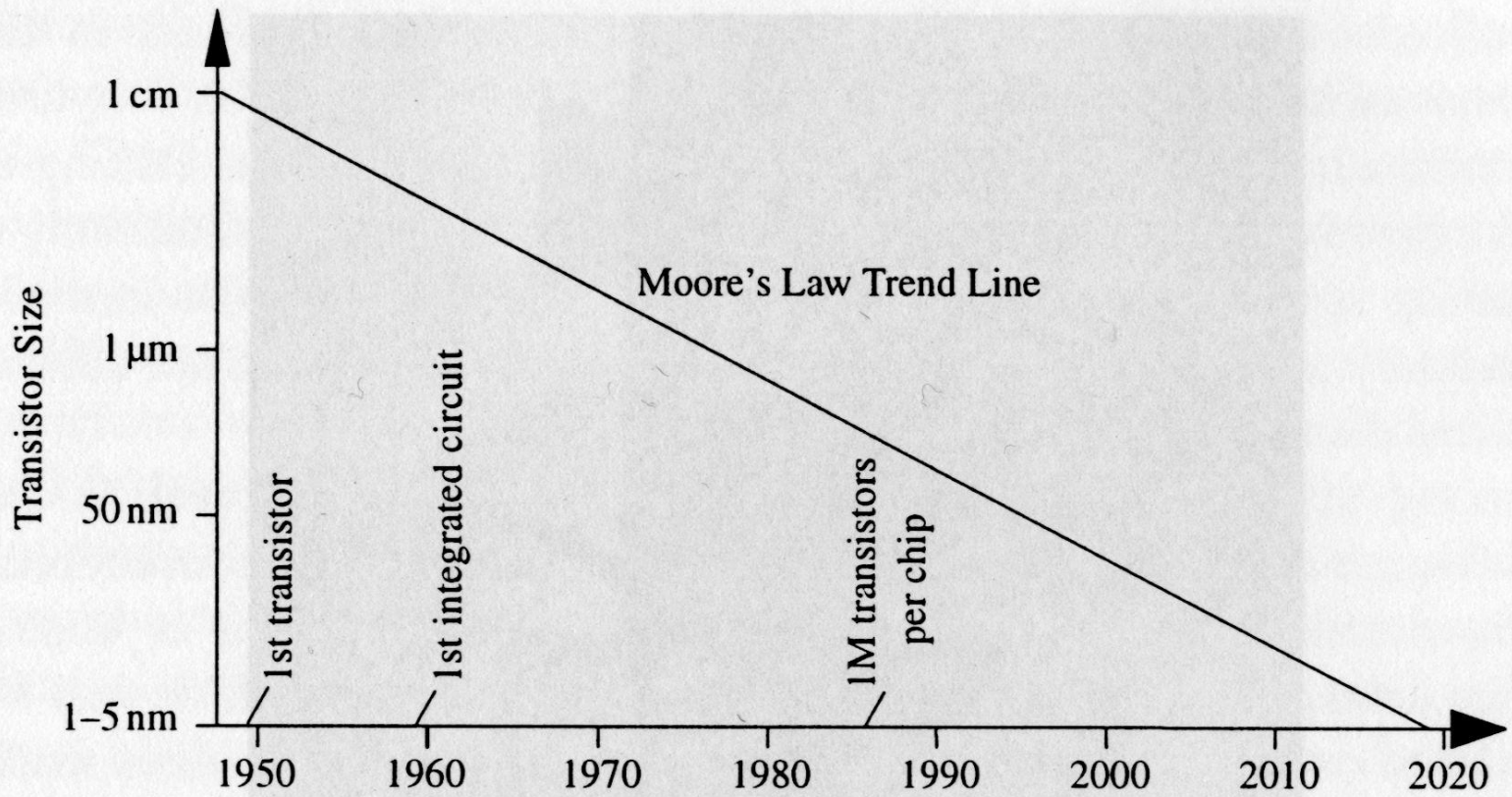


Fig. 1.2. "Moore's Law" plot of transistor size versus year. The trend line illustrates the fact that the transistor size has decreased by a factor of 2 every 18 months since 1950.

Why nanomaterials ?

Nanomaterials exhibits remarkable different characteristics from their bulk form:

- Melting point decreases as size of Au nanoparticles reduce.
- Energy gap of Si nanoparticles is larger than that of bulk Si (1.12 eV).

