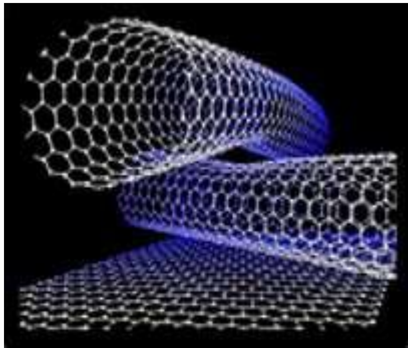
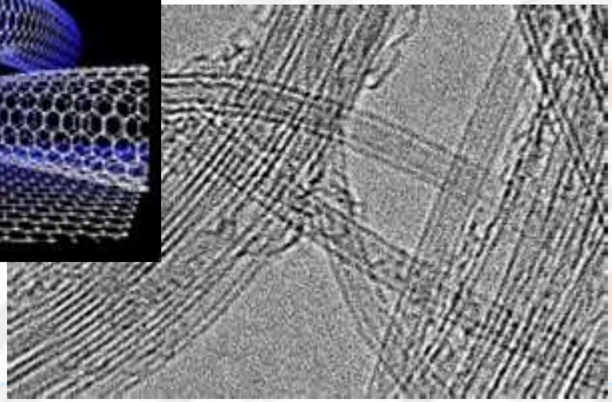
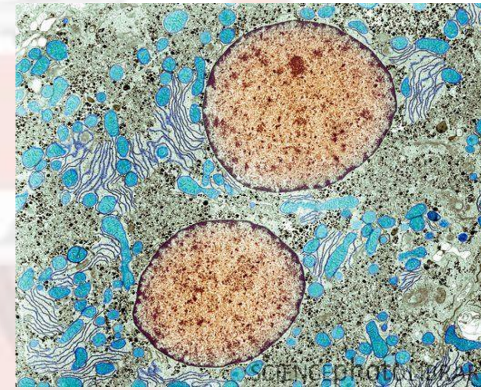
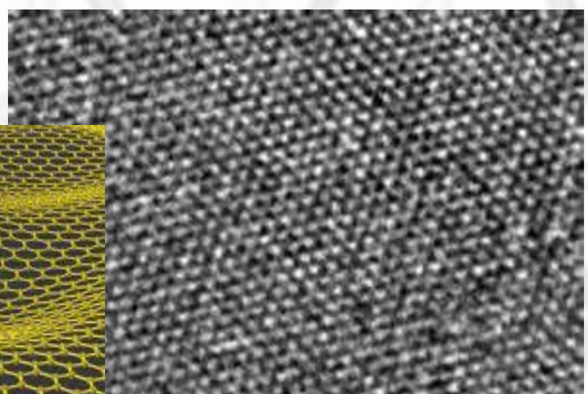


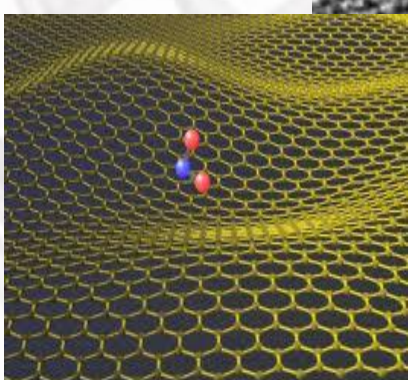


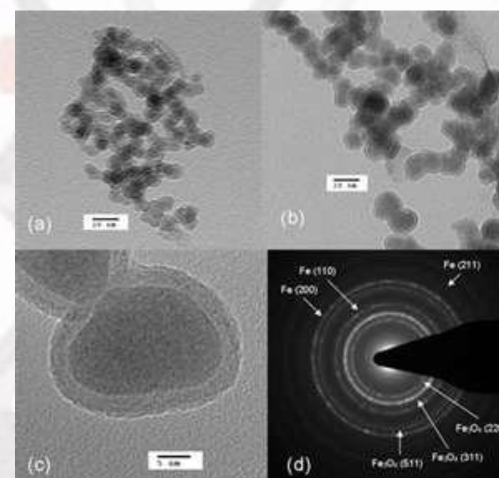


CBE 30361

Science of Engineering Materials







Office hours

Monday, **3.00 – 4.00** PM
Tuesday, **5.00 – 6.00** PM

Instructor: Prof. **Alexander Mukasyan**
Office: 210 Stinson-Remick Hall

TA's OFFICE HOURS

Joshua Pauls	jpauls@nd.edu
Michael Humbert	mhumbert@nd.edu

5:30-7:30 p.m. each Wednesday

- Location: 101 DBRT: 9/10; 9/24; 10/8; 10/15;
- Location: **140** DBRT: **9/17;**
- Location: 138 DBRT: 10/1; 10/29

November & December - TBA

Remember: Materials "Drive" our Society!

- **Ages of "Man" we survive based on the materials we control**

  - **the Stone Age** (>10,000 BC) – naturally occurring materials
    - Special rocks, skins, wood, ceramics and glasses, natural polymers and composites
  - **the Bronze Age**, (4000 BC-1000 BC)
    - Casting and forging
  - **the Iron Age**, (1000 BC-1620 AD)
  - High Temperature furnaces; Cast iron technology (1620's) established the dominance of metals in engineering;
  - **Steel Age** (1859 and up)
    - High Strength Alloys
  - **Non-Ferrous and Polymer Age** (light (1940's) and special alloys)
    - Aluminum, Titanium and Nickel (super-alloys) – aerospace
    - Silicon – Information
    - Plastics and Composites – food preservation, housing, aerospace and higher speeds
  - ***Exotic Materials Age***?
    - Nano-Material and bio-Materials – they are coming and then…

Bronze age

N. Afghanistan, 2200-1800 B.C.

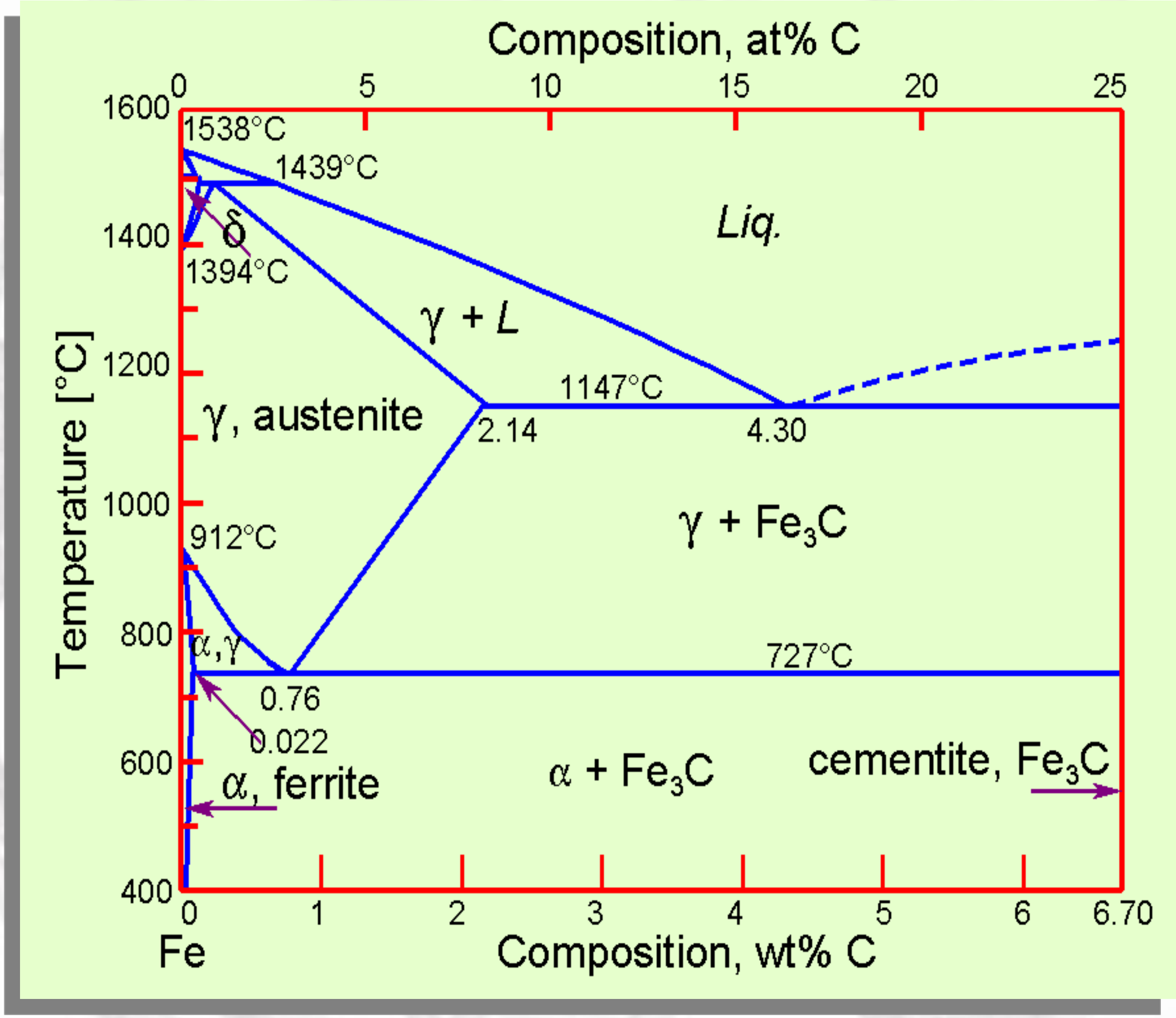
3000-800 BC
transition from
stone to bronze
for tools & arts

Bronze:
Cu + Sn
T_m 950°C

Turkey, 3000-2000 B.C.

Bronze age: not only bronze but also gold and silver.

Why not iron?



Iron is harder than bronze, keeping its cutting edge.

More complex process,

Higher temperature > ~1200°C

Reduction of ore with charcoal

Obtaining charcoal

Centuries of Materials Science

The art of materials

'Knowledge' transferred from father to son, master to apprentice.

