Engineering Materials for Electrical Engineers

INGE 3045

Pablo G. Caceres-Valencia

B.S., Ph.D., U.K

GENERAL INFORMATION

Course Number	INGE 3045 (GEEG 3045)
Course Title	Engineering Materials for Electrical Engineers
Credit Hours	3
Instructor	Dr. Pablo G. Caceres
Office	Terrat T-205
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Office Hours	Tuesday and Thursdays from 1:30 to 5:30pm
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Web-site	***http://academic.uprm.edu/pcaceres***

Assessment

The course will be assessed in the following manner:

❑ 1st Partial Exam	22%
❑ 2nd Partial Exam	20%
❑ Final Exam	18%
❑ Quizzes	32% (*)
❑ Class Attendance	8% (**)

(*) Eight quizzes total value of 32%.

(**) After the second missed class, one point will be deducted in the final grade per each missed class (up to 8 points).

Grades

Final Grade Range	Final Letter Grade
100 – 90	A
89 – 80	B
79 – 70	C
69 – 60	D
59 - 0	F

Attendance

Attendance and participation in the lecture **are mandatory** and will be considered in the grading. Students should bring calculators, rulers, pen and pencils to be used during the lectures. Students are expected to keep up with the assigned reading and be prepared to answer questions on these readings during lecture. Please refer to the Bulletin of Information for Undergraduate Studies for the Department and Campus Policies.

Exams

All exams, excepting the final exam, will be conducted during normal lecture periods on dates specified dates. The final exam will be conducted at the time and location scheduled by the University. Neatness and order will be taking into consideration in the final exam marks. Up to ten points can be deducted for the lack of neatness and order. You must bring calculators, class notes and blank pages to the exams.

Texbooks

W. D. Callister, *Materials Science and Engineering: An Introduction* (John Wiley 2003, 6th edition)

Donald R. Askeland and Pradeep P. Hule; *The Science and Engineering of Materials*; (Thomson: Brooks/Cole; 2003, 4th edition)

William F. Smith; *Foundation of Materials Science and Engineering* (McGraw Hill, 2004 3th edition)

My lecture notes are in the web **http://academic.uprm.edu/pcaceres**

TENTATIVES DATES

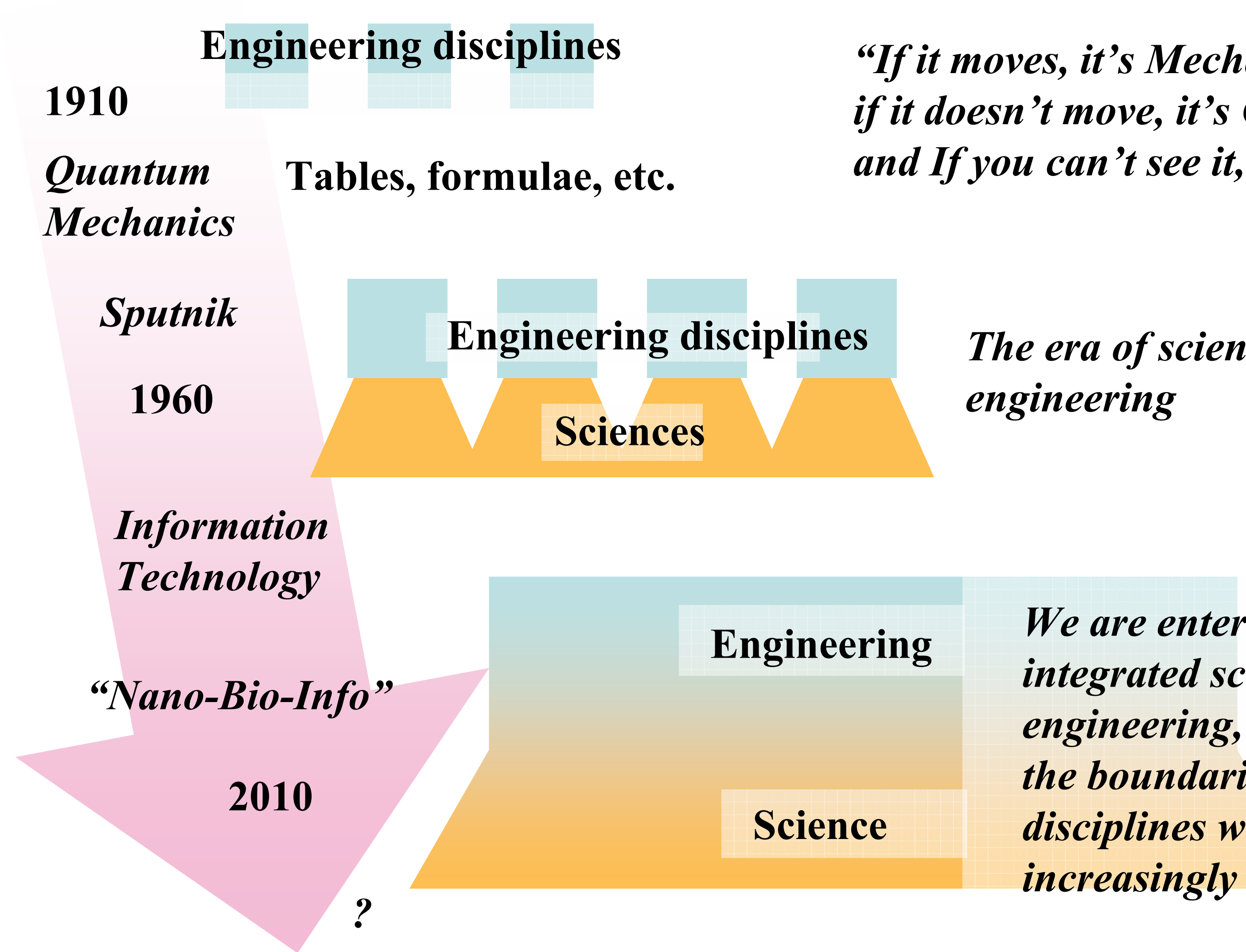
Tuesday	Thursday	Tuesday	Thursday
	01/12 Introduction. Atomic Structure	01/17 Atomic Structure & Bonding	01/19 Atomic Structure & Bonding
01/24 Atomic Structure & Bonding Quiz 1	01/26 Crystal Structure	01/31 Crystal Structure	02/02 Crystal Structure
02/07 Solidification & Defects Quiz 2	02/09 Dislocations & Grain Boundaries	02/14 Dislocations & Grain Boundaries	02/16 Grain Bound., Diffusion.
02/21 NO CLASS	02/23 Grain Bound., Diffusion. Quiz 3	02/28 Exam 1	03/02 Electronic Materials
03/07 Basic Concepts, Band Theory	03/09 Conduction in Bands Quiz 4	03/14 Semicond., Intrinsic, Extrinsic	03/16 Conductivity, Hole Mobility
03/21 Hole Mobility Quiz 5	03/23 Exam 2	03/28 Dielectric Materials, Polarization	03/30 Dielectric Materials, Polarization
04/04 Polarization Quiz 6	04/06 Supercond. Magnetism,	04/11 HOLY WEEK	04/13 HOLY WEEK.
04/18 Magnetism	04/20 NO CLASS	04/26 Magnetism Quiz 7	04/28 Optical Materials
02/05 Optical Materials	04/05 Optical Materials	09/05 Mechanical Properties. Quiz 8	

OUTCOMES

After the completion of the course the students should be able to:

- characterize structure-property-performance relationship
- distinguish the structure of different types of materials
- specify the microstructure of an alloy from phase diagrams
- analyze the mechanical, magnetic, optical and the electrical properties of materials
- select materials for various engineering applications
- establish how failures occur in materials and how to prevent them.

Evolution of Engineering Research & Education



Engineering disciplines

1910

Quantum Mechanics

Tables, formulae, etc.

"If it moves, it's Mechanical,
if it doesn't move, it's Civil,
and If you can't see it, it's Electrical"

Sputnik

Engineering disciplines

1960

Sciences

The era of science-based engineering

Information Technology

Engineering

"Nano-Bio-Info"

2010

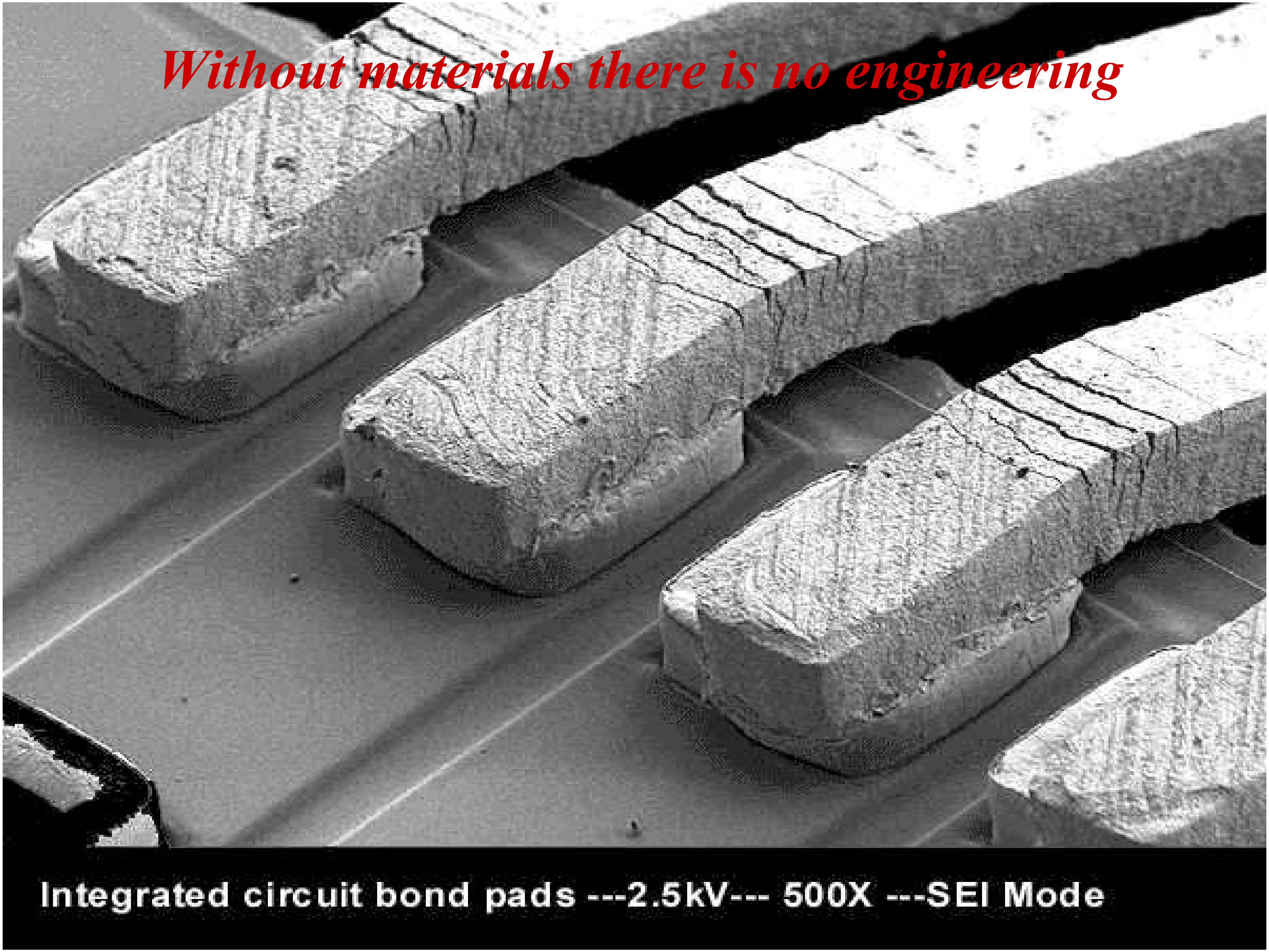
Science

?