Melting point of Au nanoparticles

diameter	Tm
bulk	1,064°C
20 nm	～990°C
5 nm	～850°C
4 nm	～750°C
2 nm	～330°C

Eg of Si materials

diameter	Eg
bulk	1.12 eV
10 nm	～1.20 eV
7 nm	～1.29 eV
5 nm	～1.62 eV
3 nm	～2.60 eV

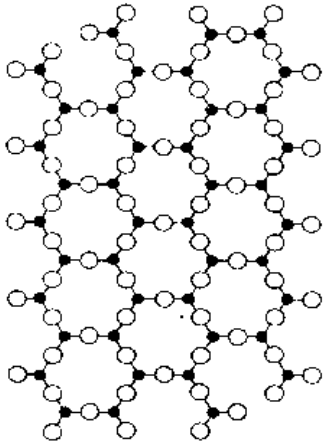
Tools for Characterization

- SEM, FESEM, TEM, HRTEM, AFM
- EDAX, ICP, Mass, XPS…
- FTIR, NMR, Raman,
- XRD, Low-angle XRD
- BET, Particle Size Analyzer
- DTA/TGA, DMA, DSC
- LCR meter, Impedance Analyzer
- Semiconductor parameter analyzers
- Conductivity/Resistivity analyzers
- Vibrating Sample Magnetometer

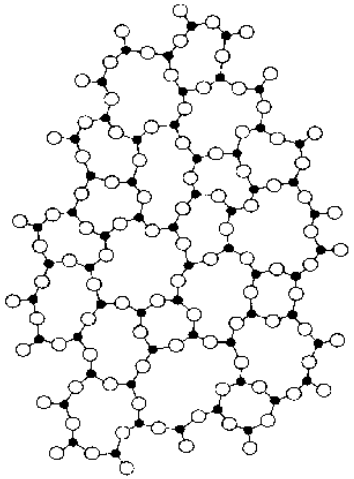
Q 2 : If we measure the size of nano-meter ceramic powder ?

Crystalline vs Amorphous Solids

- Ceramics : Crystalline solids,
  - Long-range order + short-range order



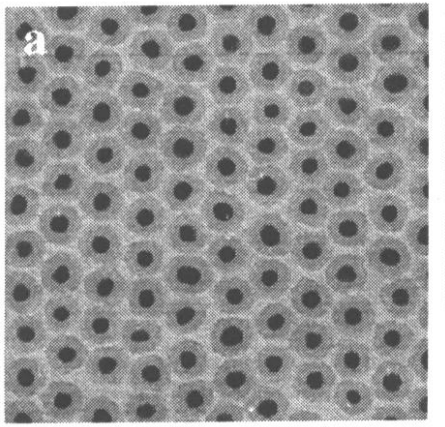
- Glass : Non-crystalline solids,
  - only short-range order no long-range order
  - Amorphous solids