Combination of **tough** and **hard**

19th Century

Meanwhile demands of society on materials grew:

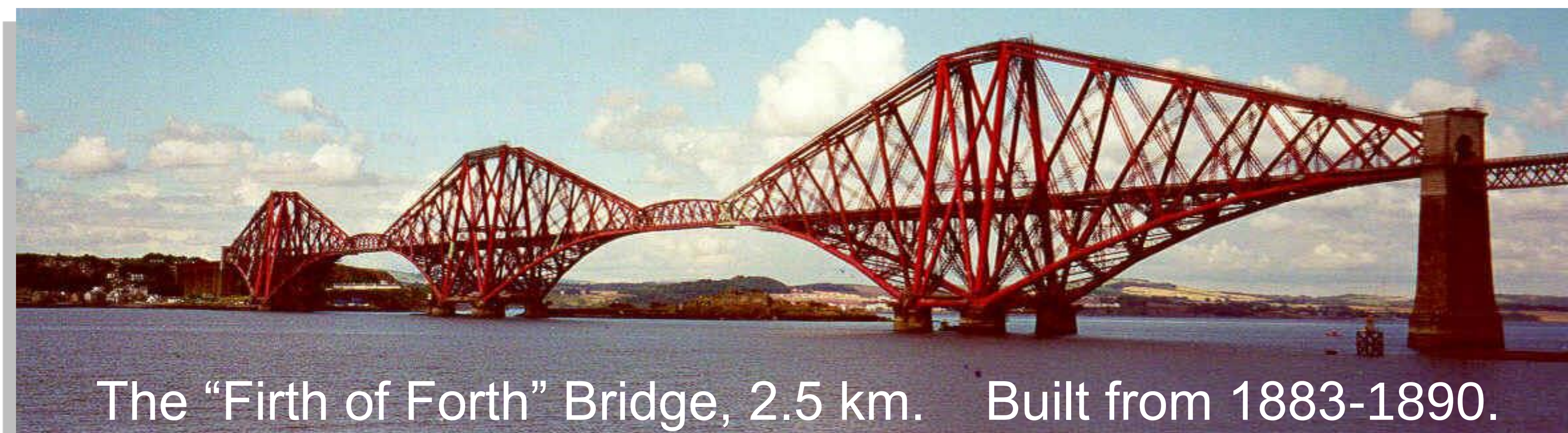
Bigger, larger, faster ….

But materials science was still largely empirical.

The era of steam …

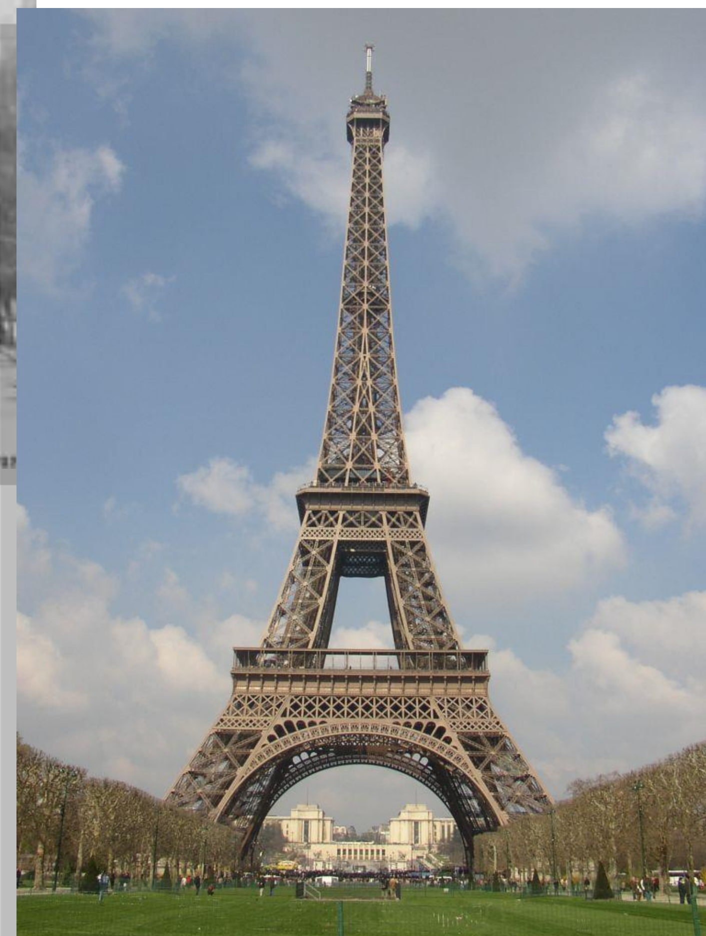
Factories, commerce, travel … placed ever increasing demands on iron

Fundamental knowledge of iron & steel?



The “Firth of Forth” Bridge, 2.5 km. Built from 1883-1890.

While in Paris



Construction of the Eiffeltower.
World exhibition 1889.

From art to science

Materials science became a real science due to the development of modern analysis and imaging techniques.

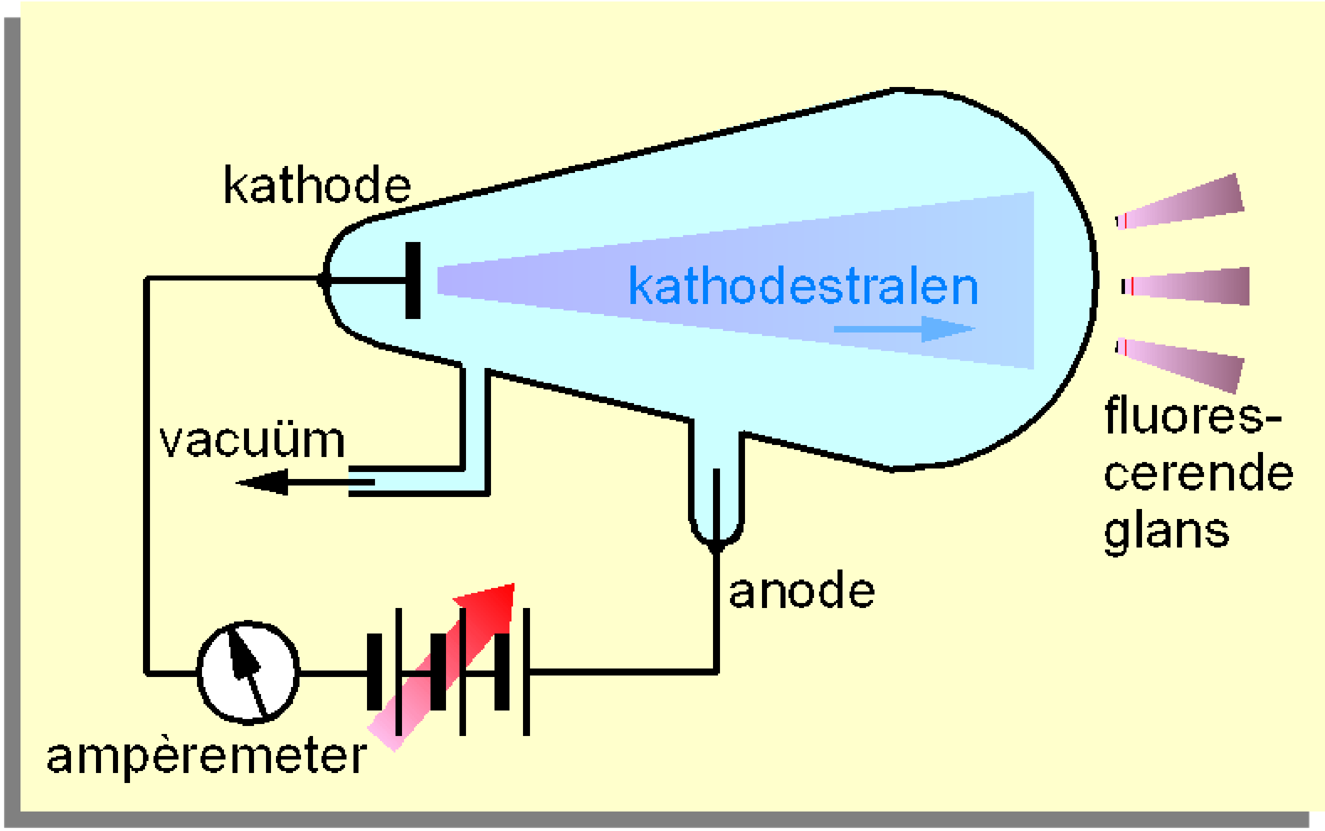
Modern analysis and imaging techniques become possible due to developments in the materials science ……

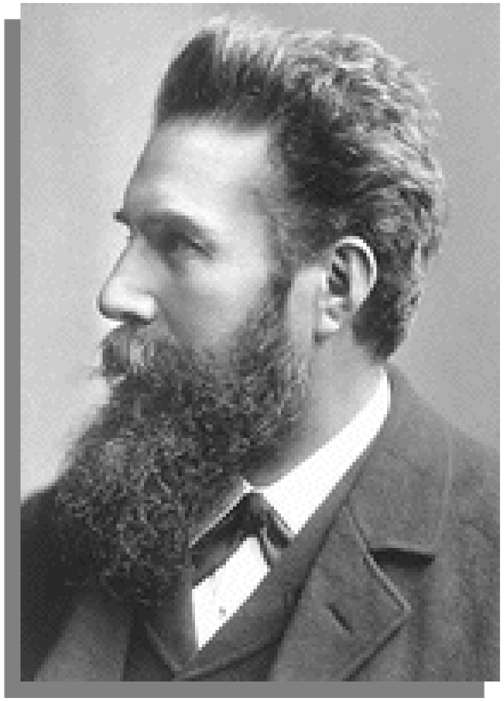
Turn of the century

Wilhelm Conrad Röntgen

Invisible rays

Discovered the ‘Röntgen’ rays in 1895.Named these ‘X=rays’.