We are entering an era of integrated science & engineering, during which the boundaries of the disciplines will grow increasingly indistinct

Taken from Tim Sands, Prof. UC. Berkeley

Without materials there is no engineering



Integrated circuit bond pads ---2.5kV--- 500X ---SEI Mode

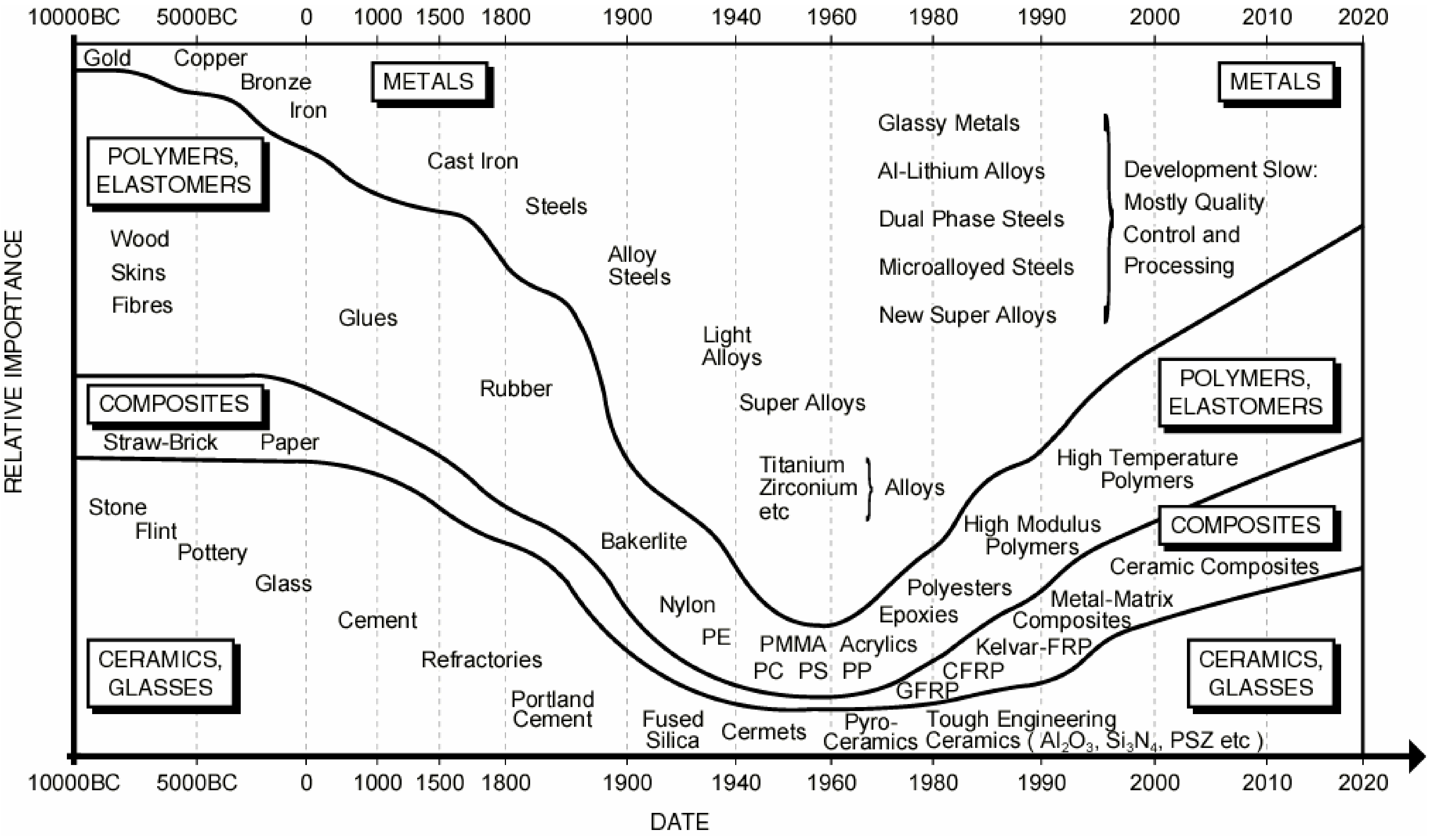
Chapter Outline

- Historical Perspective
  - Stone → Bronze → Iron → Advanced materials
- What is Materials Science and Engineering ?
  - Processing → Structure → Properties → Performance
- Classification of Materials
  - Metals, Ceramics, Polymers, Semiconductors
- Advanced Materials
  - Electronic materials, superconductors, etc.
- Modern Material's Needs, Material of Future
  - Biodegradable materials, Nanomaterials, “Smart” materials

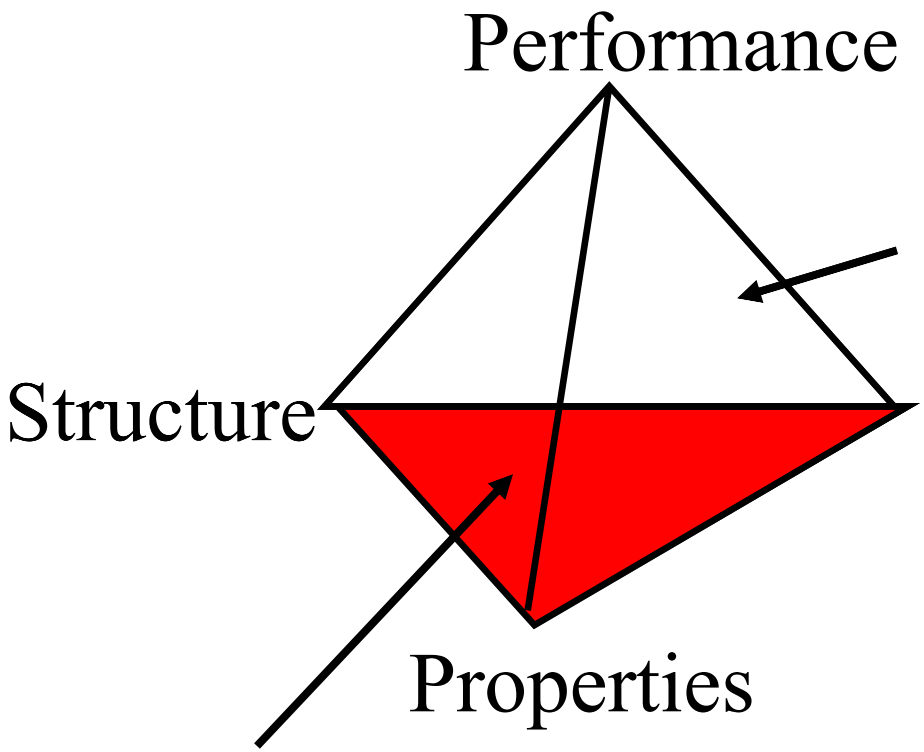
Historical Timeline

- Beginning of the Material Science - People began to make tools from stone – Start of the Stone Age about two million years ago. Natural materials: stone, wood, clay, skins, etc.
- The Stone Age ended about 5000 years ago with introduction of Bronze in the Far East. Bronze is an **alloy** (a metal made up of more than one element), copper + < 25% of tin + other elements. Bronze: can be hammered or cast into a variety of shapes, can be made harder by alloying, corrode only slowly after a surface oxide film forms.
- The Iron Age began about 3000 years ago and continues today. Use of iron and steel, a stronger and cheaper material changed drastically daily life of a common person.
- Age of Advanced materials: throughout the Iron Age many new types of materials have been introduced (ceramic, semiconductors, polymers, composites…). Understanding of the **relationship among structure, properties, processing, and performance of materials**. Intelligent design of new materials.

Evolution of Materials: A better understanding of structure-composition-properties relations has lead to a remarkable progress in properties of materials.



Materials Science & Engineering in a Nutshell



Materials Engineering

Designing the structure to achieve specific properties of materials.

Materials Science

Investigating the relationship between structure and properties of materials.

- Processing
↓
- Structure
↓
- Properties
↓
- Performance

Properties

Properties are the way the material responds to the environment and external forces.

Mechanical properties – response to mechanical forces, strength, etc.

Electrical and magnetic properties - response electrical and magnetic fields, conductivity, etc.

Thermal properties are related to transmission of heat and heat capacity.

Optical properties include to absorption, transmission and scattering of light.

Chemical stability in contact with the environment – corrosion resistance.

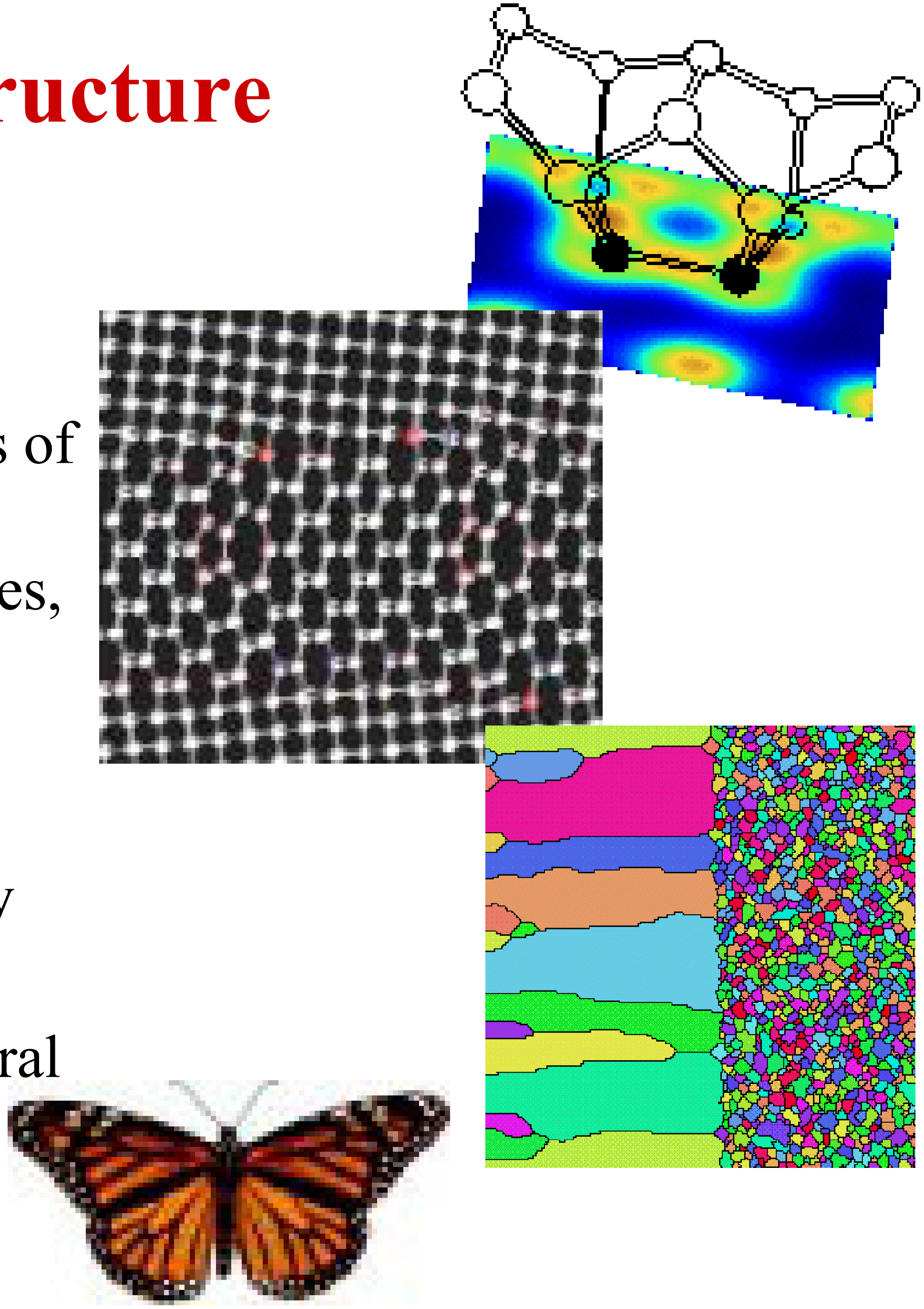
Structure

Subatomic Level: Electronic structure of individual atoms that define interaction among atoms.

Atomic Level: 3-D arrangements of atoms in materials (for the same atoms can have different properties, eg. Diamond and graphite).

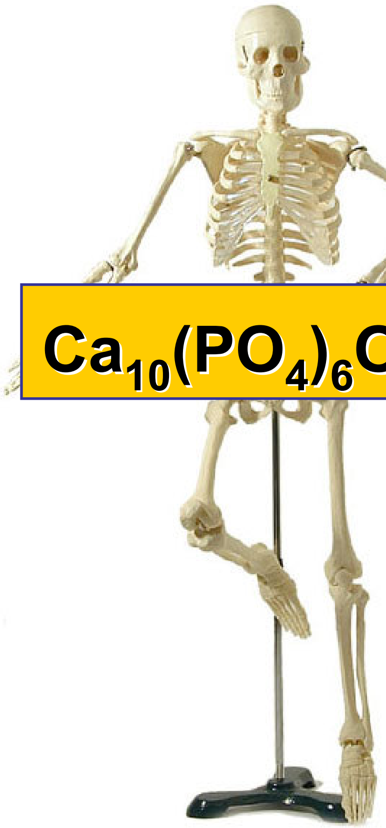
Microscopic Structure: Arrangement of small grains of materials that can be identified by microscopy.

Macroscopic Structure: Structural elements that can be viewed by naked eye.