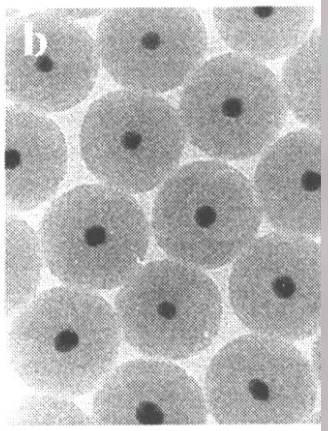


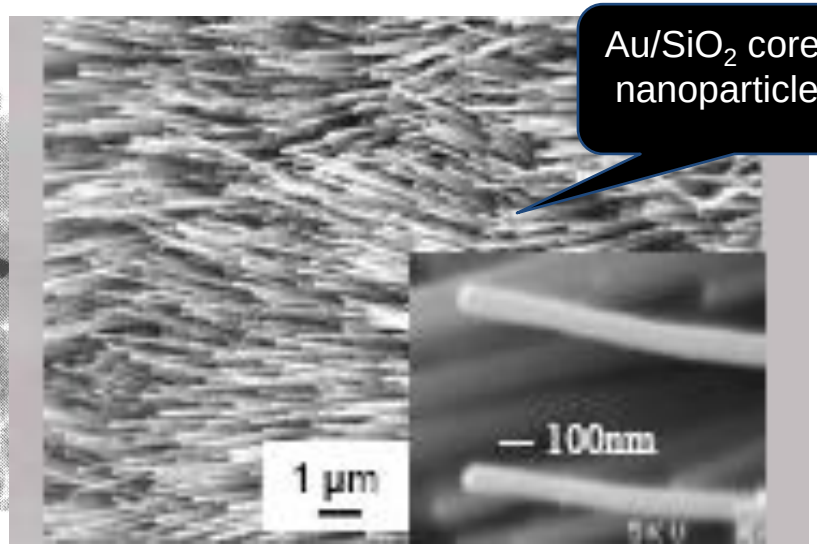
Process for Nanomaterials

- Nanoparticles :
  - colloidal processing,
  - flame combustion,
  - phase segregation.
- Nanorods or nanowires :
  - template-based electroplating,
  - Vapor-liquid-solid growth (VLS),
  - spontaneous anisotropic growth.
- Thin films :
  - molecular beam epitaxy (MBE)
  - atomic layer deposition (ALD)
- Nanostructured bulk materials : self-assembly of nanosized particles for photonic band gap crystals.

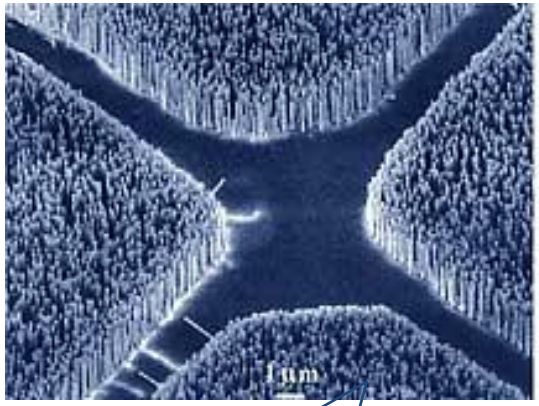
Selected Microstructures of Nanomaterials