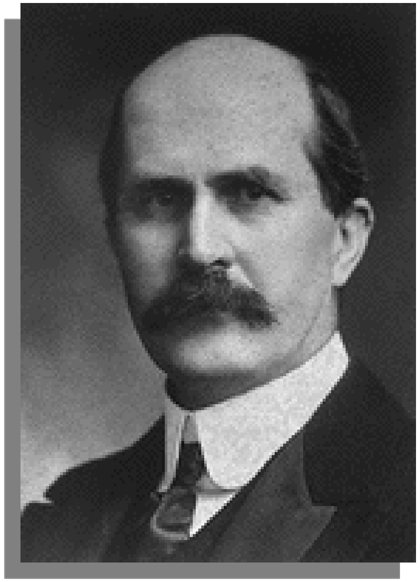
Radiation went straight through a closed, black carton, hitting a fluorescent screen.

Nobel prize
1901

Sir William Henry Bragg:

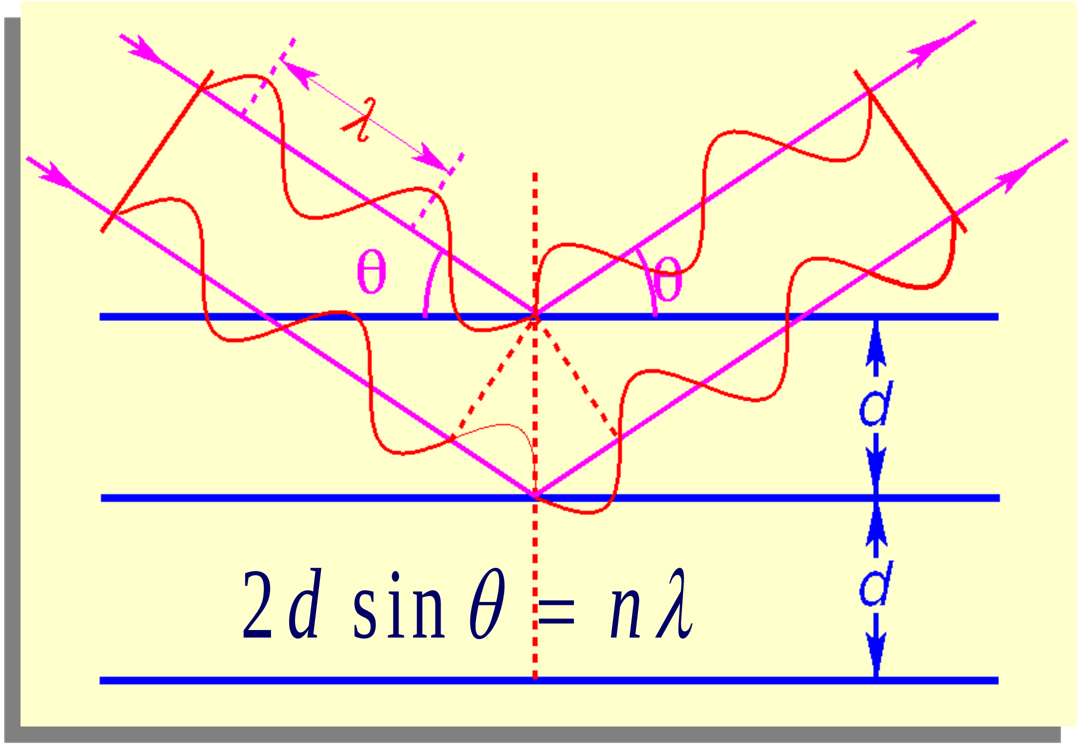
Bragg's law

He saw the shortcomings of the Von Laue method.
His solution: rotating single crystal.

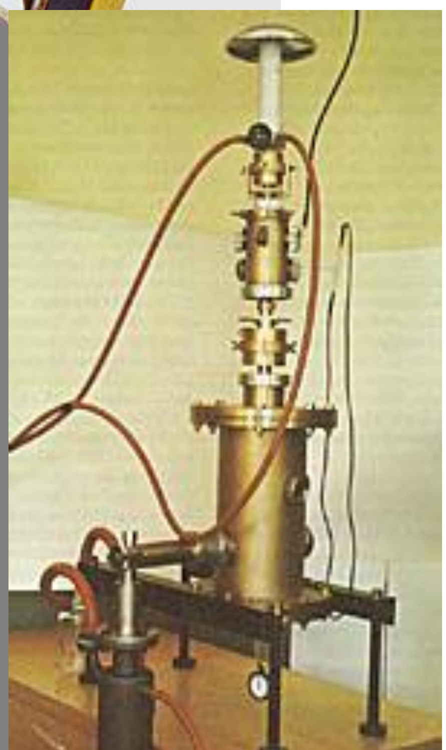


Noble prize 1915!

Conditions for reflection:



The most important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.

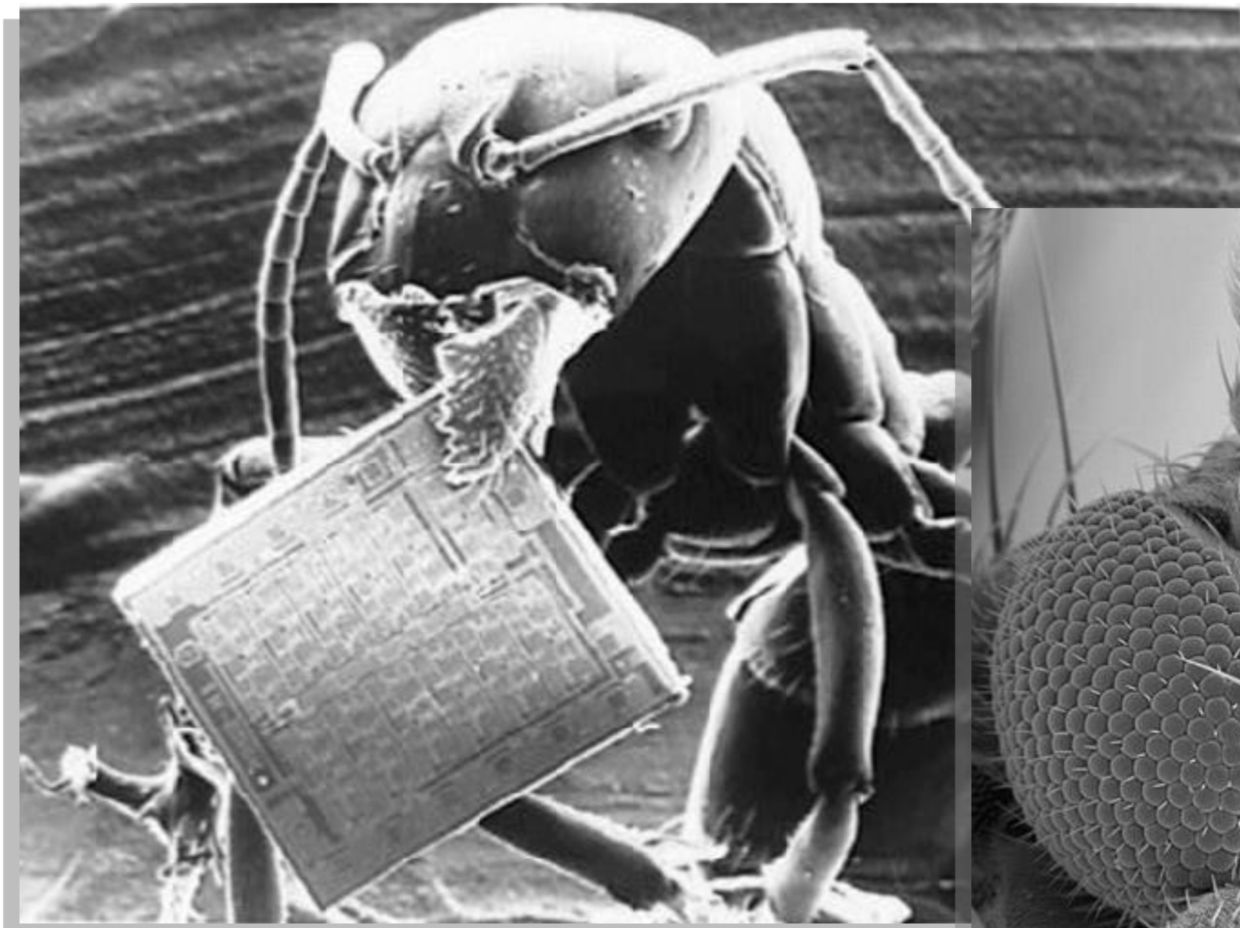


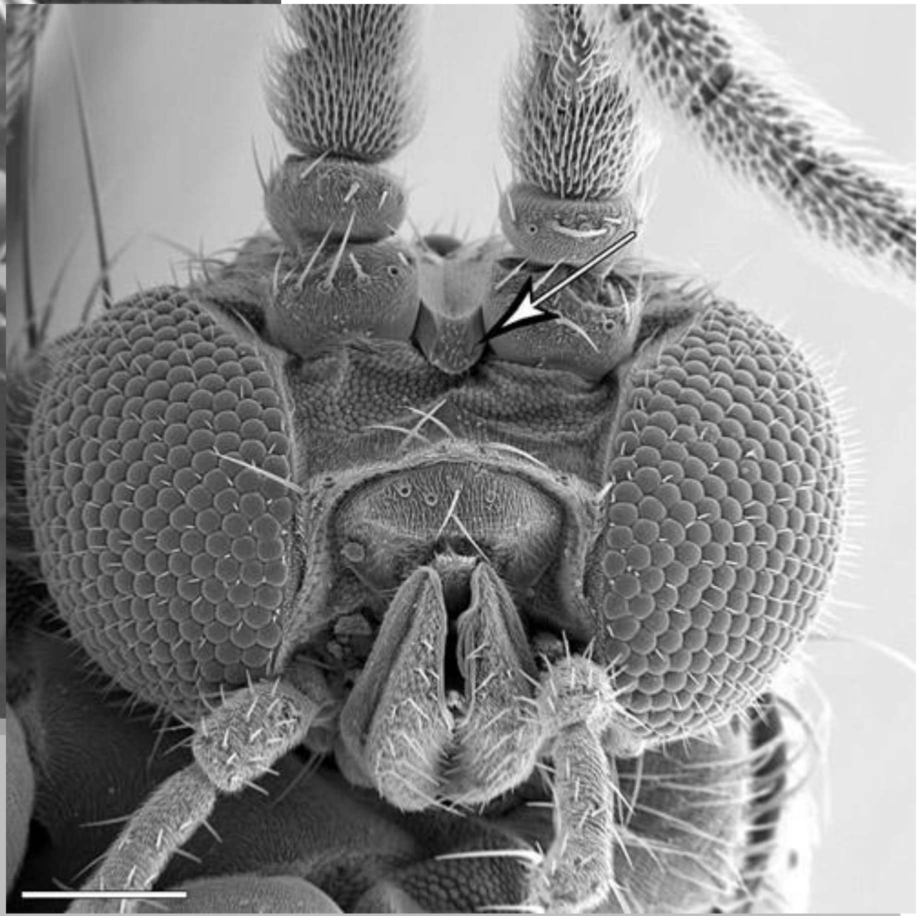
Microscopes!