Solids

we are interested in their mechanical properties…



$Ca_{10}(PO_4)_6OH_2$

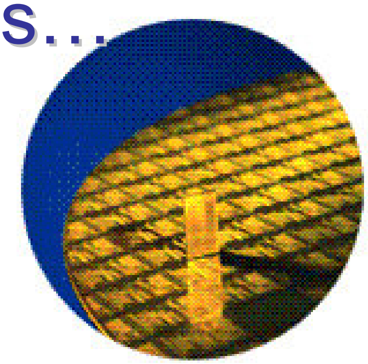
oxide

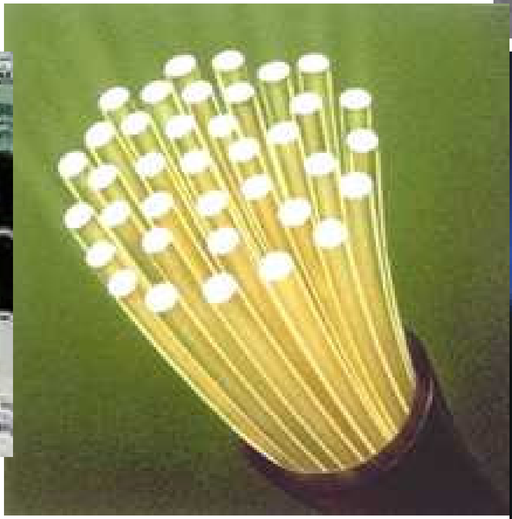
polymer

metal

polymer

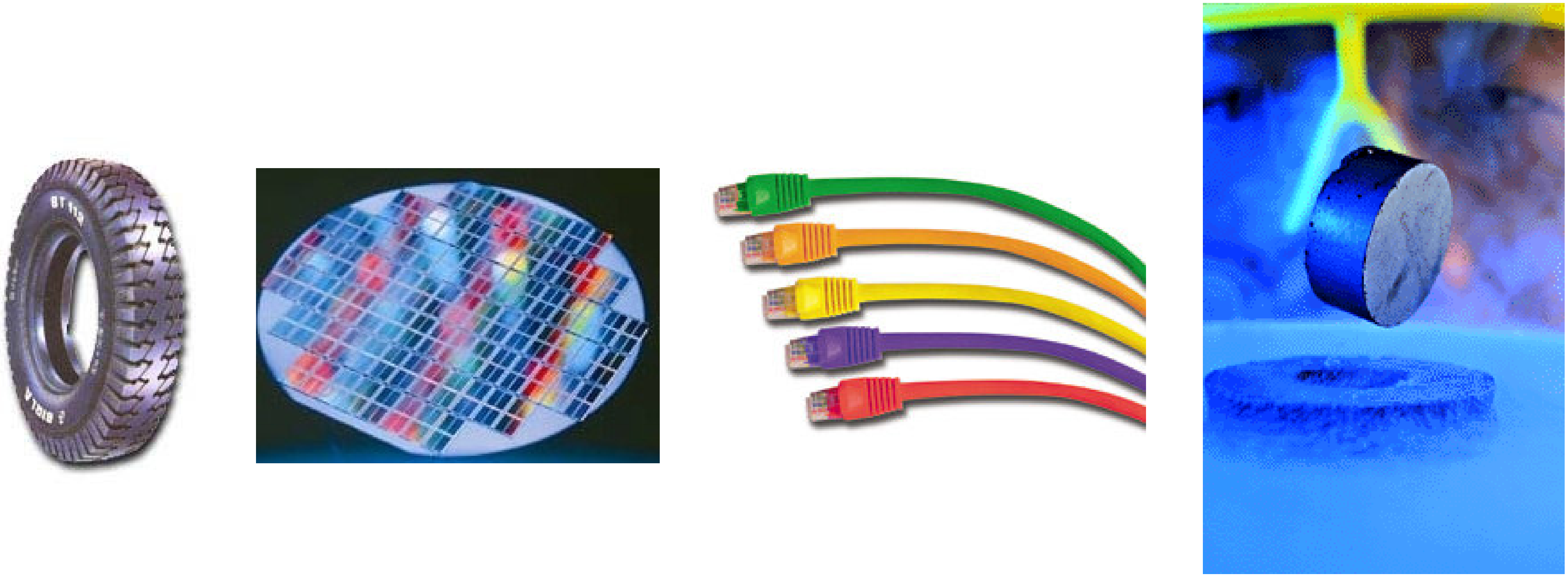
we are interested in their electronic properties…





'Electronic' properties of solids:
….those dominated by the behavior of the electrons

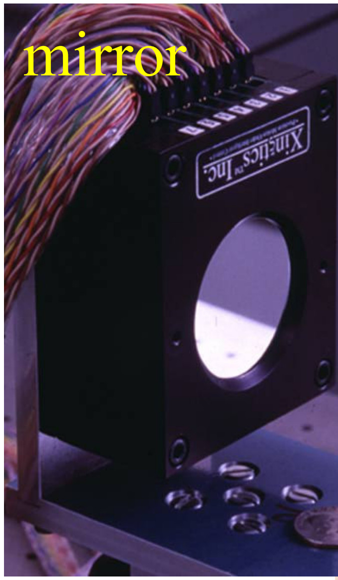
- Electrical conduction: insulating, semiconducting, metallic, superconducting

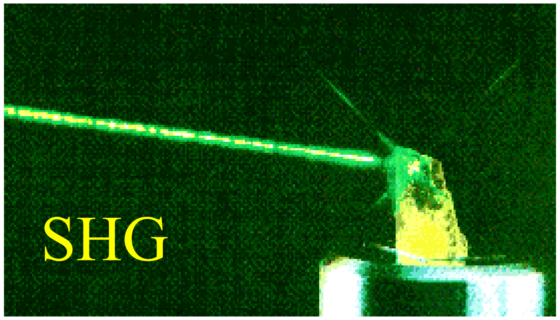


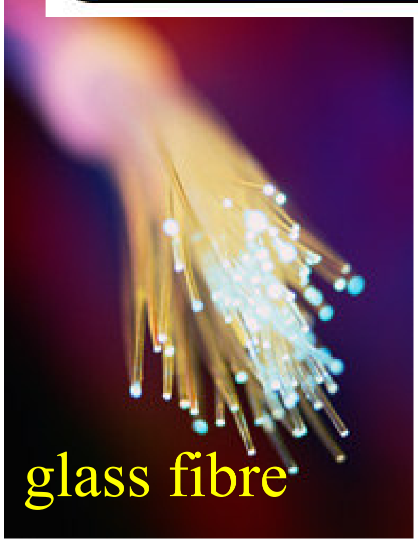
Can we understand this huge variation in conductivity ?

'Electronic' properties of solids:
….those dominated by the behavior of the electrons

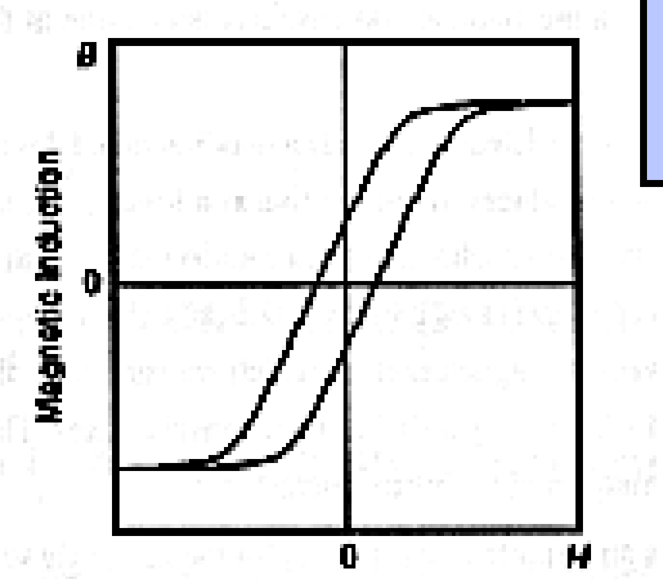
- Optical properties: absorption, emission, amplification and modification of light

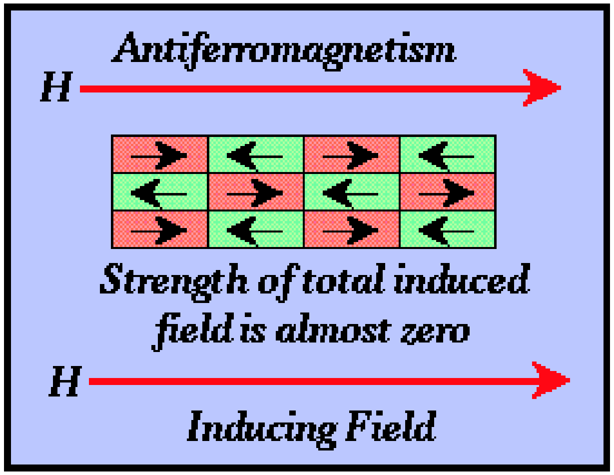






Magnetic properties: paramagnetism, ferromagnetism, antiferromagnetism





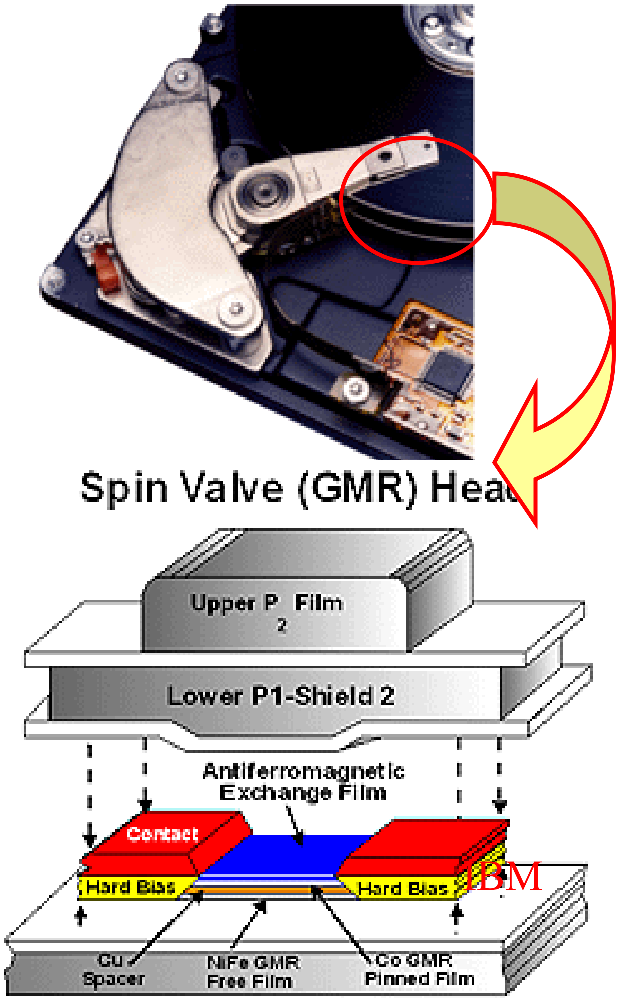
Antiferromagnetism

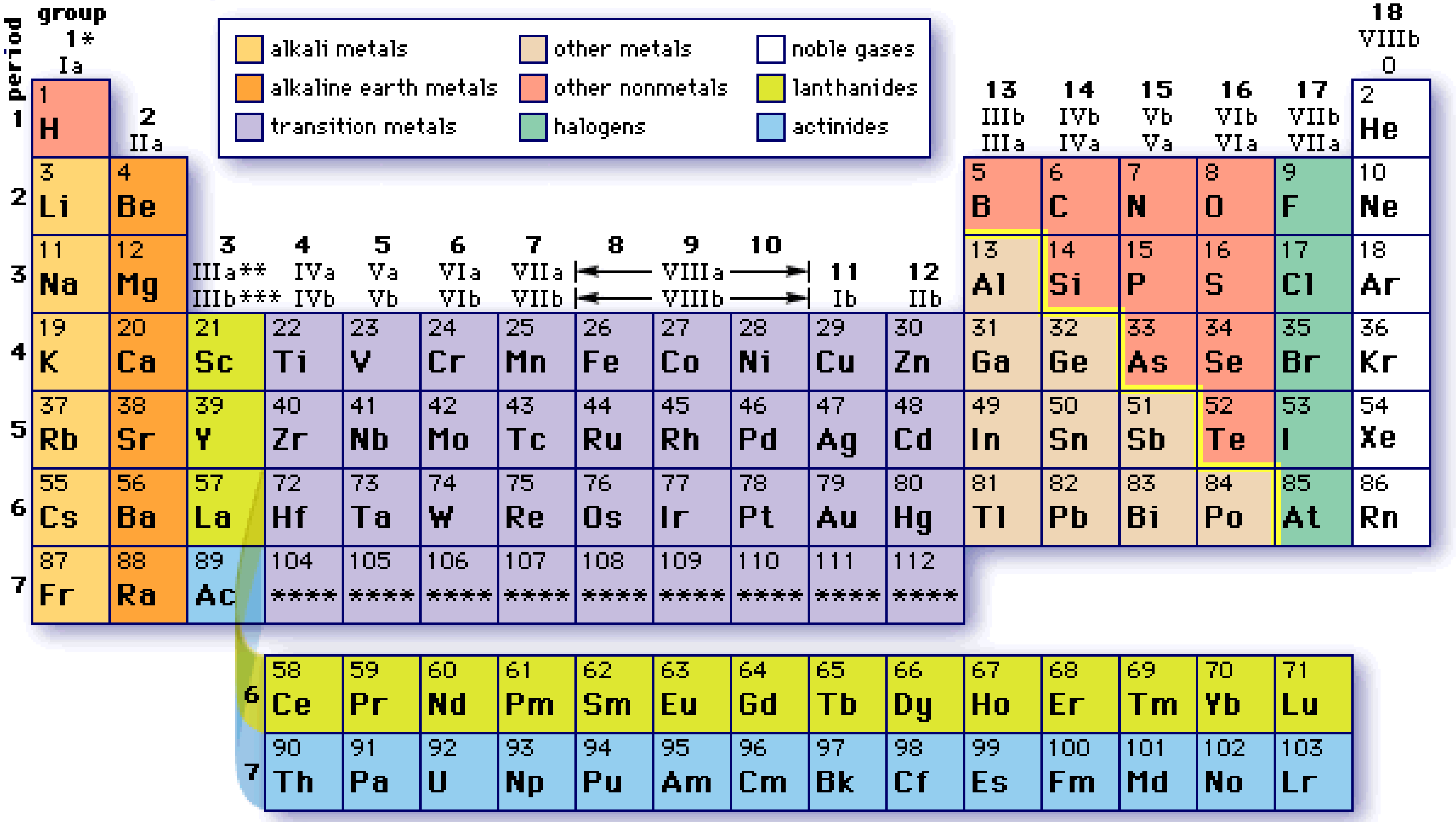
H

Strength of total induced field is almost zero

H

Inducing Field





- alkali metals
- alkaline earth metals
- transition metals
- other metals
- other nonmetals
- halogens
- noble gases
- lanthanides
- actinides

period	group 1* Ia	2 IIa	3 IIIa** IIIb***	4 IVa IVb	5 Va Vb	6 VIa VIb	7 VIIa VIIb	8	9 VIIIa VIIIb	10	11 Ib	12 IIb	13 IIIb IIIa	14 IVb IVa	15 Vb Va	16 VIb VIa	17 VIIb VIIa	18 VIIIb 0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 ****	105 ****	106 ****	107 ****	108 ****	109 ****	110 ****	111 ****	112 ****						

6	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
7	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

* Numbering system recommended by the International Union of Pure and Applied Chemistry (IUPAC)
** Previous IUPAC numbering system
*** Numbering system recommended by the Chemical Abstracts Service
**** For the names of elements 104–112, see Table 27.