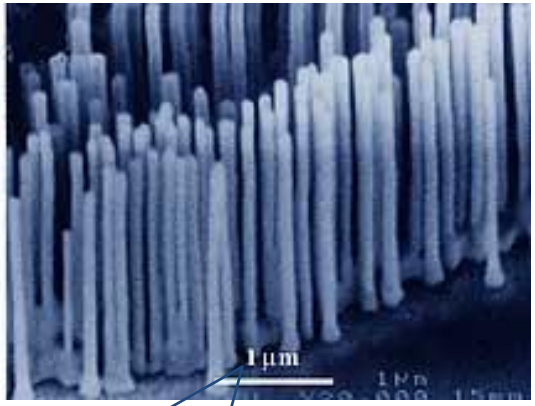






Au/SiO_2 core-shell nanoparticles



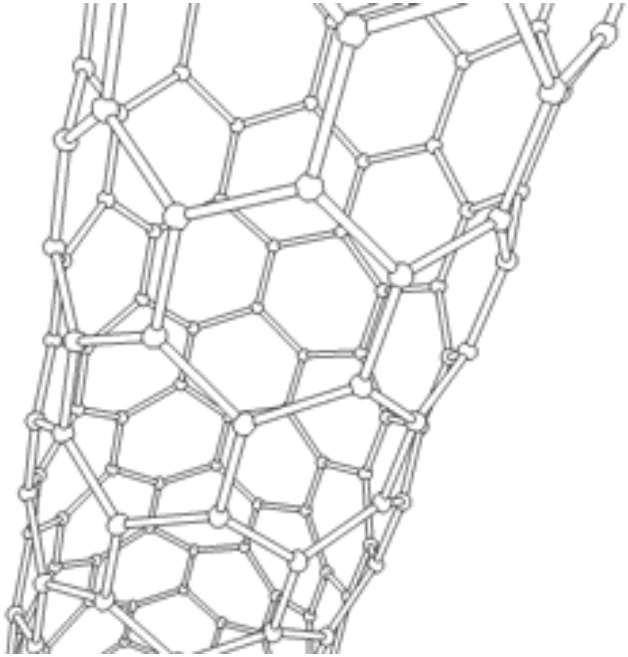


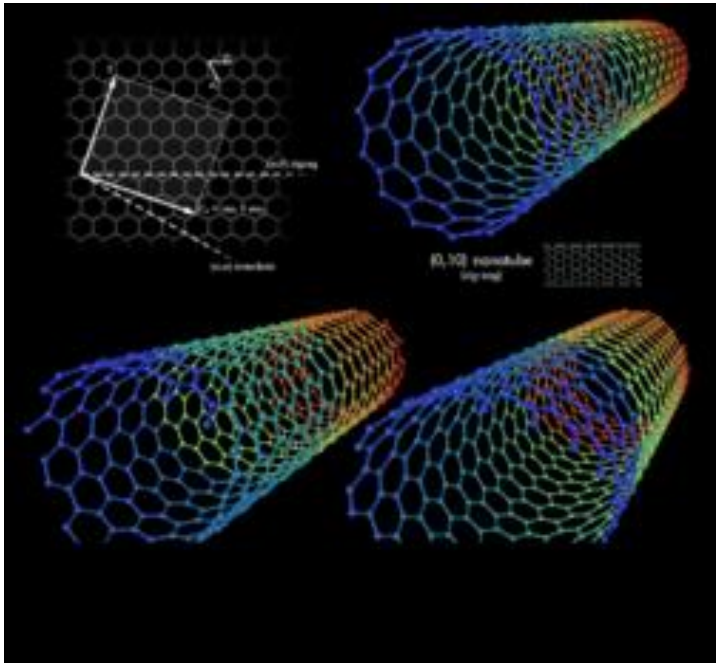
ZnO nanorods

TiO_2 nanowires

Carbon Nanotubes

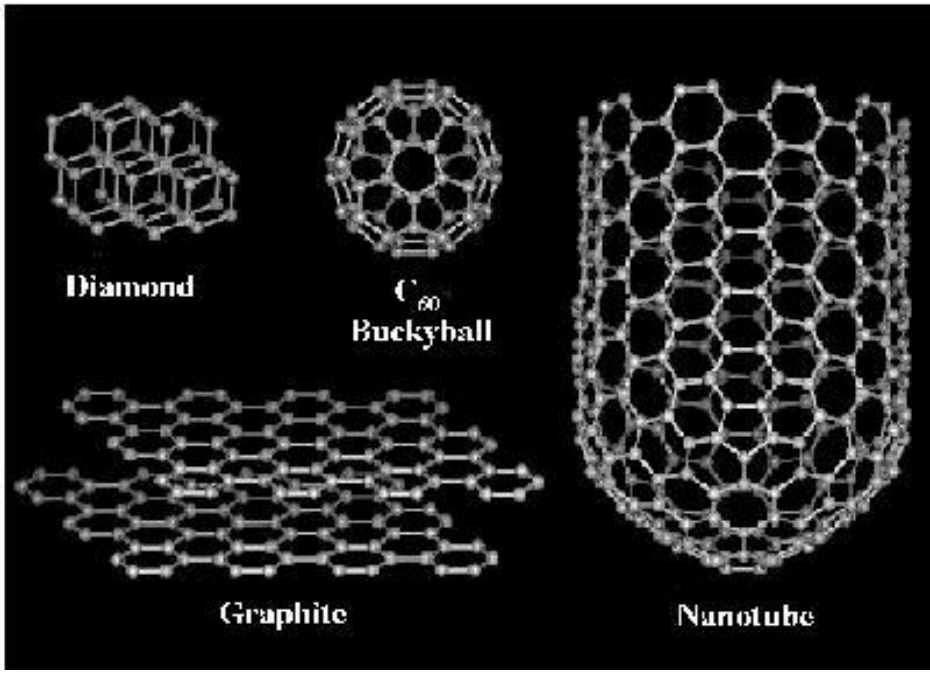
- Consist of sheets of graphite which roll up to form cylinders.
- Initially multilayered (mulit-walled nanotubes, MWNTs) and now can be single walled (SWNTs).





Carbon Nanotubes

- Single-wall carbon nanotubes are a new form of carbon made by rolling up a single graphite sheet to a narrow but long tube closed at both sides by fullerene-like end caps.
- through intentional alteration of their physical and chemical properties fullerenes exhibit an extremely wide range of interesting and potentially useful properties.



Properties of Carbon Nanotubes

- Metallic conductivity (e.g. the salts A_3C_{60} (A=alkali metals))
- Superconductivity with T_c's of up to 33K (e.g. the salts A_3C_{60} (A=alkali metals))
- Ferromagnetism (in (TDAE)C_{60} - without the presence of d-electrons)
  - TDAE is tetrakis(dimethylamino)ethylene
- Non-linear optical activity
- Polymerization to form a variety of 1-, 2-, and 3D polymer structures