- **1931** Max Knoll and Ernst Ruska build first electron microscope
- **1933** Ruska developes an EM with higher resolution than an optical microscope
- **1937** The first scanning electron microscope is built
- **1939** Siemens brings the first commercial EM on the market
- **1965** First commercial SEM (Oatley)

Impact of high resolution microscopic images.

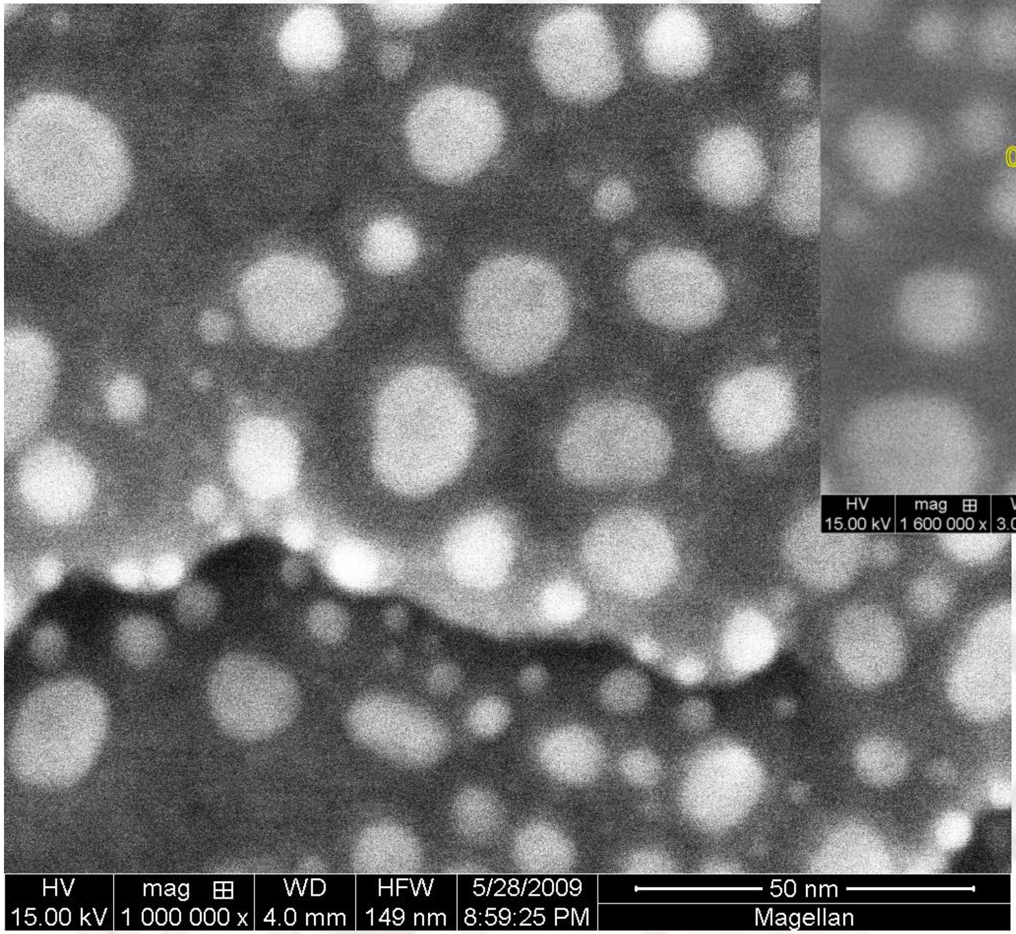
Beyond our imagination

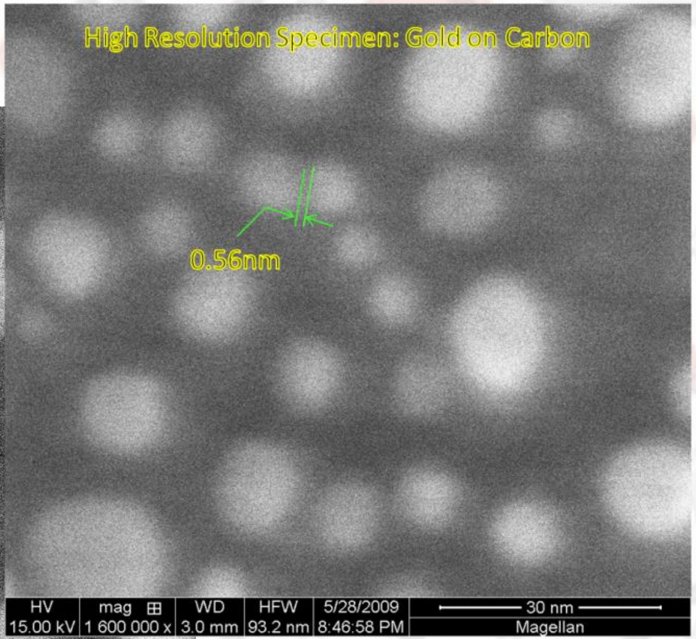




Tremendous depth of sharpness!

Gold on Carbon: Record Resolution <0.6 nm





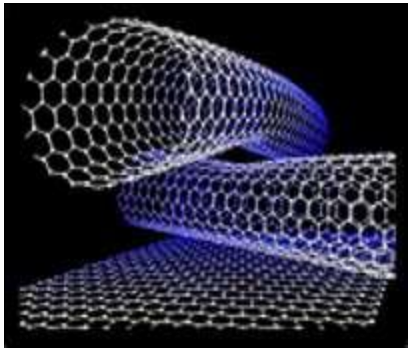
FESEM Magellan 400

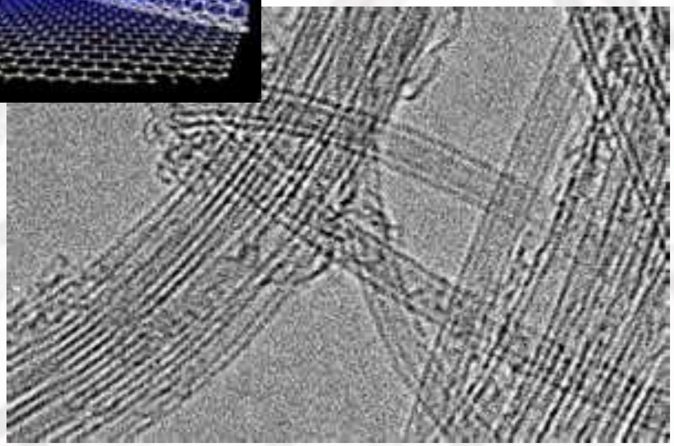
Magnification x1,600,000

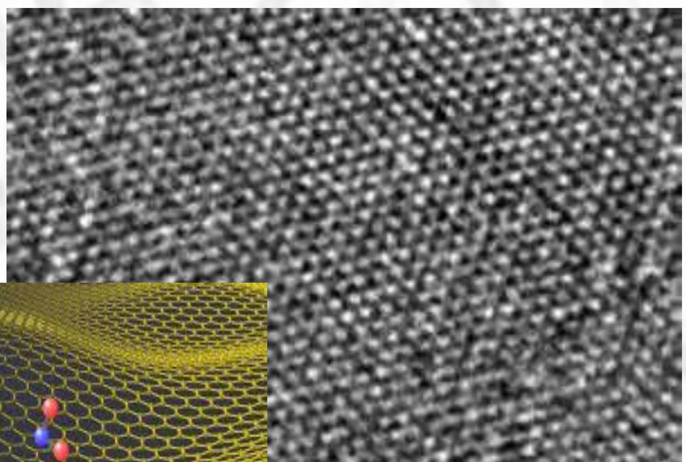
Resolution 0.58 nm

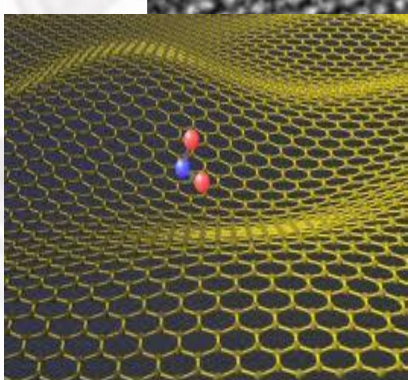
Magnification x1,000,000

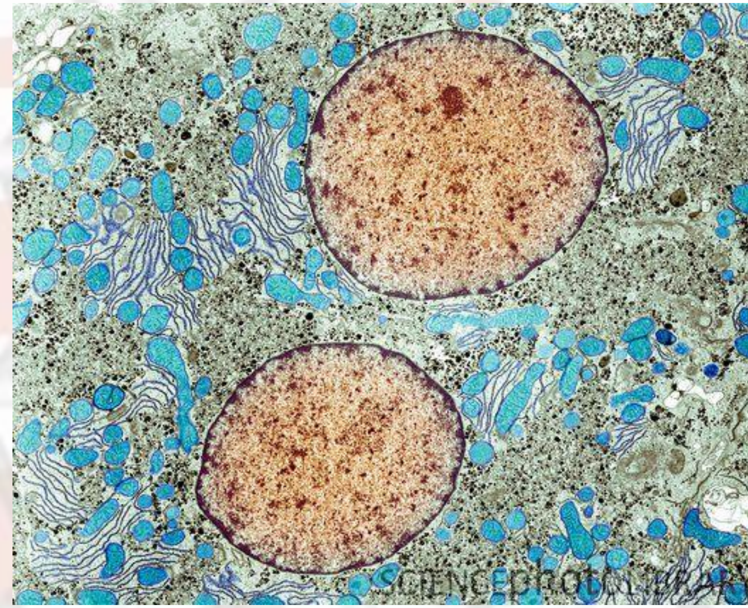
We can see atoms!