We are going to study real, complex solids. PT should be familiar !

Length-scales

Angstrom = 1Å = 1/10,000,000,000 meter = 10^{-10} m

Nanometer = 10 nm = 1/1,000,000,000 meter = 10^{-9} m

Micrometer = 1μm = 1/1,000,000 meter = 10^{-6} m

Millimeter = 1mm = 1/1,000 meter = 10^{-3} m

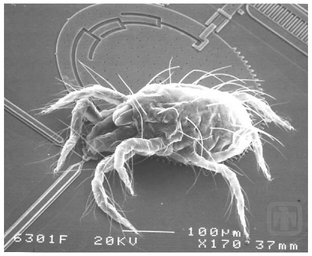
Interatomic distance ~ a few Å

A human hair is ~ 50 μm

Elongated bumps that make up the data track on CD are ~ 0.5 μm wide, minimum 0.83 μm long, and 125 nm high

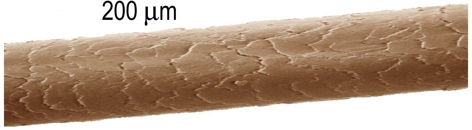
The Scale of Things – Nanometers and More

Natural Things



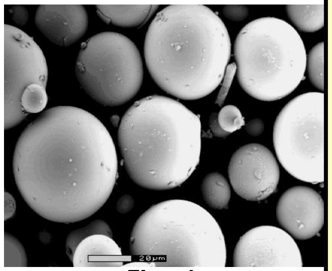
Dust mite

200 µm

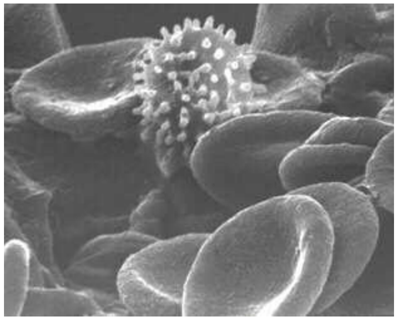


Human hair
~ 60-120 µm wide

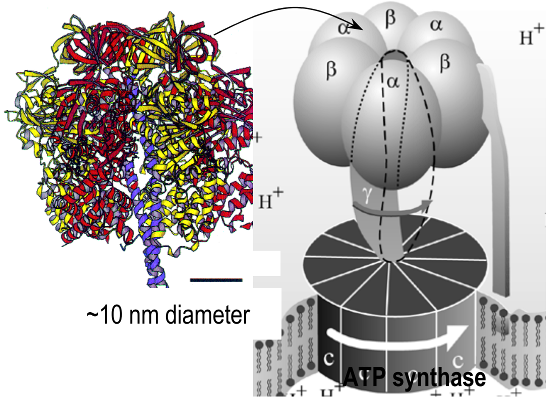
Ant
~ 5 mm



Fly ash
~ 10-20 µm



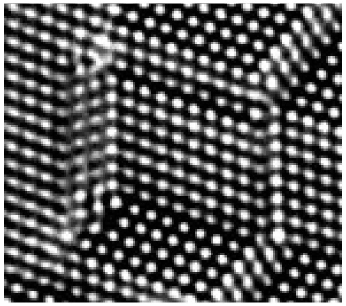
Red blood cells
with white cell
~ 2-5 µm



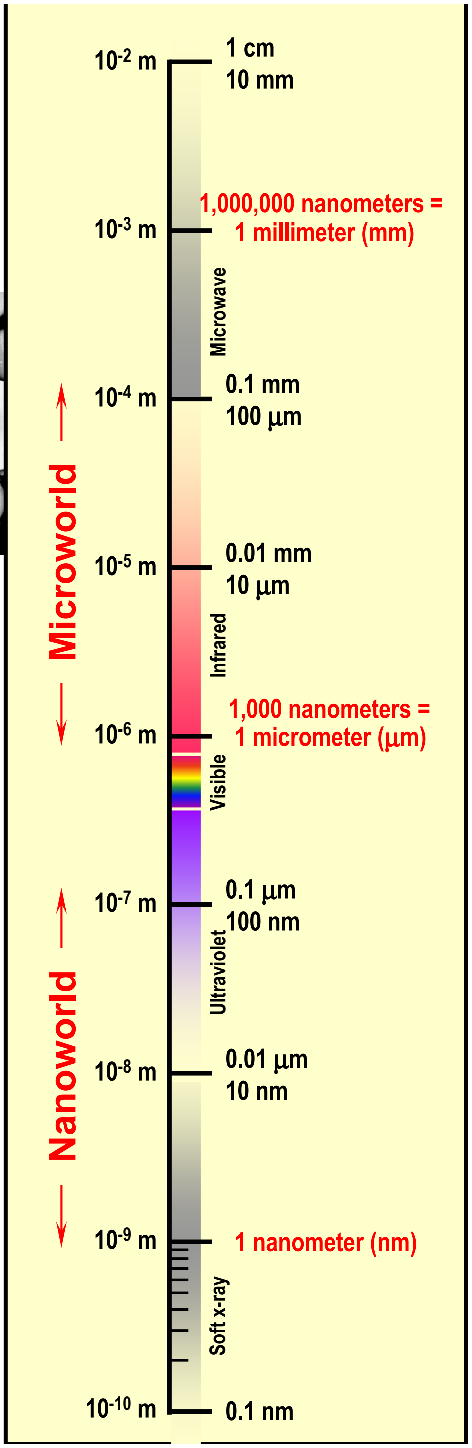
~10 nm diameter

ATP synthase

DNA
~2-1/2 nm diameter



Atoms of silicon
spacing ~tenths of nm



10^{-2} m — 1 cm, 10 mm

1,000,000 nanometers = 1 millimeter (mm)

10^{-3} m

Microwave

10^{-4} m — 0.1 mm, 100 µm

Microworld

10^{-5} m — 0.01 mm, 10 µm

Infrared

1,000 nanometers = 1 micrometer (µm)

10^{-6} m

Visible

10^{-7} m — 0.1 µm, 100 nm

Ultraviolet

Nanoworld

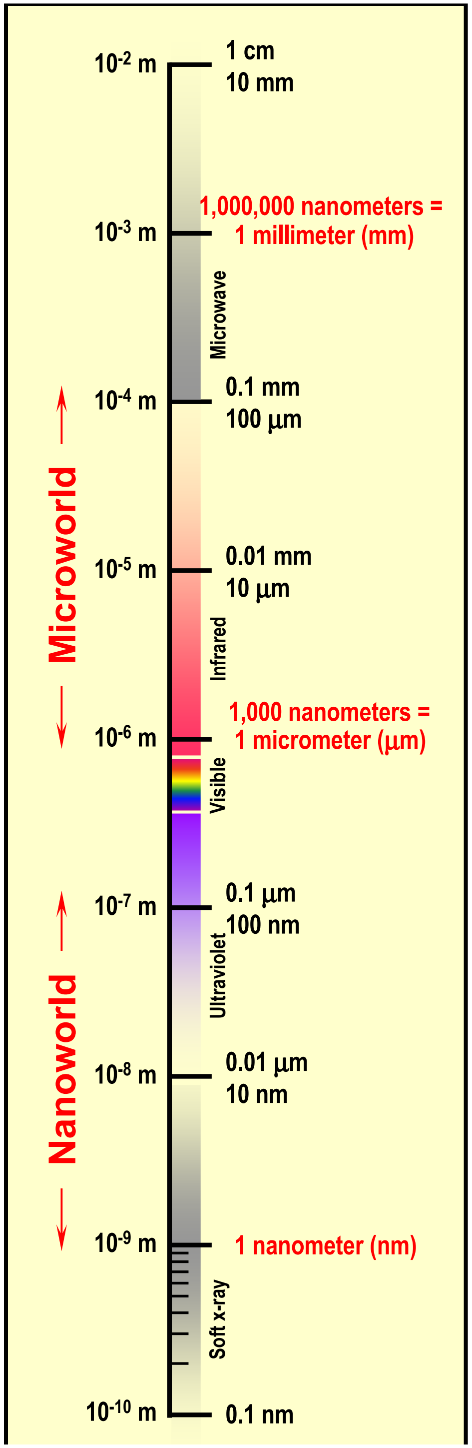
10^{-8} m — 0.01 µm, 10 nm

10^{-9} m — 1 nanometer (nm)

Soft x-ray

10^{-10} m — 0.1 nm

The Scale of Things – Nanometers and More



10^{-2} m — 1 cm
10 mm

10^{-3} m — 1,000,000 nanometers = 1 millimeter (mm)

10^{-4} m — 0.1 mm
100 µm

10^{-5} m — 0.01 mm
10 µm

10^{-6} m — 1,000 nanometers = 1 micrometer (µm)

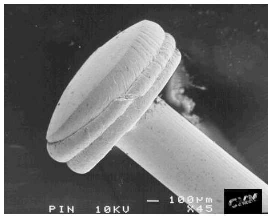
10^{-7} m — 0.1 µm
100 nm

10^{-8} m — 0.01 µm
10 nm

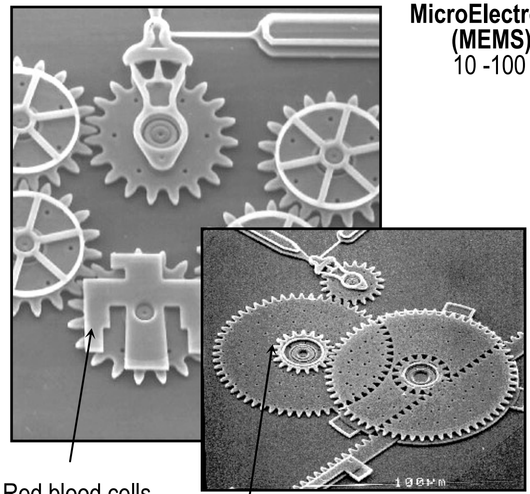
10^{-9} m — 1 nanometer (nm)

10^{-10} m — 0.1 nm

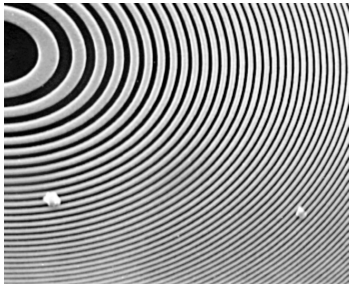
Manmade Things



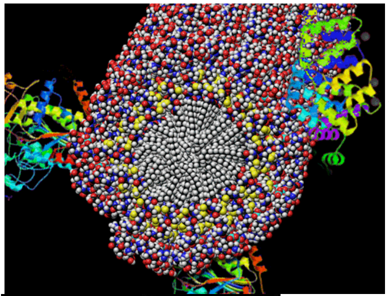
Head of a pin
1-2 mm



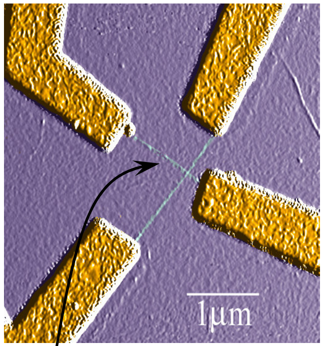
MicroElectroMechanical (MEMS) devices
10 -100 µm wide



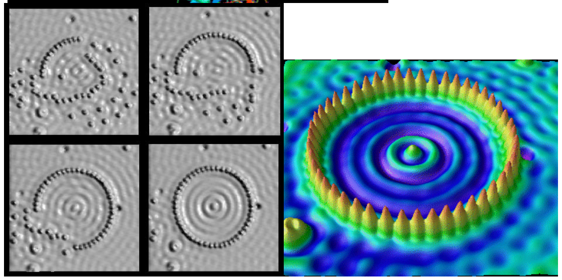
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