Properties of Carbon Nanotubes

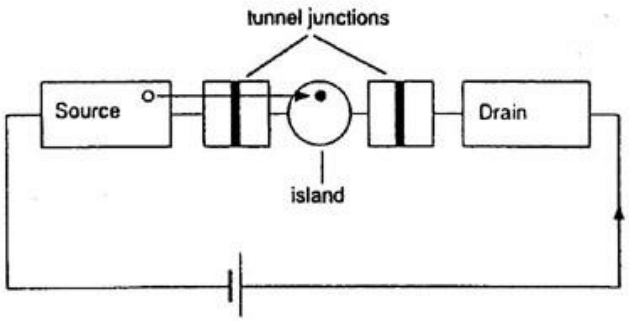
- SWNTs have diameters of about 1nm, and lengths of 1 μm.
- Absorb 100 times their volume of hydrogen and could be developed as a safe storage medium for hydrogen for fuel cells.
- Remarkable tensile strength, 100 times greater than steel.
- Very light, with half the density of Al.
- Can be conductors or semiconductors

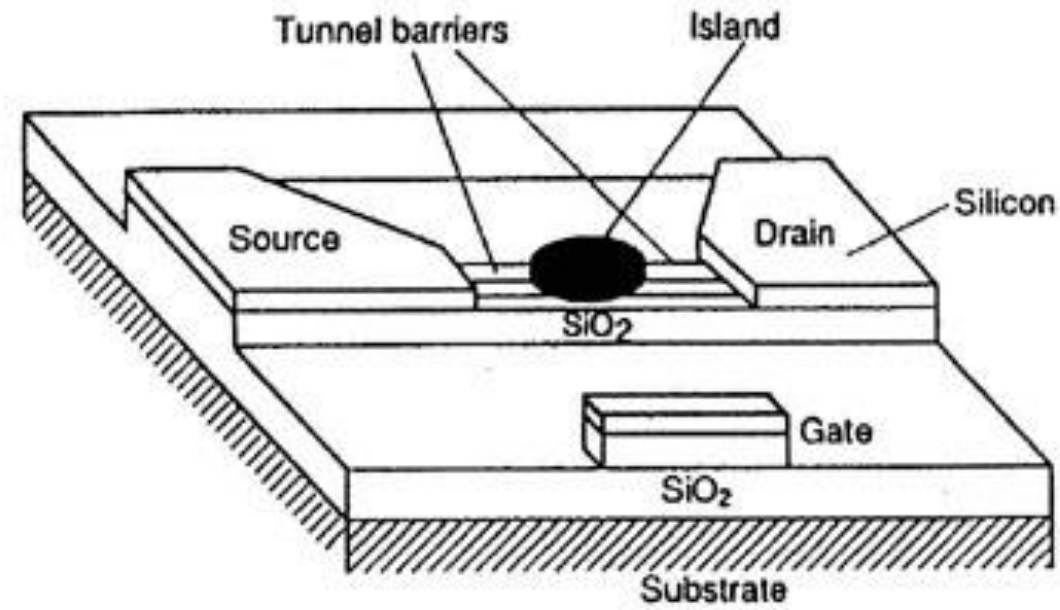
Applications of nanoparticles (quantum dots)

- Blue light laser
- Light sensor device
- Single electron transistor SET
- Memory storage
- Catalyst
- Quantum computing
- Nanosized barcode (奈米條碼)
- Nanosized colored labels (量子點螢光標籤)
    - **Observation of protein reaction and activity.**
    - **Detection cancer at early stage.**
- Localized virus via magnetic nanoparticles.