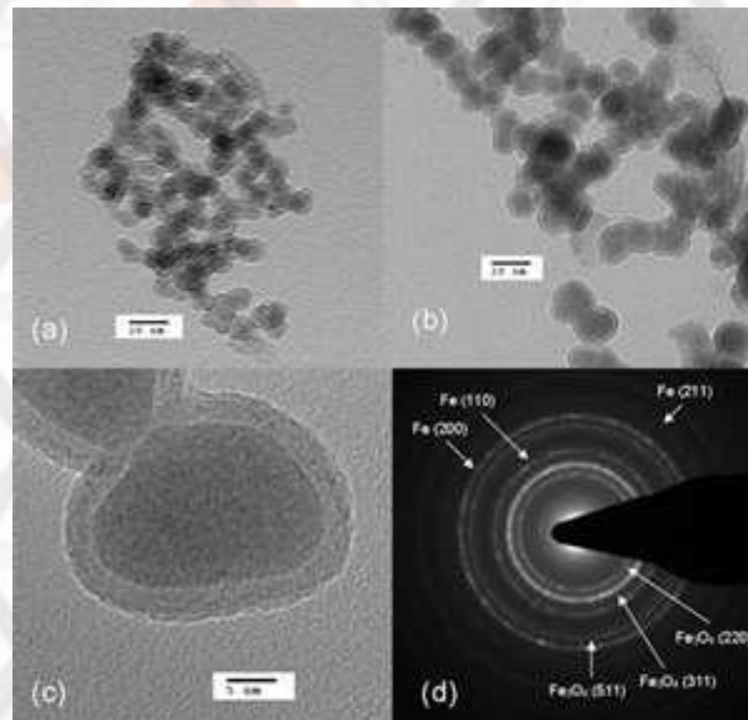




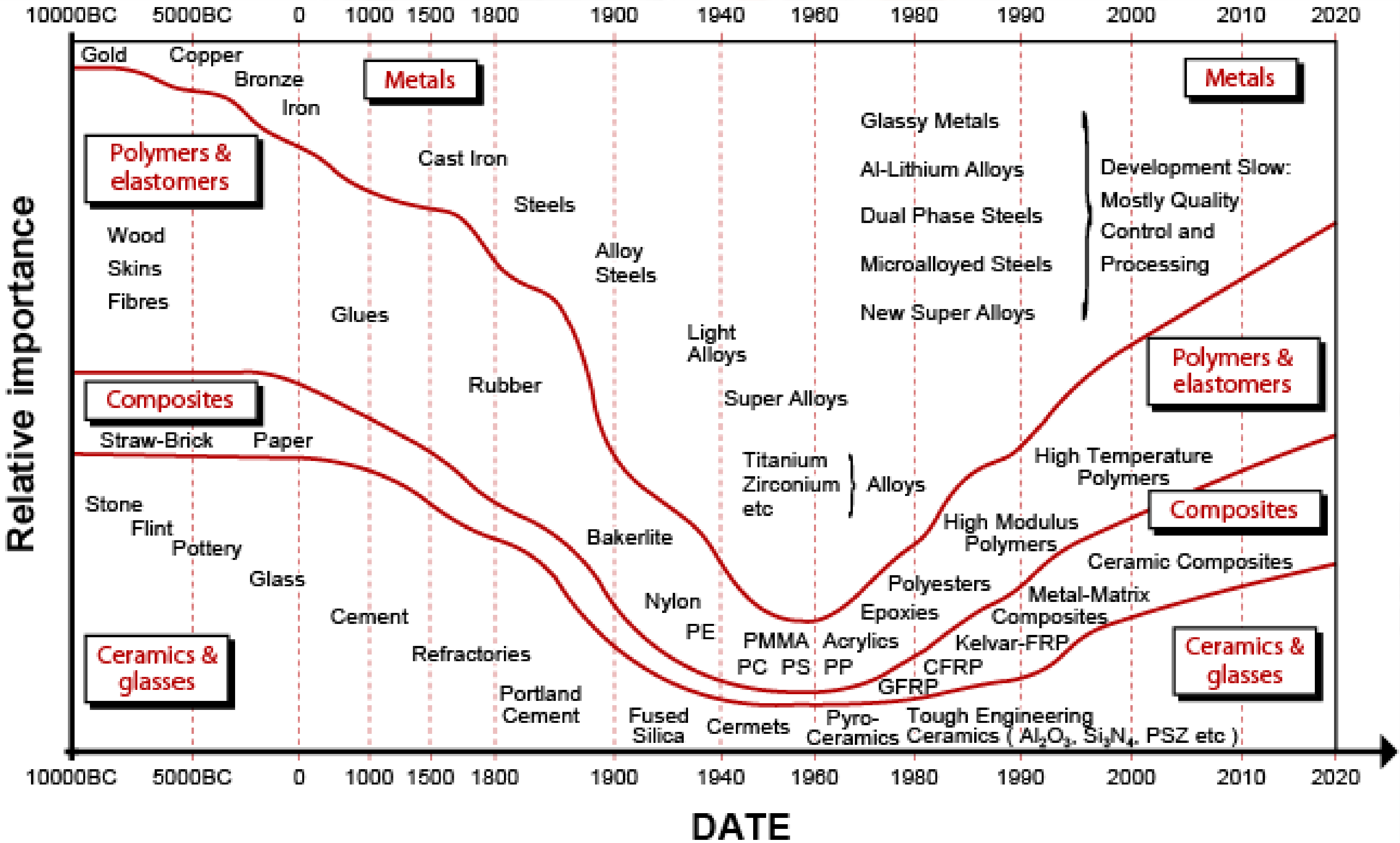






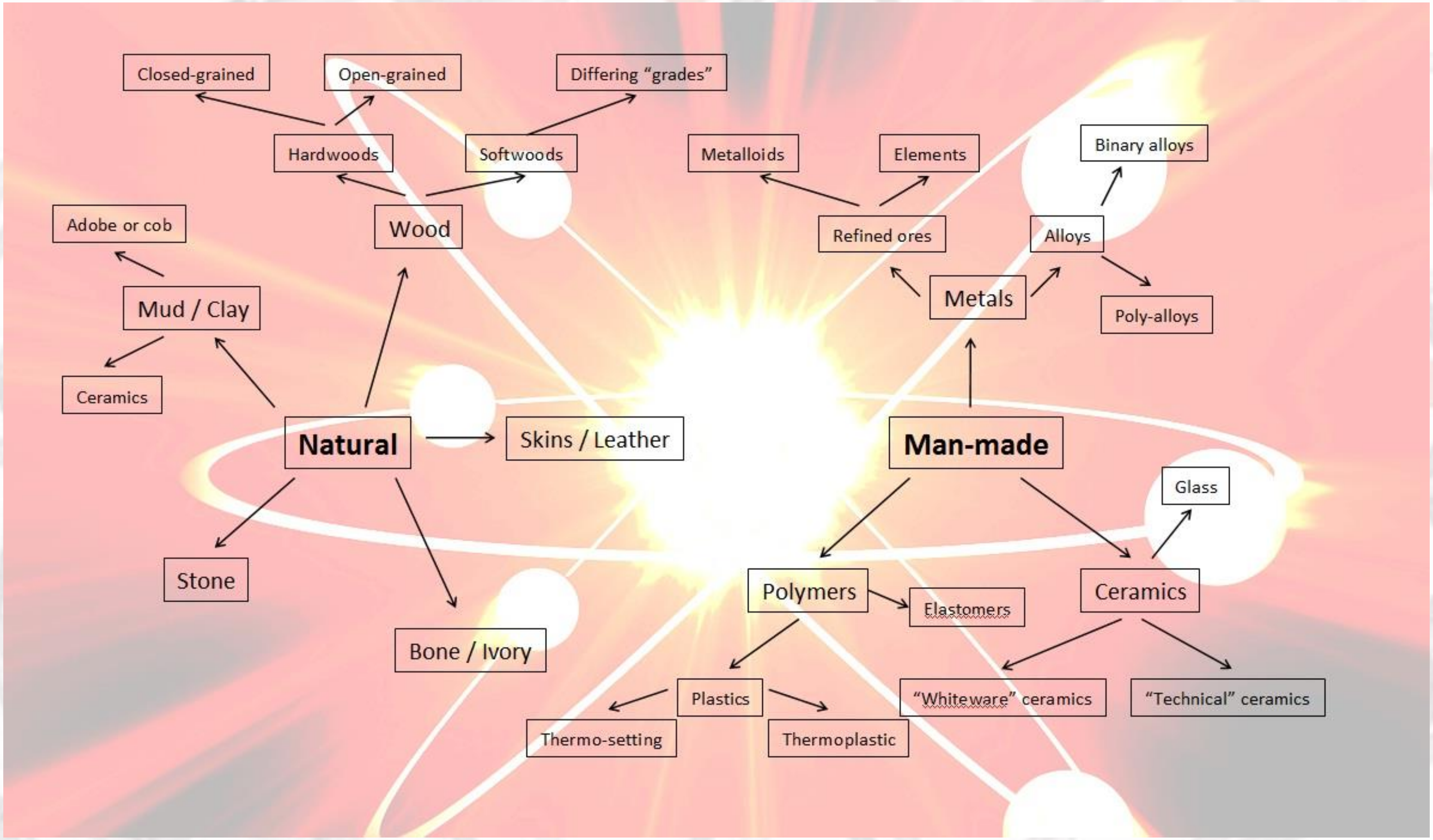


History – the evolution of materials

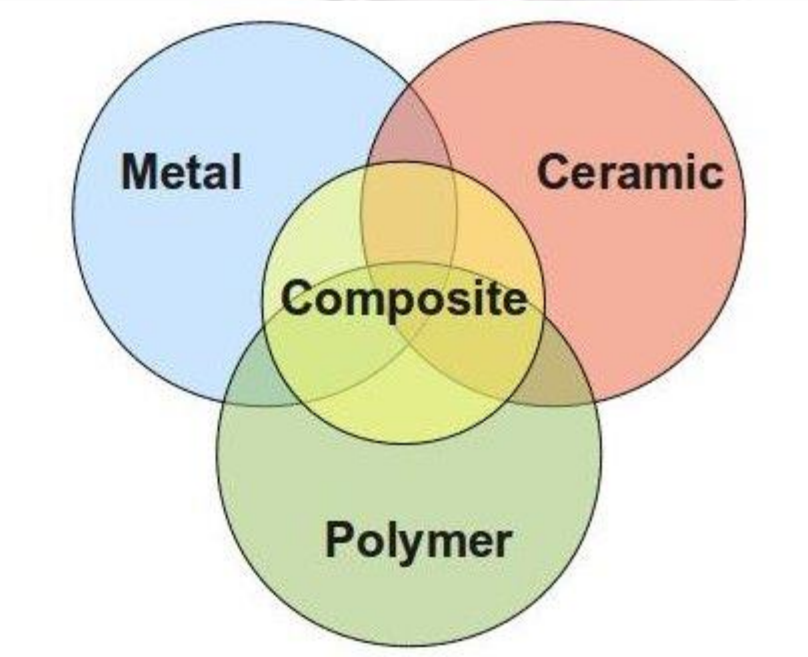


Classification of Materials

MATERIALS CLASSIFICATION



MATERIALS CLASSIFICATION



Composites: consist of more than one material type. Producing properties not found in any single material.

Examples: concrete, fiberglass, carbon-carbon-composite Kevlar-fiber composites .

Metals and Alloys: valence electrons are detached from atoms, and spread in an 'electron sea' that "glues" the ions together (**metallic bonding**). Strong, ductile, with high electrical and heat conductivity.
Examples: Al, Cu, Ni, Ti, steels and etc.

Ceramics: atoms behave like either positive or negative ions, and are bound by Coulomb forces (**ionic bonding**). They are usually combinations of metals or non-metals with oxygen, nitrogen or carbon (oxides:Al_2O_3, SiO_2; nitrides: TiN Si_3N_4; and carbides: TiC, SiC). Hard, brittle, insulators.
More examples: glass, porcelain.

Polymers: are bound by **covalent** forces (electrons are shared between atoms) and also by weak van der Waals forces (**secondary bonding**), and usually based on C and H. They decompose at moderate temperatures (100 – 400 C), and are lightweight. Examples: plastics rubber.

Classification of Materials (Metals)

•Metals can be further classified as Ferrous & Non-Ferrous, some examples include;

Ferrous	Non-Ferrous
Steels	Aluminium
Stainless Steels	Copper
High Speed Steels	Brass
Cast Irons	Titanium

Classification of Materials (Ceramics)

- Ceramics are compounds of metallic and non-metallic elements, examples include;

- Oxides (alumina – insulation and abrasives, zirconia – dies for metal extrusion and abrasives)
- Carbides (tungsten-carbide tools)
- Nitrides (cubic boron nitride, 2nd in hardness to diamond)

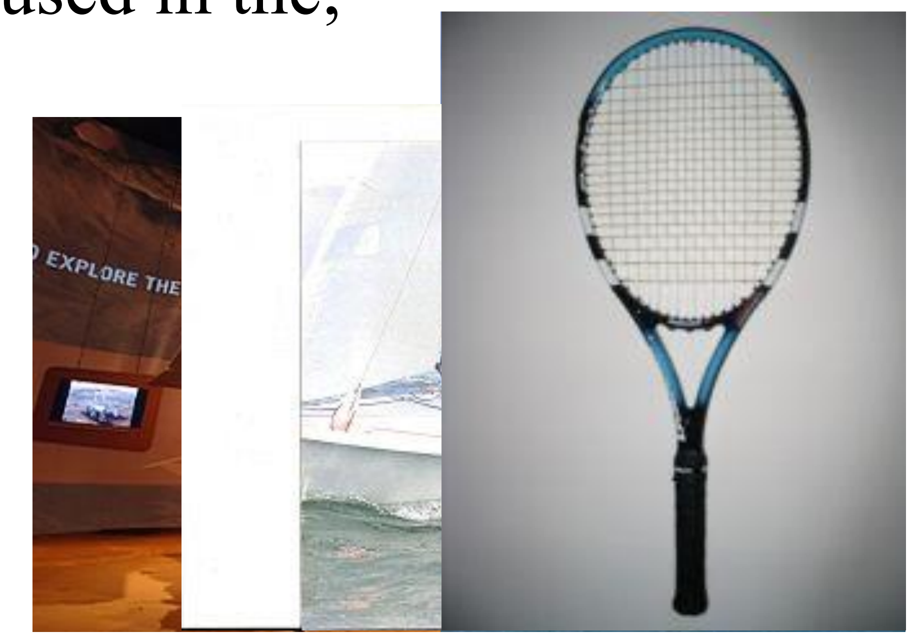
Classification of Materials (Plastics)

- Plastics can be further classified as;