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

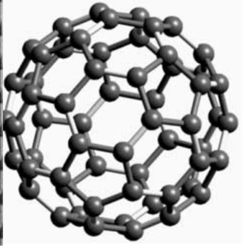


Nanotube electrode



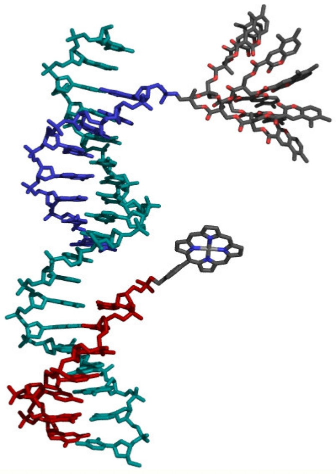
Quantum corral of 48 iron atoms on copper surface positioned one at a time with an STM tip
Corral diameter 14 nm

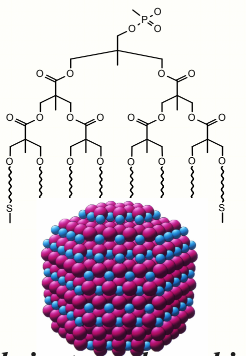
Carbon nanotube ~1.3 nm diameter



Carbon buckyball ~1 nm diameter

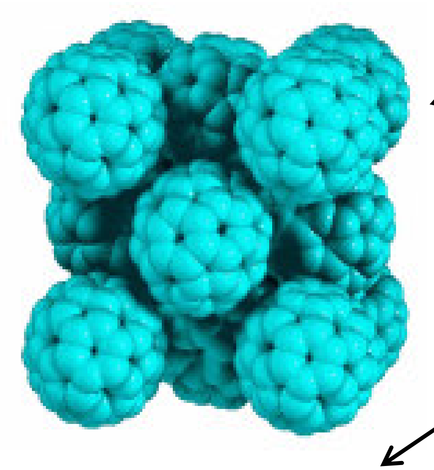
The Challenge



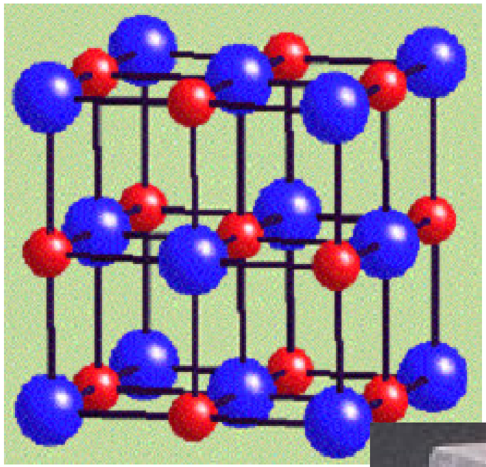


Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.

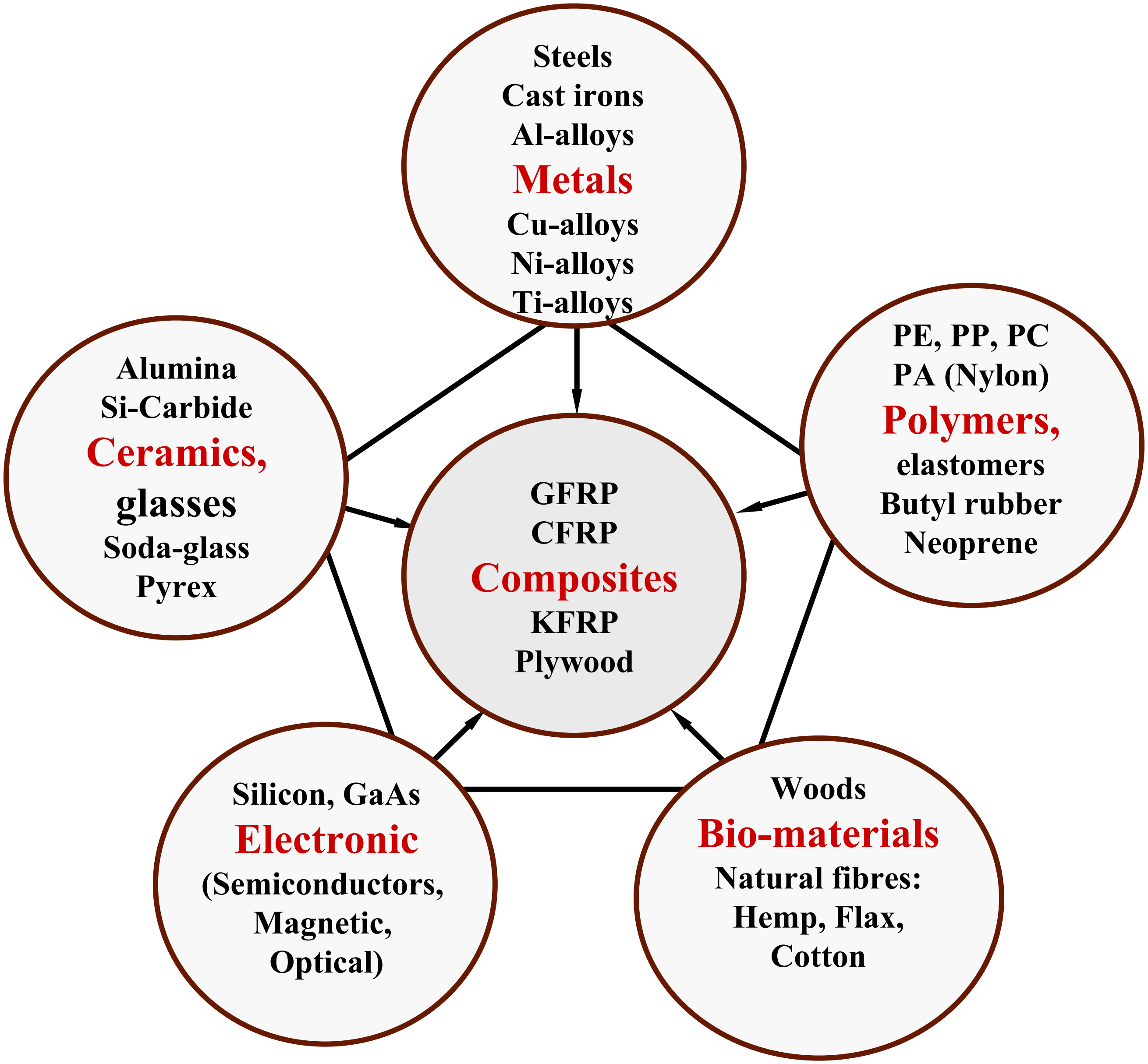
Chemical classification: → ***bonding***



- molecular
- ionic
- covalent
- metallic



The world of materials



Steels
Cast irons
Al-alloys
Metals
Cu-alloys
Ni-alloys
Ti-alloys

PE, PP, PC
PA (Nylon)
Polymers,
elastomers
Butyl rubber
Neoprene

Alumina
Si-Carbide
Ceramics,
glasses
Soda-glass
Pyrex

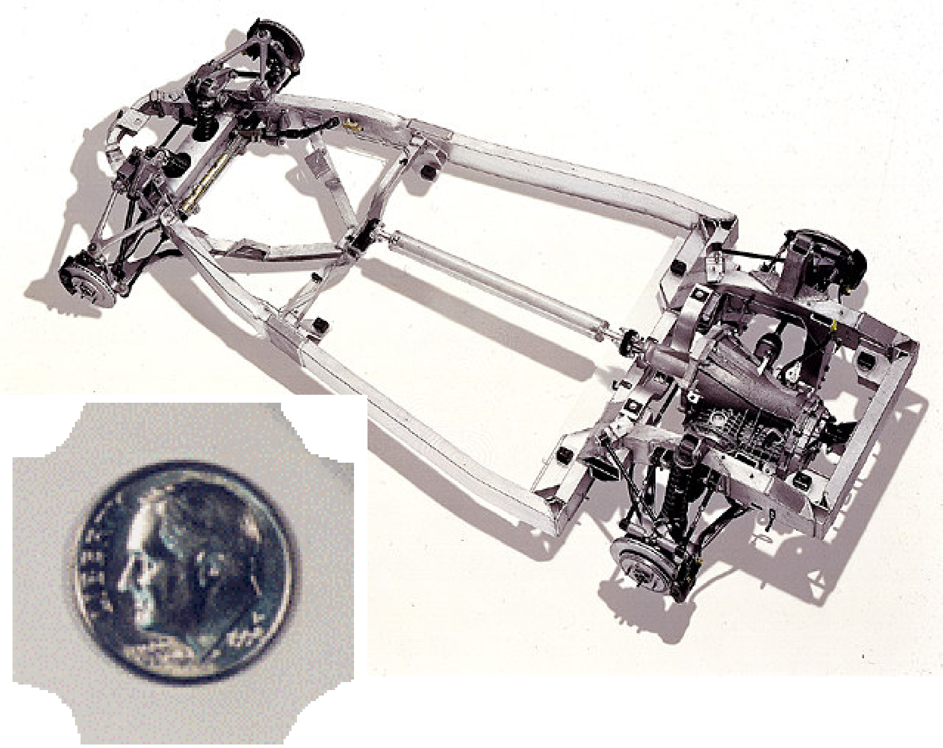
GFRP
CFRP
Composites
KFRP
Plywood

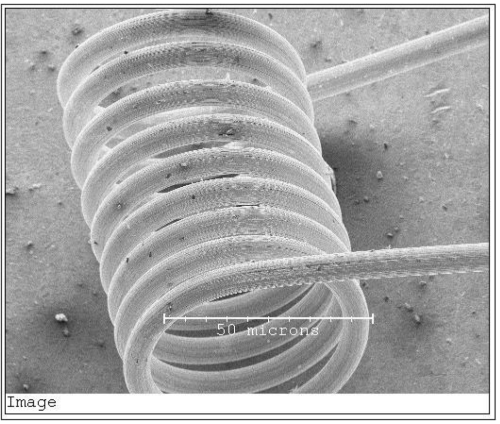
Silicon, GaAs
Electronic
(Semiconductors,
Magnetic,
Optical)

Woods
Bio-materials
Natural fibres:
Hemp, Flax,
Cotton

Metals: Examples iron (Fe), copper (Cu), aluminum (Al), nickel (Ni), titanium (Ti). Non metallic elements such as carbon (C), nitrogen (N) and oxygen (O) may also be contained in metallic materials.

Metals usually are good conductors of heat and electricity. Metals have a crystalline structure in which the atoms are arranged in an orderly manner. Also, they are quite strong but malleable and tend to have a lustrous look when polished.



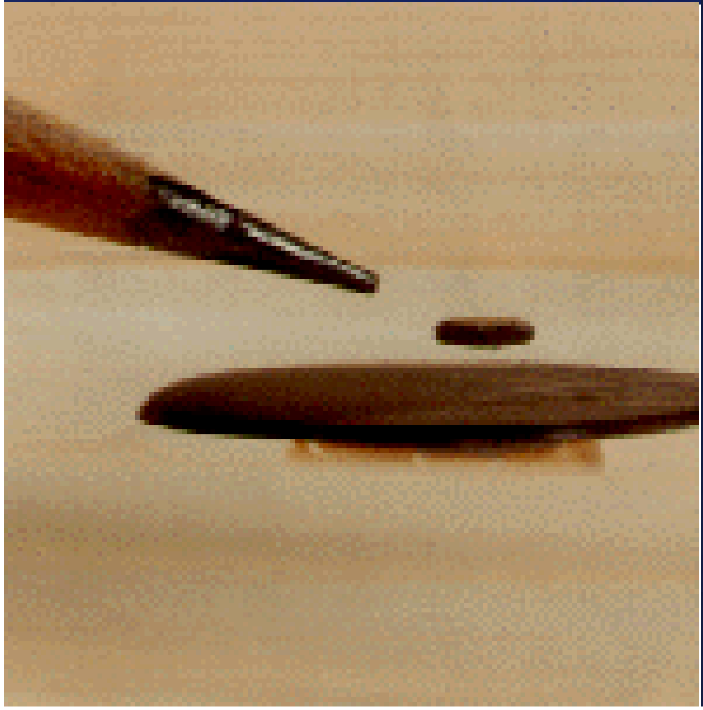


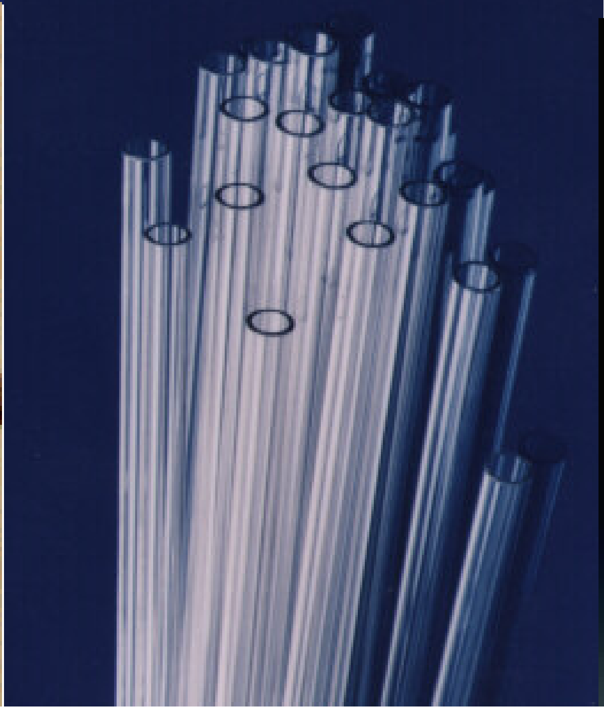
Ceramics: They are generally compounds between metallic and nonmetallic elements chemically bonded together and include such compounds as oxides, nitrides, and carbides. Ceramic materials can be crystalline, non-crystalline, or mixtures of both.