SET, single electron transistor

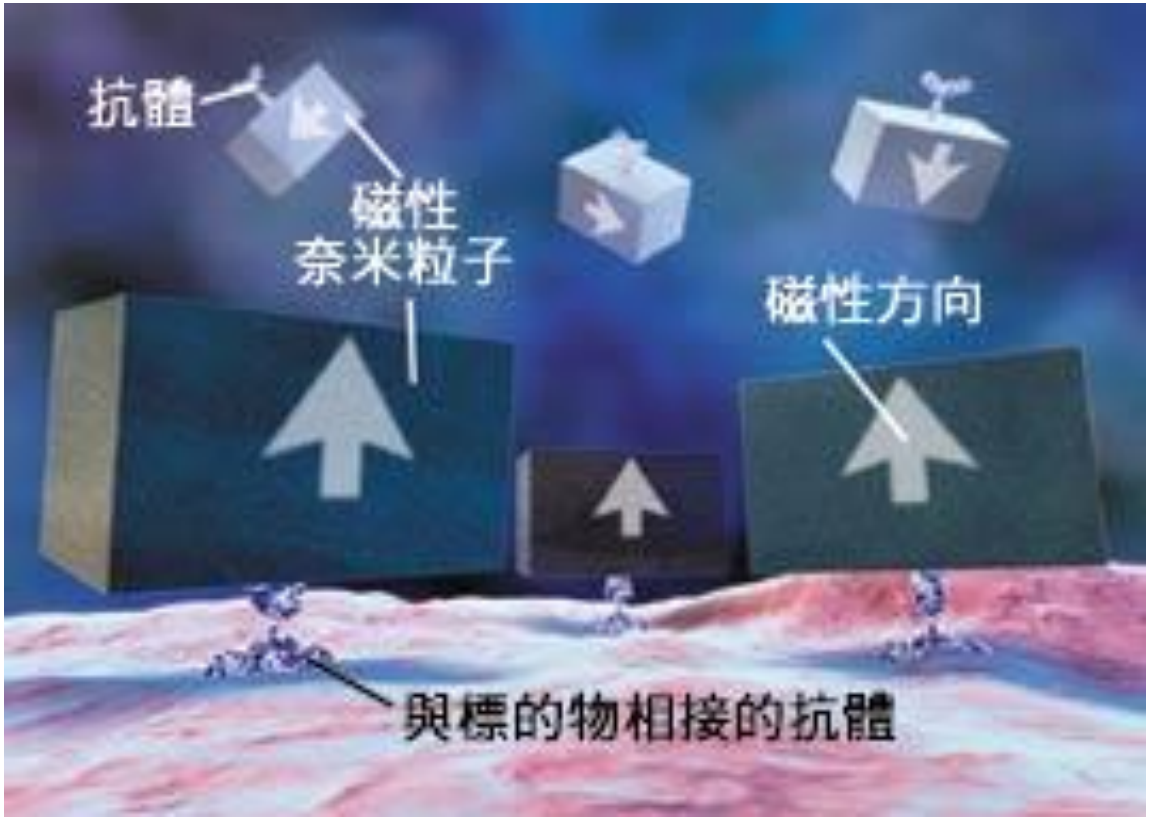
- The difference between SET and traditional transistor is that SET control the motion of single electron, while traditional transistor control the motion of electron current.





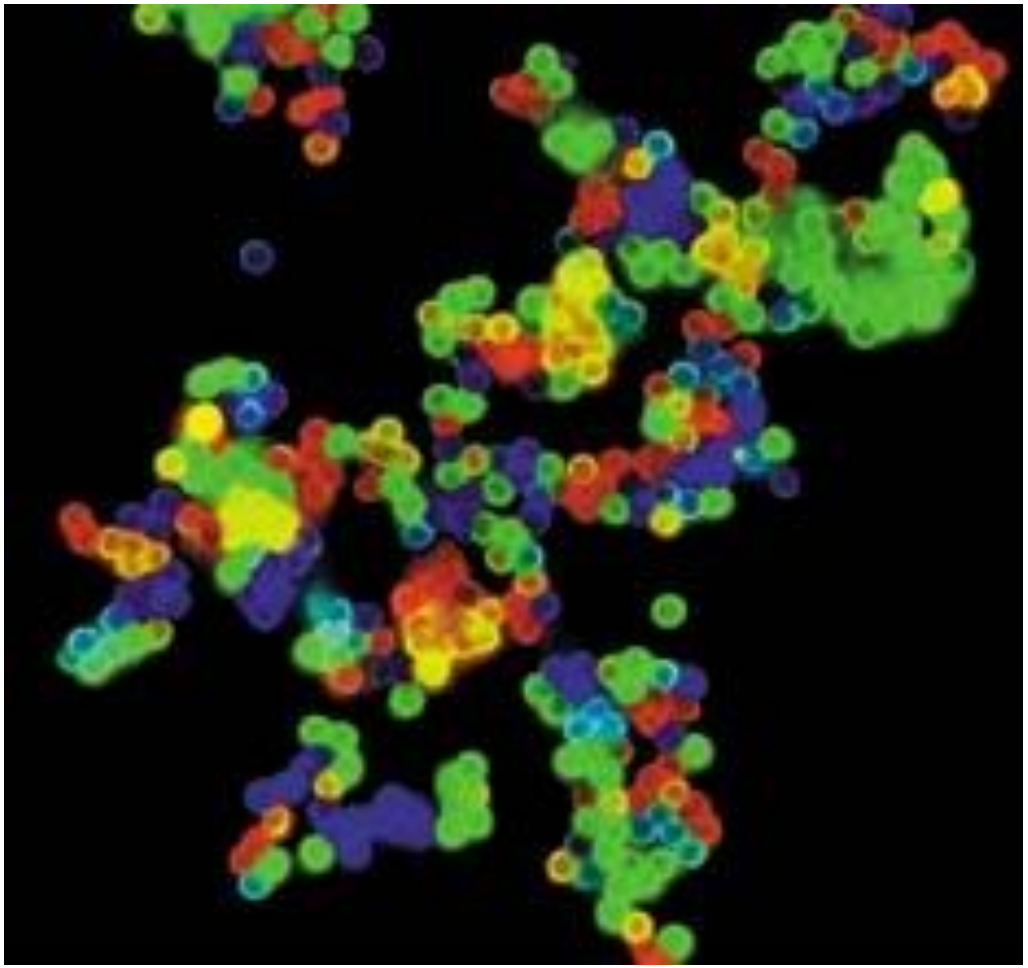
Detecting Virus using magnetic nanoparticles