- Thermoplastic
- Thermoset
- Elastomers

Thermoplastics	**Thermosets**	**Elastomers**
Acrylics	Epoxy resins	Rubbers
Nylons	Phenolic	Silicones
PVC	Polyesters	Polyurethanes
Polyethylene		

Classification of Materials (Composites)

- A composite is a combination of two or more chemically distinct materials whose physical characteristics are superior to its constituents acting independently.
- Because of their high strength/stiffness to weight ratio they are widely used in the;
- Aerospace industry
- Offshore structures
- Boats
- Sporting goods



The Materials Science Mantra:

The ***properties*** of a material depend upon its ***composition*** and ***microstructure***

The ***microstructure*** of a material depends upon its ***composition*** and the ***processing*** that it undergoes

Structure

Q1: What is materials' composition?

- Composition: the chemical make up of a material!
- Examples: C – carbon; BN- boron nitride; $La_{0.6}Sr_{0.4}Fe_{0.7}Ni_{0.3}O_3$ – lanthanum-based perovskite

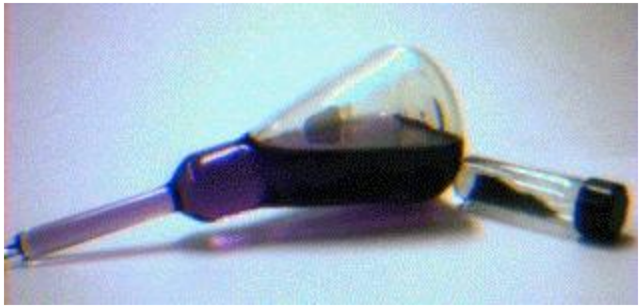
Q2: What are materials' properties?

- *Mechanical Properties* describe how well a material withstands applied forces, including tensile or compressive, impact, cycling or fatigue at room or high temperature
- *Physical properties* describe material characteristics such as color, elasticity, electrical and thermal conductivity, magnetism and optical behavior that generally are not significantly influenced by forces acting on a material.

Q3: Can materials have same composition but possess different properties?

- Answer: **Yes !!!**
- Examples: C – carbon can be in different modifications,

  e.g. **graphite, diamond, Bucky ball.**



Graphite, is a **black**, lustrous solid that is **completely opaque**.

Pure diamonds are **clear** and **colorless**

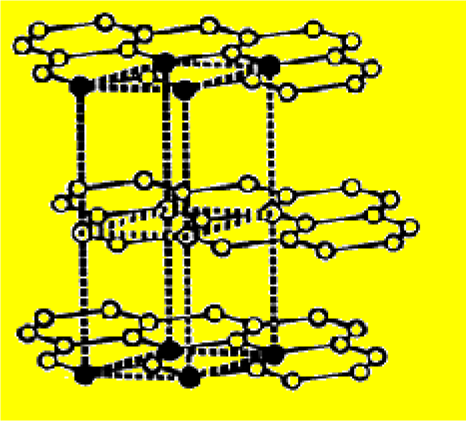
In solution buckminsterfullerene deep **red color** is revealed

Q4: Why it could be so?

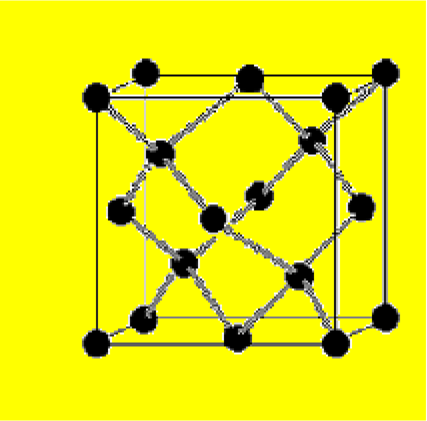
The properties are defined by ***material structure***!