Typically they have high hardness and high-temperature strength but they tend to have mechanical brittleness. They are usually insulating and resistant to high temperatures and harsh environments.

Ceramics can be divided into two classes: ***traditional*** and ***advanced***. Traditional ceramics include clay products, silicate glass and cement; while advanced ceramics consist of carbides (SiC), pure oxides (Al_2O_3), nitrides (Si_3N_4), non-silicate glasses and many others.

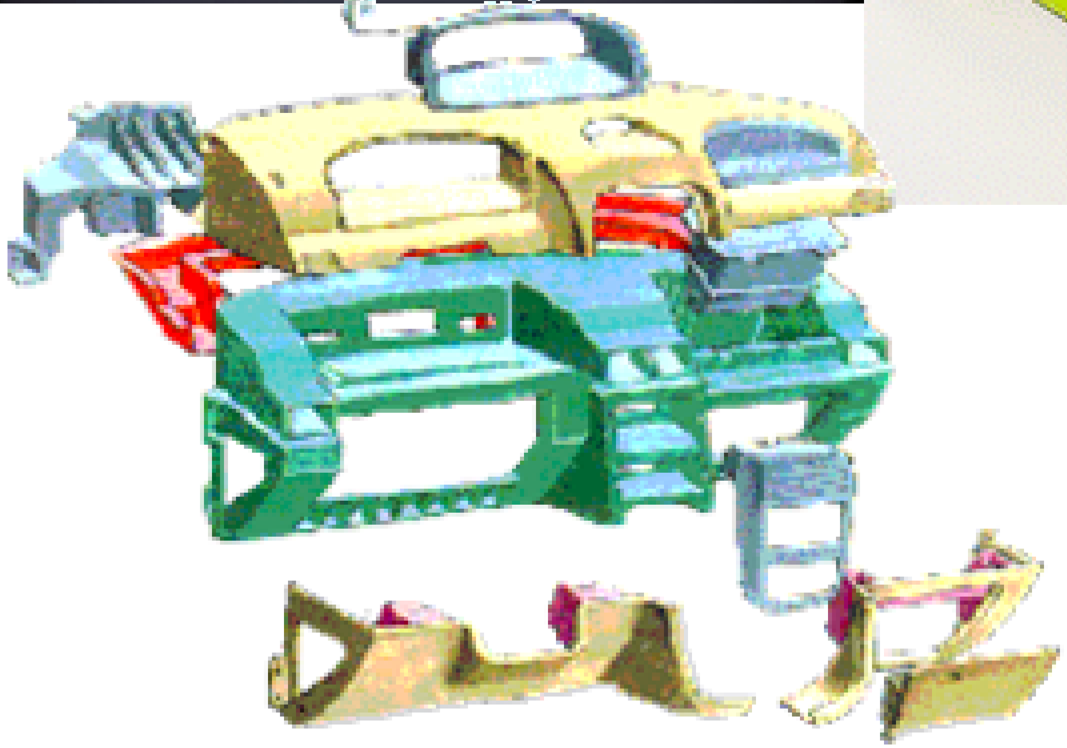
Ceramic rotors under commercial production
Materials: Sintered silicon nitride





Plastics: Plastics or polymers are substances containing a large number of structural units joined by the same type of linkage. These substances often form into a chain-like structure and are made of organic compounds based upon carbon and hydrogen. Usually they are low density and are not stable at high temperatures.

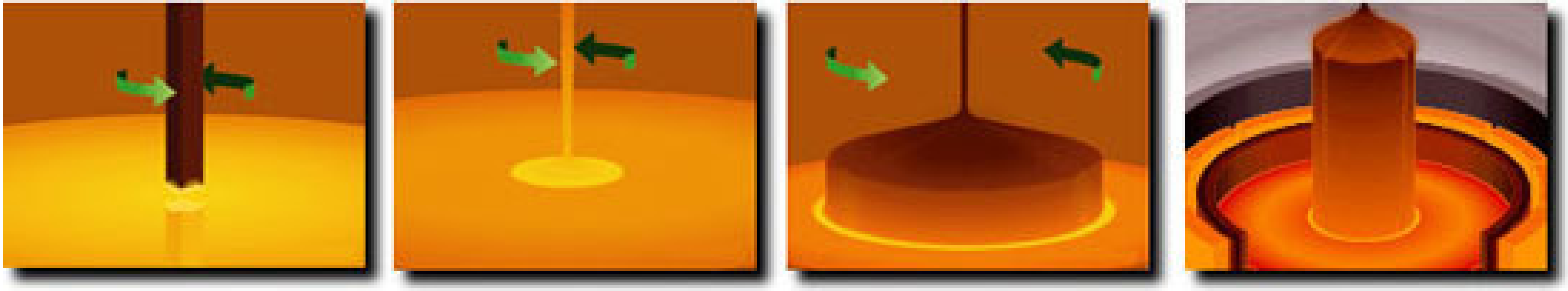
Polymers already have a range of applications that far exceeds that of any other class of material. Current applications extend from adhesives, coatings, foams, and packaging materials to textile and industrial fibers, composites, electronic devices, biomedical devices, optical devices, and precursors for many newly developed high-tech ceramics. Today, tge polymer industry has grown to be larger than the aluminum, copper and steel industries combined.

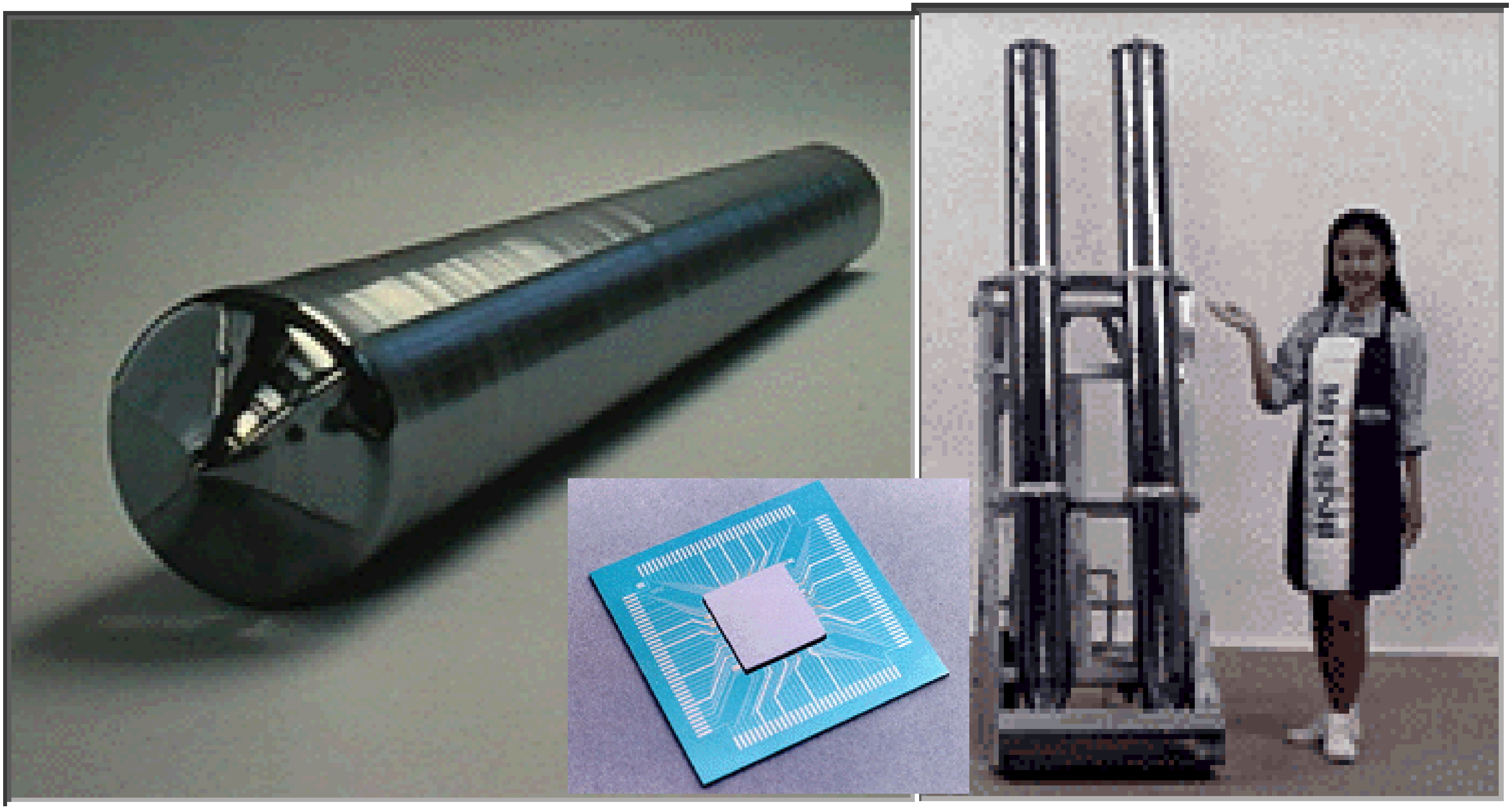


Semiconductors (Electronic Materials):

Semiconductors are materials which have a conductivity between conductors (generally metals) and nonconductors or insulators (such as most ceramics). Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide or cadmium selenide. In a process called doping, small amounts of impurities are added to pure semiconductors causing large changes in the conductivity of the material.

Due to their role in the fabrication of electronic devices, semiconductors are an important part of our lives.

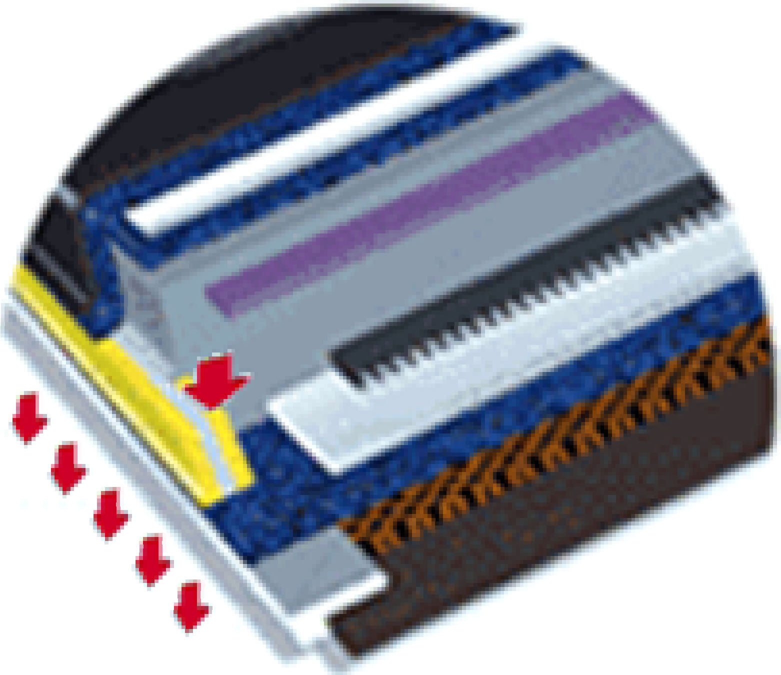


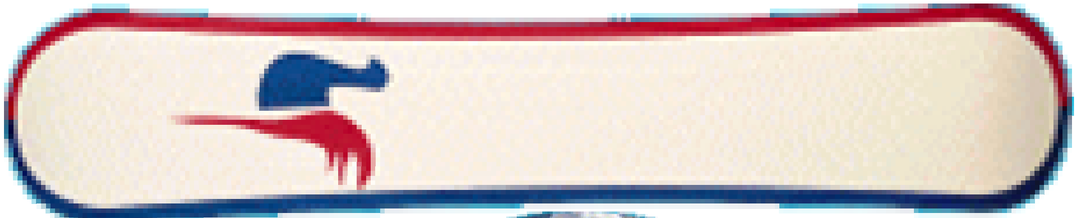


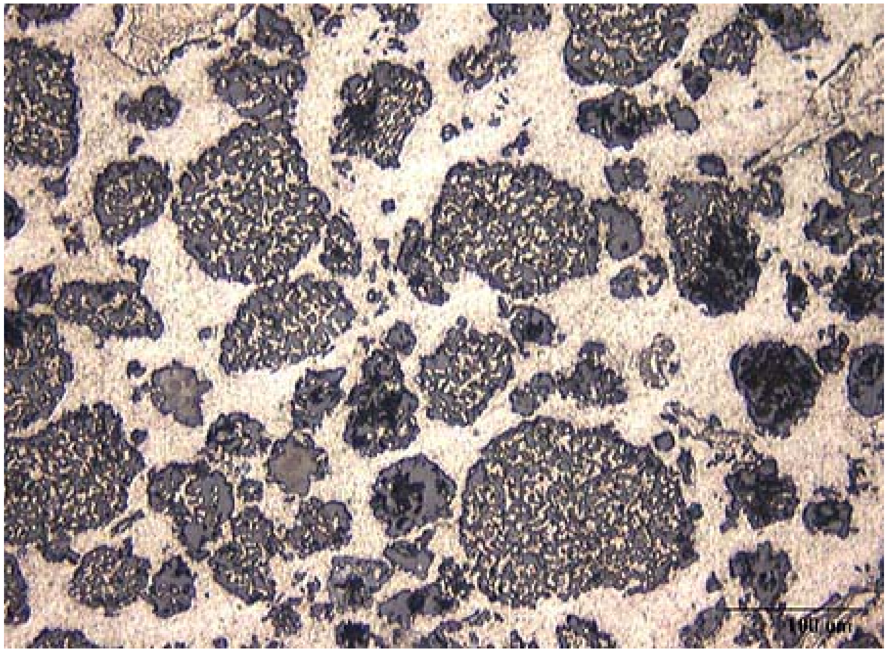
Composites:

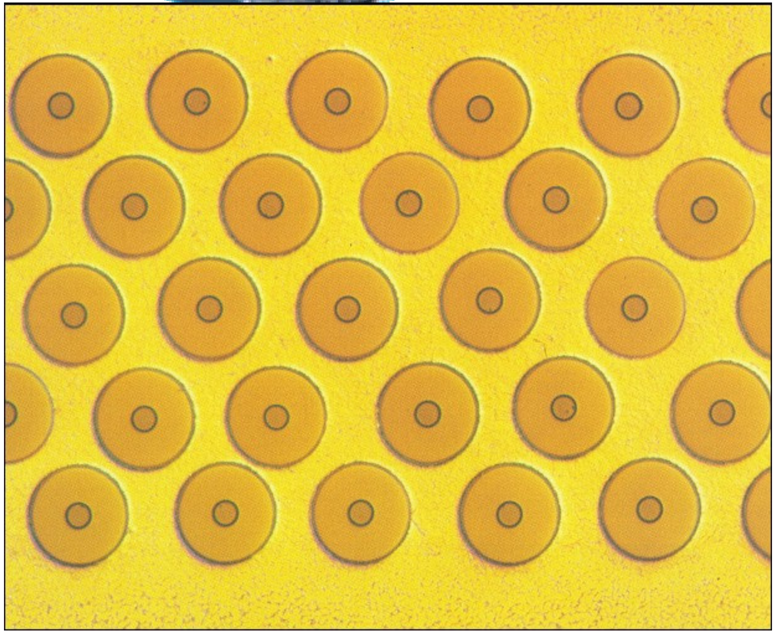
Composites consist of a mixture of two or more materials. Most composite materials consist of a selected filler or reinforcing material and a compatible resin binder to obtain the specific characteristics and properties desired. Usually, the components do not dissolve in each other and can be physically identified by an interface between the components.

Fiberglass, a combination of glass and a polymer, is an example. Concrete and plywood are other familiar composites. Many new combinations include ceramic fibers in metal or polymer matrix.






100 µm

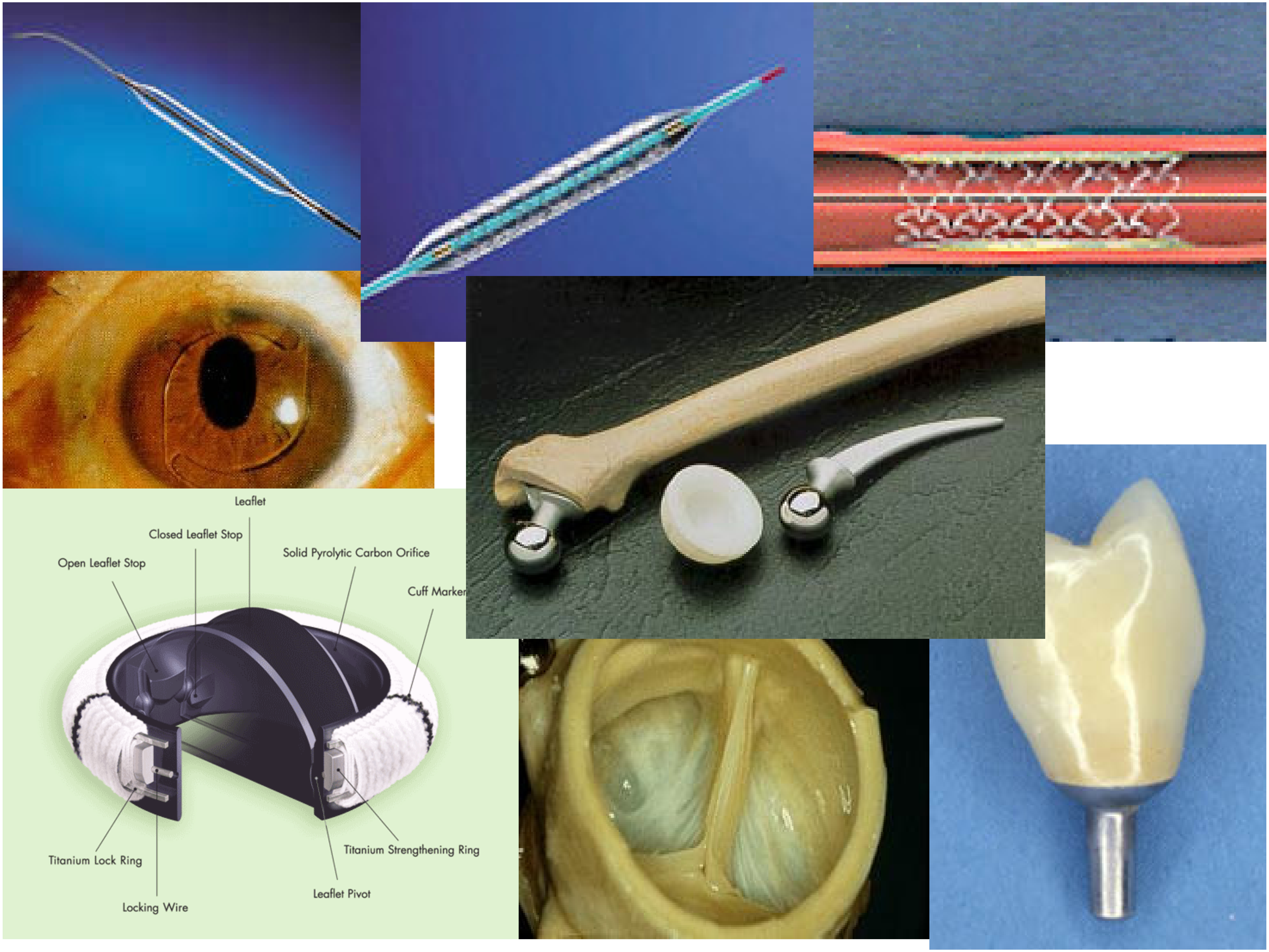


Biomaterials

A biomaterial is "any substance (other than drugs) or combination of substances synthetic or natural in origin, which can be used for any period of time, as a whole or as a part of a system which treats, augments, or replaces any tissue, organ, or function of the body".

Biocompatibility — The ability of a material to perform with an appropriate host response in a specific application

Host Response — The response of the host organism (local and systemic) to the implanted material or device.


Leaflet
Closed Leaflet Stop
Solid Pyrolytic Carbon Orifice
Open Leaflet Stop
Cuff Marker
Titanium Strengthening Ring
Titanium Lock Ring
Leaflet Pivot
Locking Wire

Future of Materials Science

Design of materials having specific desired characteristics directly from our knowledge of atomic structure.

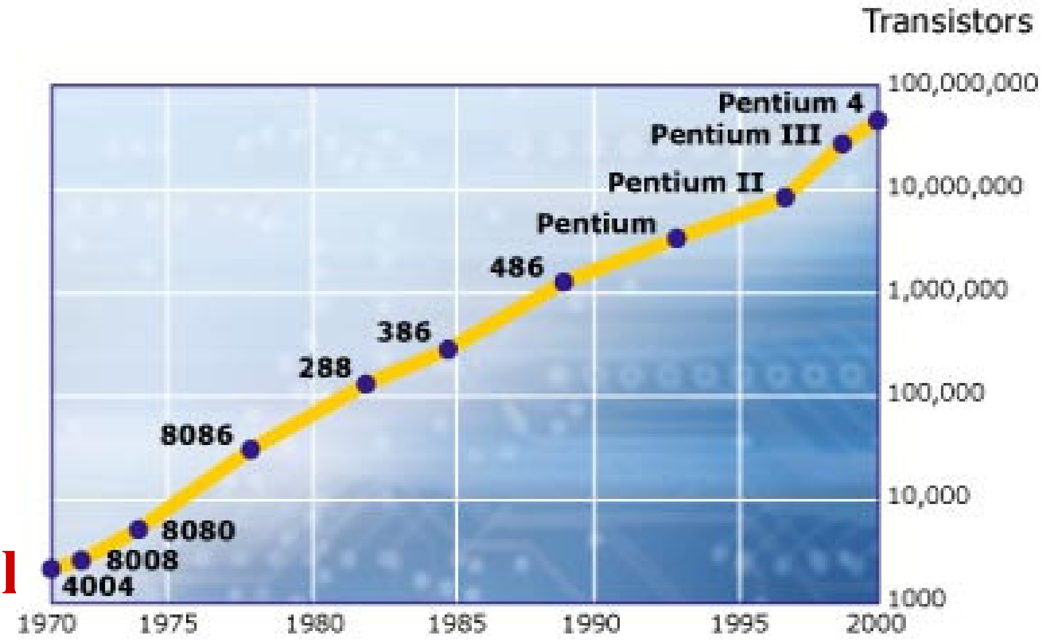
Miniaturization

Smart materials

Environment-friendly material

Learning from Nature

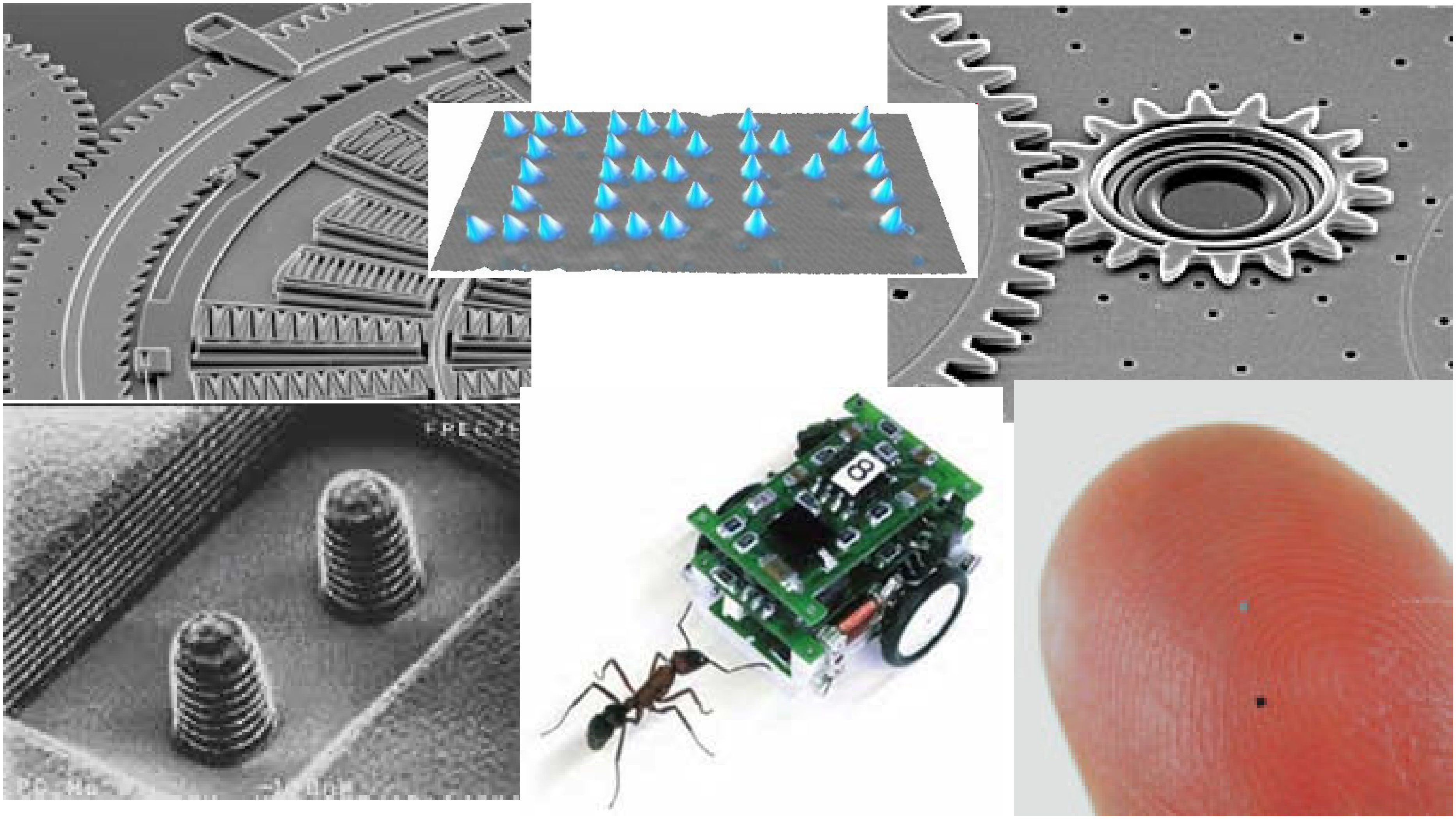
Materials for lightweight batteries with high storage densities, for turbine blades that can operate at 2500°C, room-temperature superconductors? chemical sensors (artificial nose) of extremely high sensitivity.