- magnetic resonance imaging, MRI,
- nuclear magnetic resonance, NMR



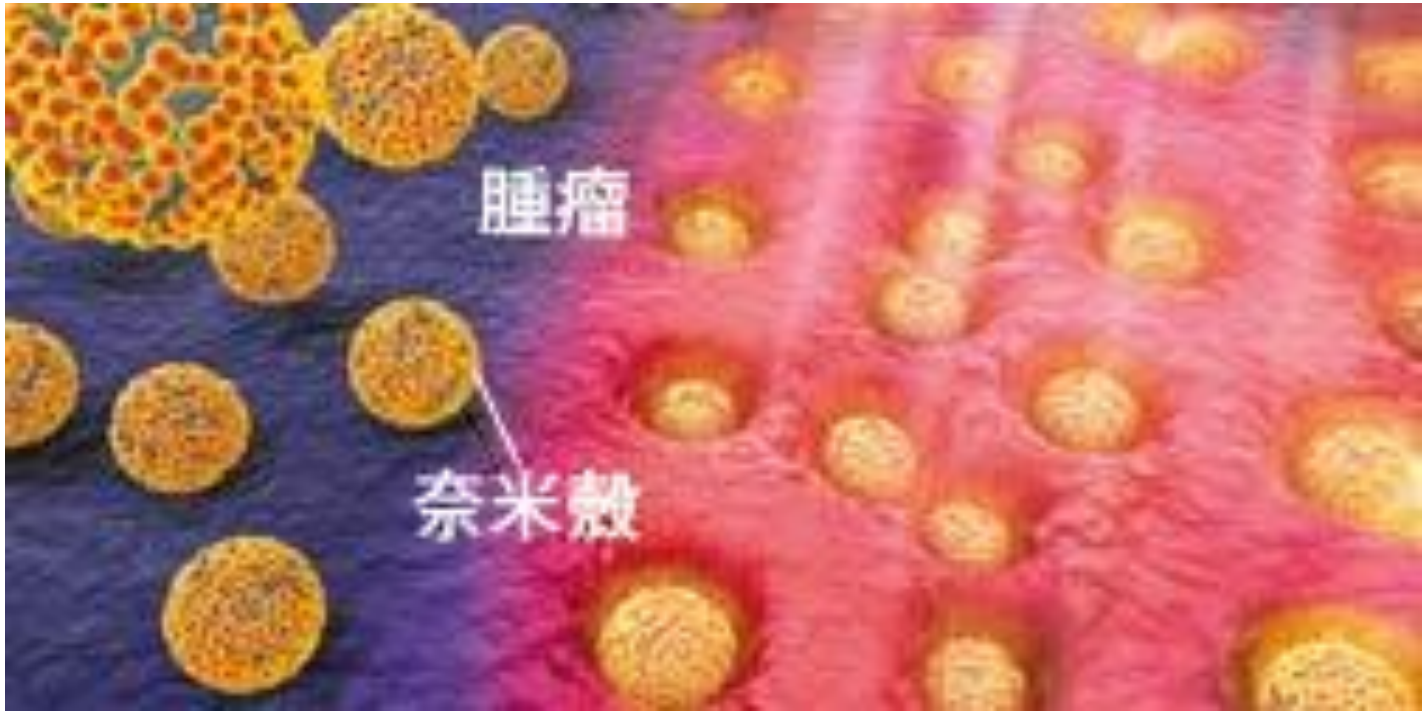
Quantum Dots for bio-labeling

- Inorganic QDs do not fade away as organic dye.
- Very important for observation of protein position. (cystic fibrosis, Alzheimer‘s disease)