Material structure describes the arrangement of atoms or ions in material and profoundly influences the material properties

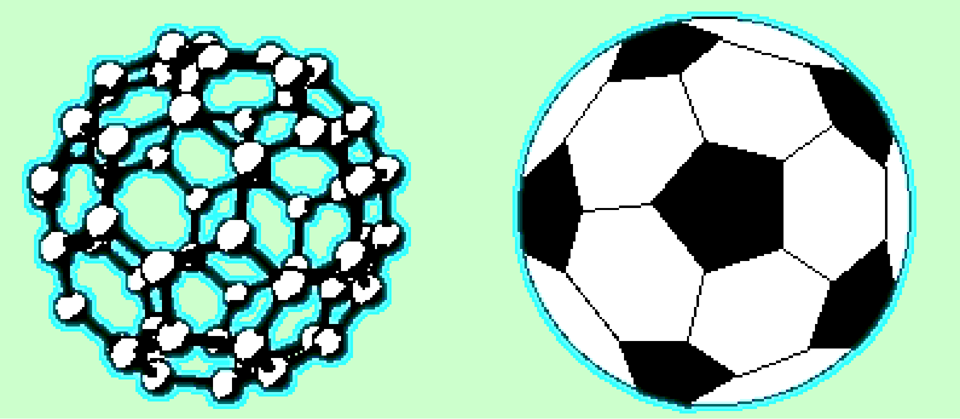
graphite



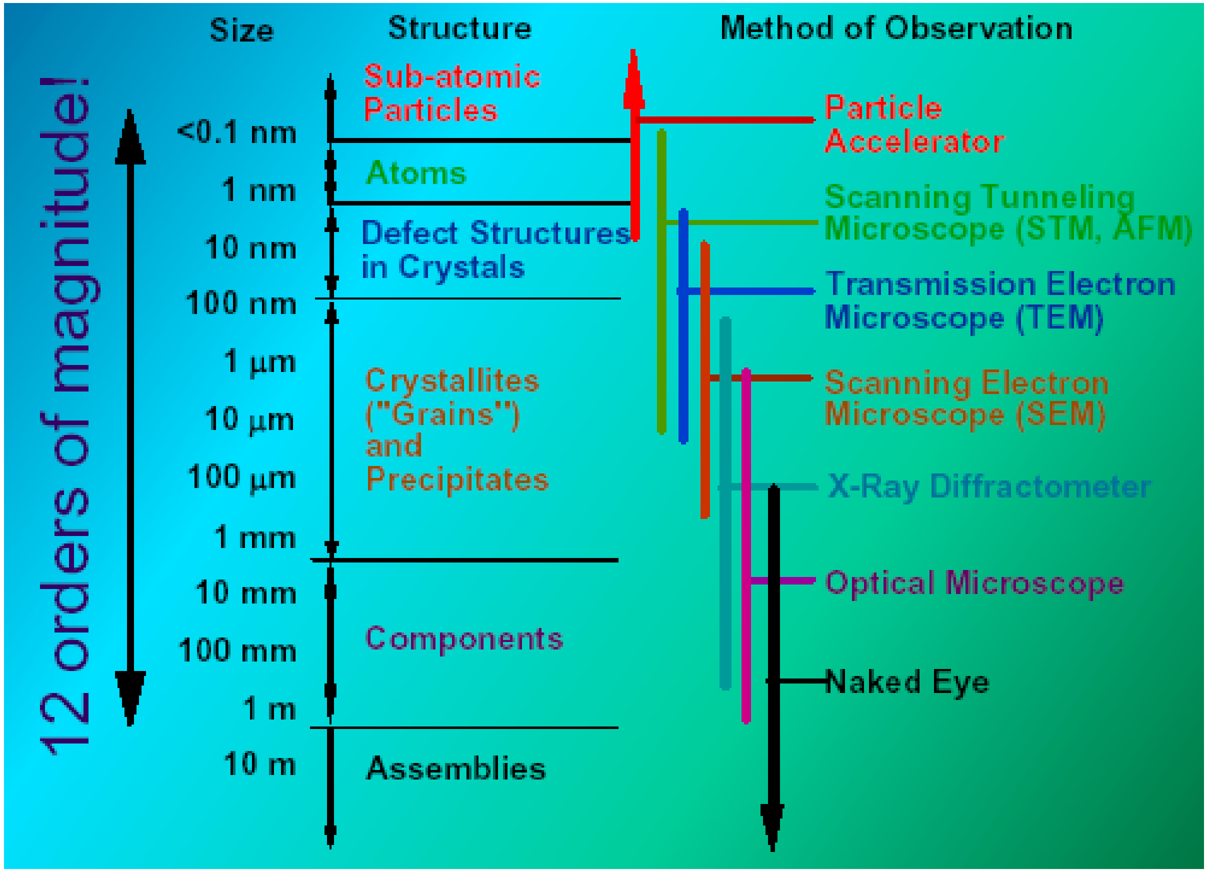
diamond



Bucky ball



Scale of Structure Organization



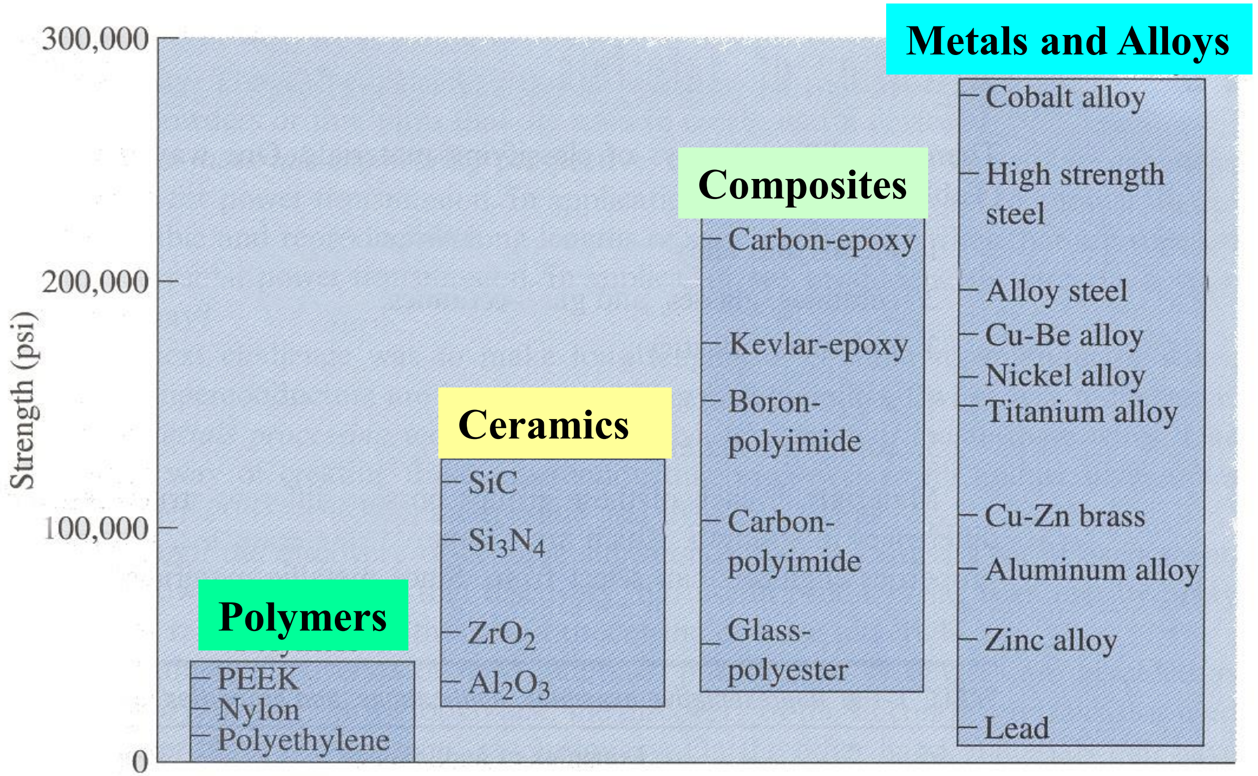
Units:

micrometer = 10^{-6}m = 1µm
nanometer= 10^{-9} m = 1nm
Angstrom = 10^{-10} m = 1Å

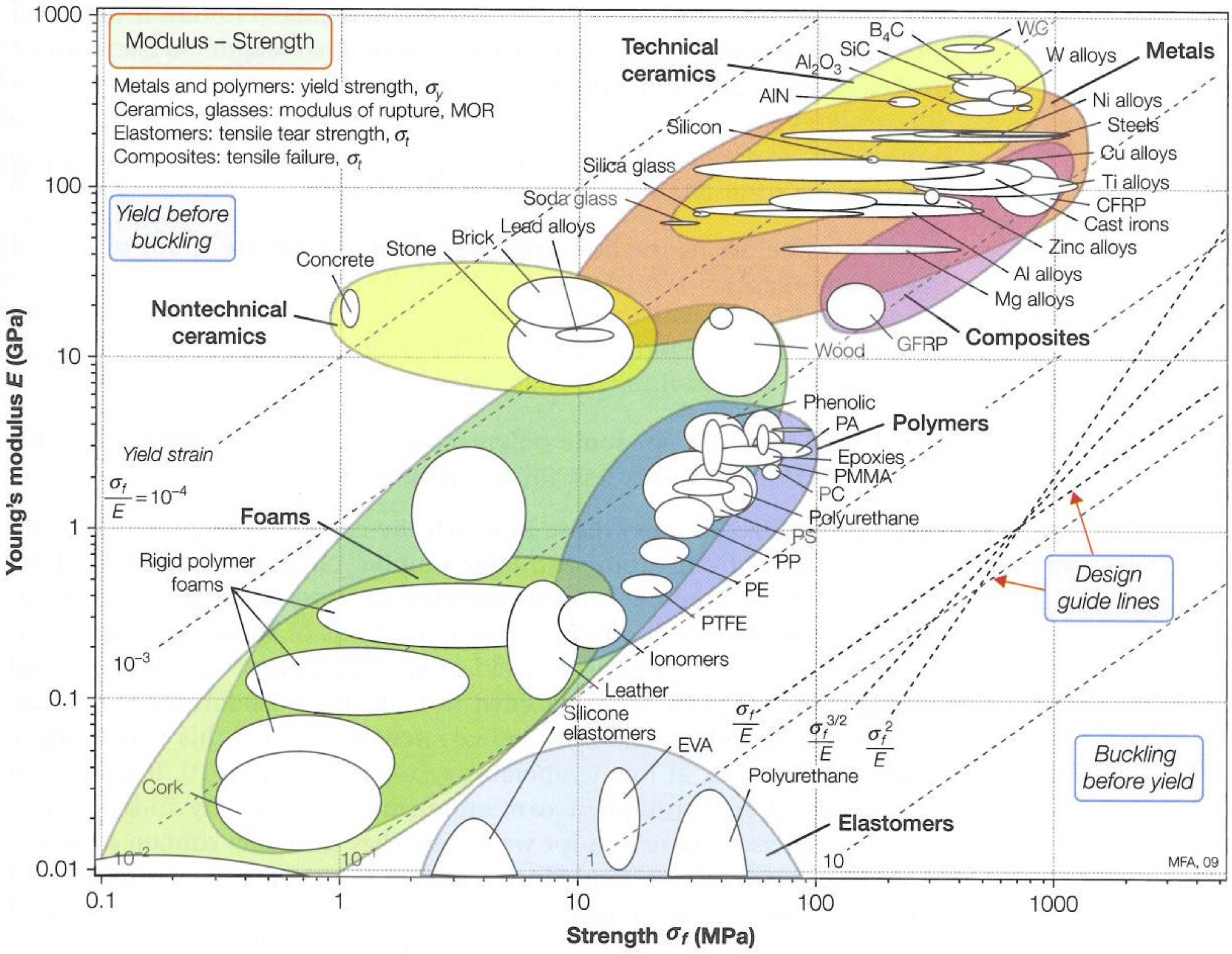
- **A hair is ~ 100 µm**
- **A diameter of single wall carbon nanotube ~ 2 nm**
- **A size of H_2 molecule ~ 2.5 Å**