Moore’s Law: Computer chips (processors, memory, etc.) will double their complexity every 12-24 months.

Miniaturization

“Nanostructured" materials, with microstructure that has length scales between 1 and 100 nanometers with unusual properties. Electronic components, materials for quantum computing.

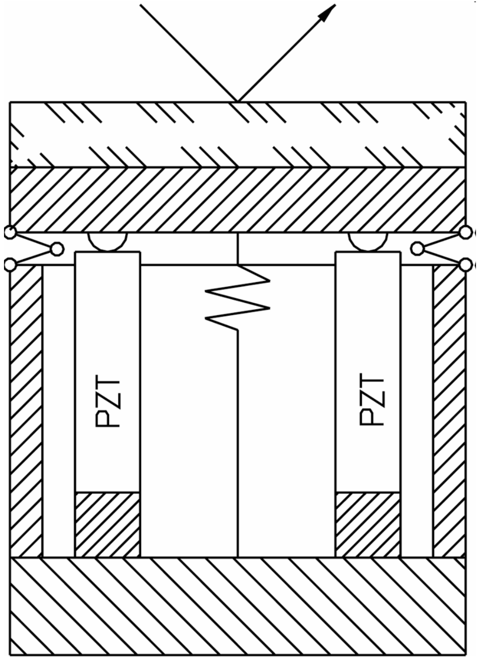


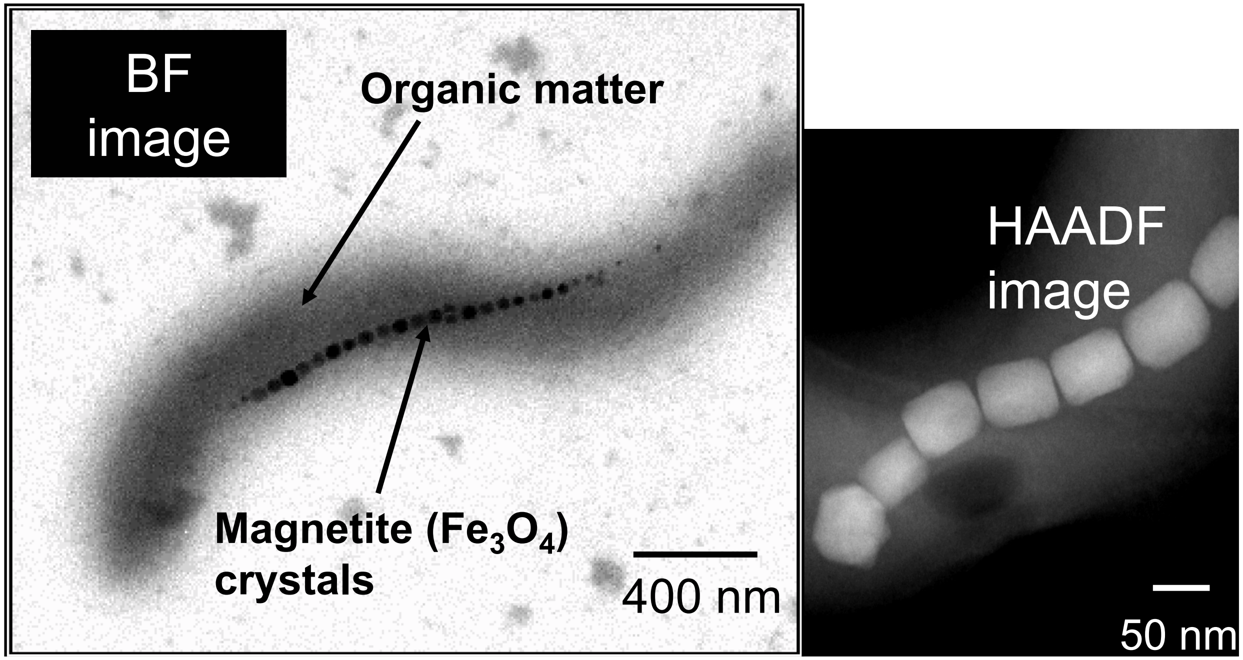
Smart materials

Smart materials are those that respond to environmental stimuli in a timely manner with particular changes in some variables. These are materials that receive, transmit or process a stimulus and respond by producing a “useful” reversible effect.

The piezoelectric effect is:

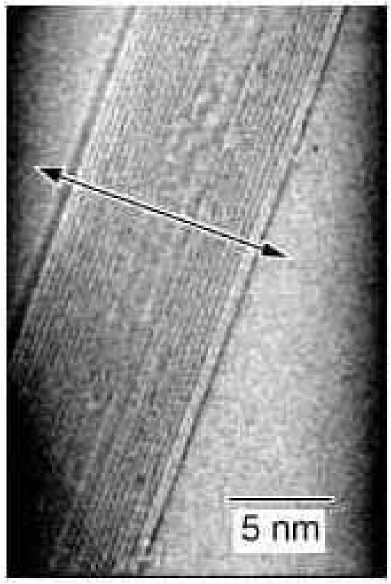
1. the production of a voltage when a crystal plate is subjected to mechanical pressure or when it is physically deformed by bending.
2. The physical deformation of the crystal plate (bending) when it is subjected to a voltage.



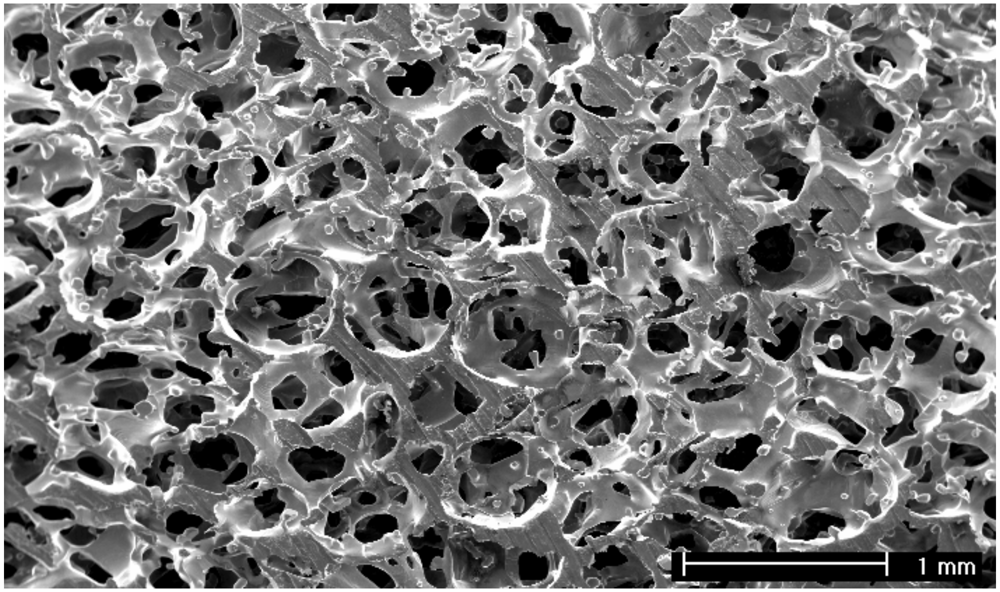


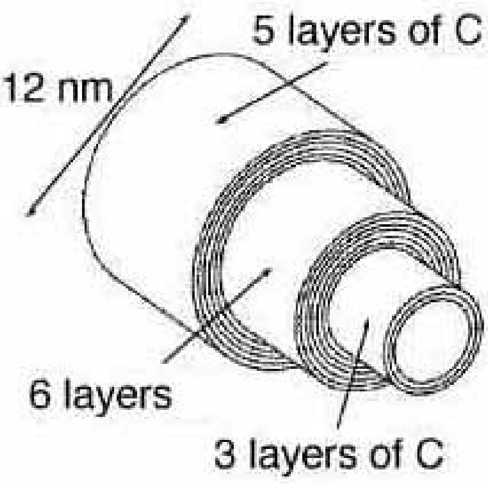
Environment-friendly materials

biodegradable or photodegradable plastics, advances in nuclear waste processing, etc.



Open-cell
aluminum
foam





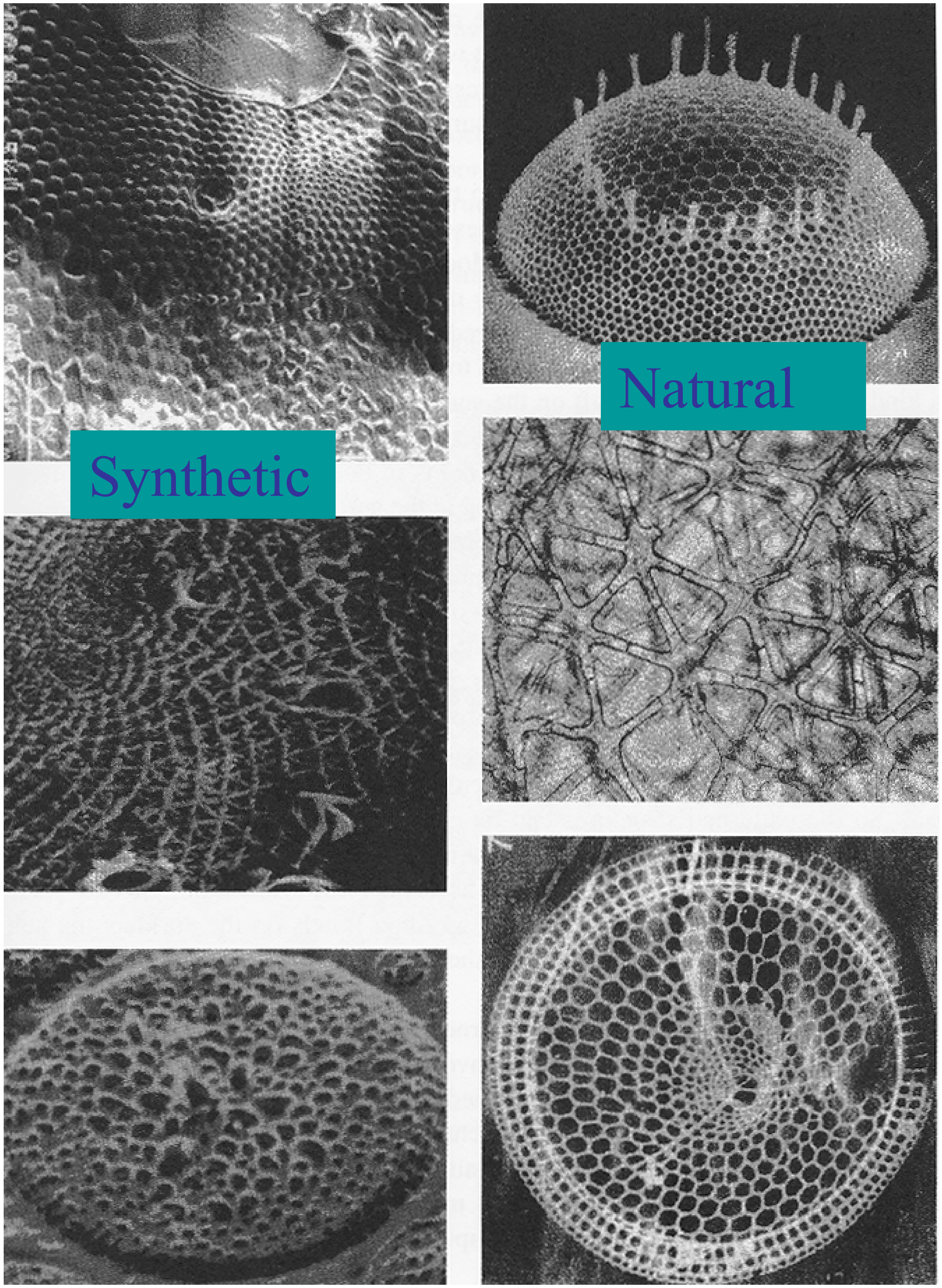
Capacitors

If you can increase the total surface area of the the two plates, your energy storage increases.

Composite nanotube

Learning from Nature

Using nature as a template. Synthetic structures can duplicate natural structures, shells and biological hard tissue can be as strong as the most advanced laboratory-produced ceramics, mollusces produce biocompatible adhesives that we do not know how to copy.



- Question: Of the 100 top revenue generating entities in the world, how many are multinational corporations and how many are nation states?

76 multinational corporations

24 nations