Quantum Dots for drug delivery

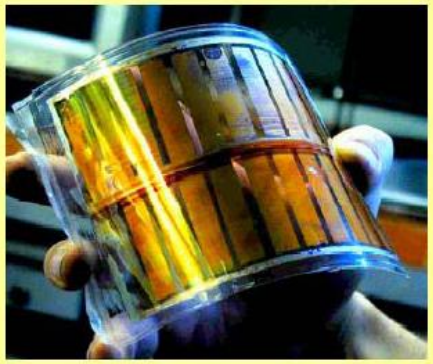
- Hollow spheres can be delivered to cancer location and proceed its specific therapy.



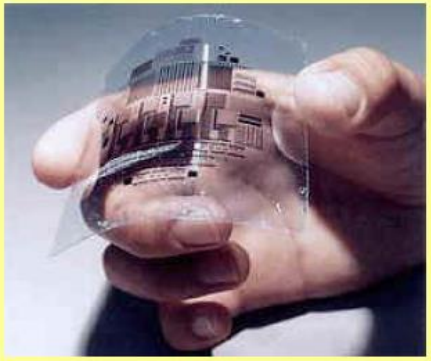
Organic LEDs

- Organic Semiconductors
  - Large area & flexible substrates possible
  - Large variety of materials
  - Low cost

Organic materials



Photovoltaic cells



Integrated circuits

OLED benefits

Thinness

Brightness and colour

Viewing Angle

Source: Kodak

Some OLED products on the market

Passive Matrix

Game-RiTdisplay

Phone-T Pioneer

Sub-display

Phone-T Pioneer

Sub-display

Phone

SNMD

RGB PM

Shaver-Philips

PLED

Car Audio

Car Audio TDK

Phone-RiTdisplay

Phone-T Pioneer

Active Matrix

Sanyo-Kodak

Currently: 98% small molecule OLED

What is possible with OLED: Sony 13” full color display

Nanofabrication techniques

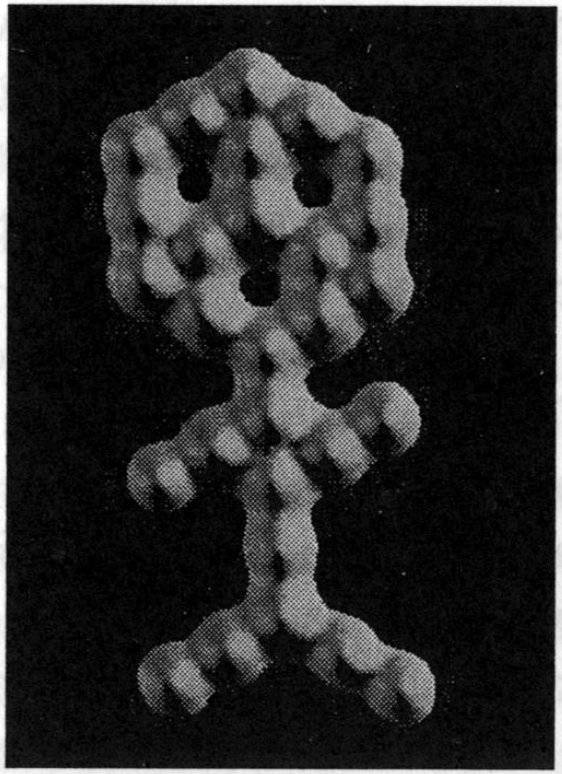


Fig. 1.6. A molecular person consisting of 14 carbon monoxide molecules arranged on a metal surface fabricated and imaged by scanning tunneling microscopy. [P. Zeppenfeld & D.M. Eigler, *New Scientist* **129,** 20 (23 February 1991), and http://www.almaden.ibm.com/vis/stm/atomo.html]

1.4. Challenges in Nanotechnology

- Overcome the huge surface energy, a result of enormous surface area or large surface to volume ratio.
- Ensure all nanomaterials with desired size, uniform size distribution, morphology, crystallinity, chemical composition, and microstructure, that all together result in desired physical properties.
- Prevent nanomaterials and nanostructures from coarsening through either Ostwald ripening or agglomeration as time evolutes.

Summary and Discussion

- Define Nanomaterials ?
- What makes nanomaterials so special ?
- What should we do when Si process hits the physical limit of materials ?
- How many methods to prepare nanomaterials ?
- What tools do you use to characterize nanomaterials ?