Properties

MECHANICAL PROPERTIES

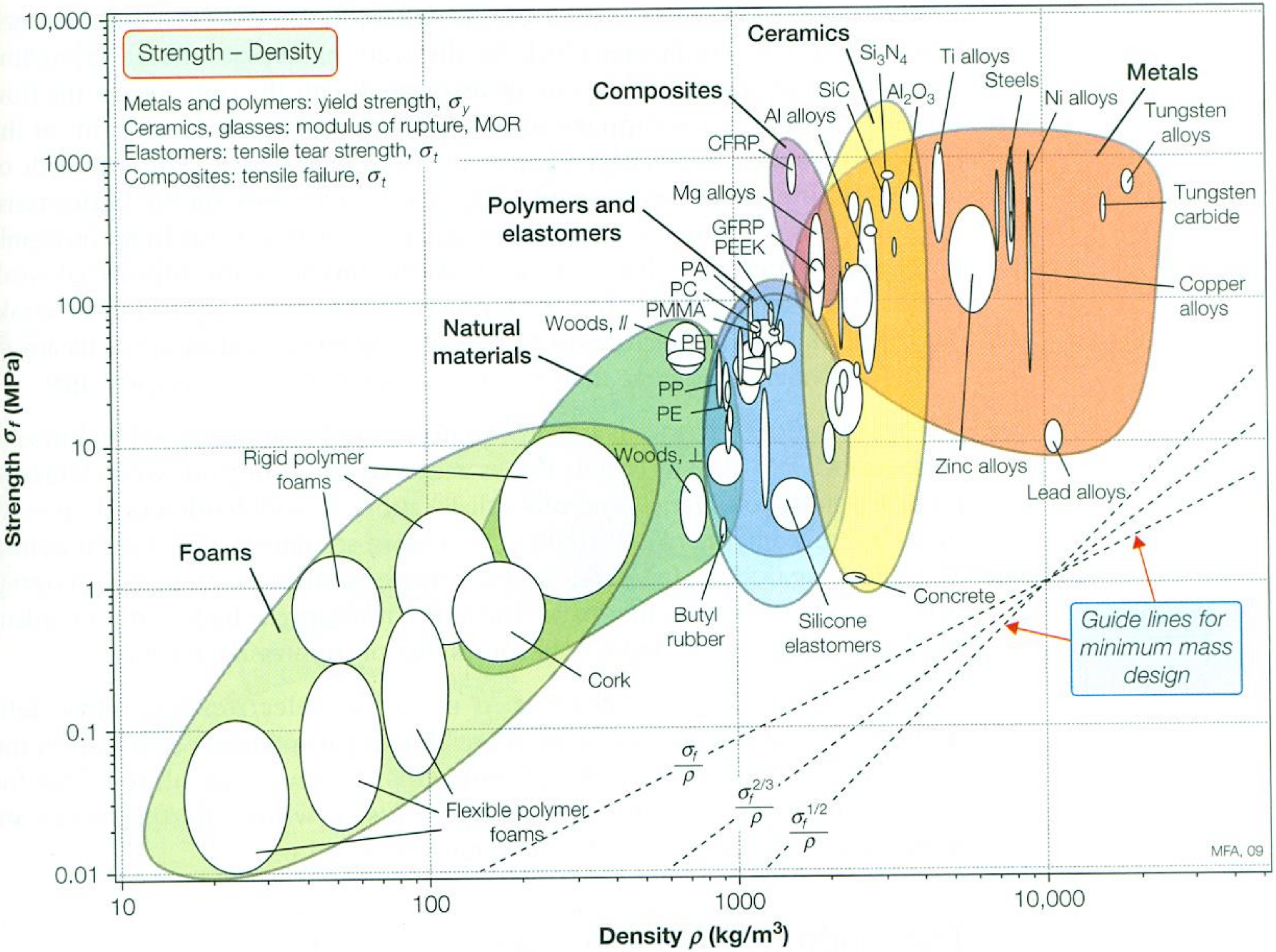


Stress - force per unit area; **Strain** – change of dimension divided by original dimension; If the strain goes away after the stress is removed – **elastic** strain;
If the strain remains – **plastic** strain; During elastic deformation stress and strain are linearly related with the slope known as **Young's modulus**; A level of stress needed to initiate plastic deformation is called **yield strength**;
The maximum percent of deformation is a measure of the material **ductility**



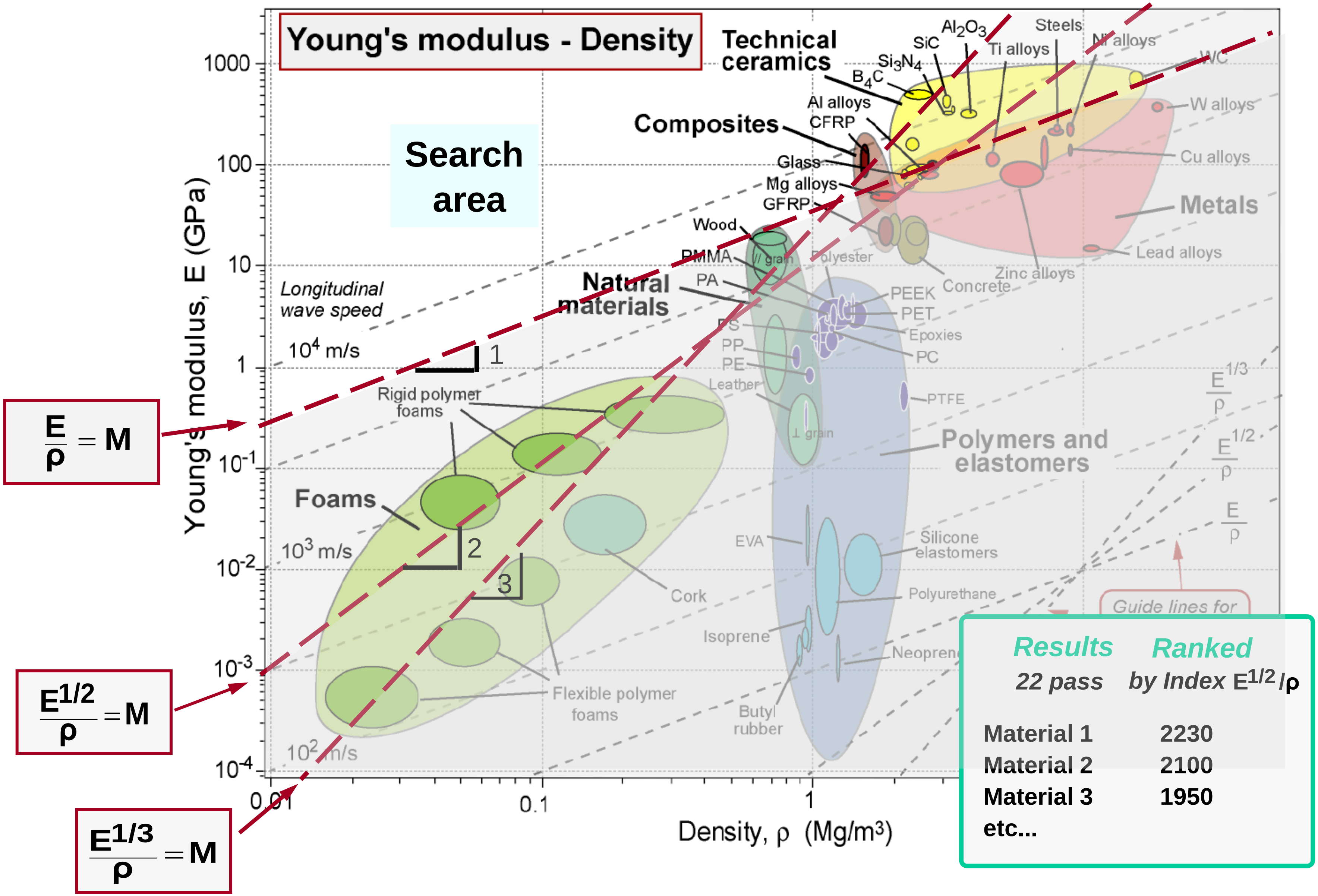
Modulus – Strength
Metals and polymers: yield strength, σ_y
Ceramics, glasses: modulus of rupture, MOR
Elastomers: tensile tear strength, σ_t
Composites: tensile failure, σ_t
Yield before buckling
Buckling before yield
Design guide lines
Yield strain
$\frac{\sigma_f}{E} = 10^{-4}$
10^{-3}
10^{-2}
10^{-1}
1
10
$\frac{\sigma_f}{E}$
$\frac{\sigma_f^{3/2}}{E}$
$\frac{\sigma_f^2}{E}$
Technical ceramics
B_4C
SiC
Al_2O_3
AlN
WC
Silicon
Silica glass
Soda glass
Metals
W alloys
Ni alloys
Steels
Cu alloys
Ti alloys
CFRP
Cast irons
Zinc alloys
Al alloys
Mg alloys
GFRP
Composites
Lead alloys
Brick
Stone
Concrete
Nontechnical ceramics
Wood
Phenolic
PA
Polymers
Epoxies
PMMA
PC
Polyurethane
PS
PP
PE
PTFE
Ionomers
Leather
Foams
Rigid polymer foams
Cork
Silicone elastomers
EVA
Polyurethane
Elastomers
MFA, 09
Young's modulus E (GPa)
1000
100
10
1
0.1
0.01
Strength σ_f (MPa)
0.1
1
10
100
1000

FIGURE 4.5



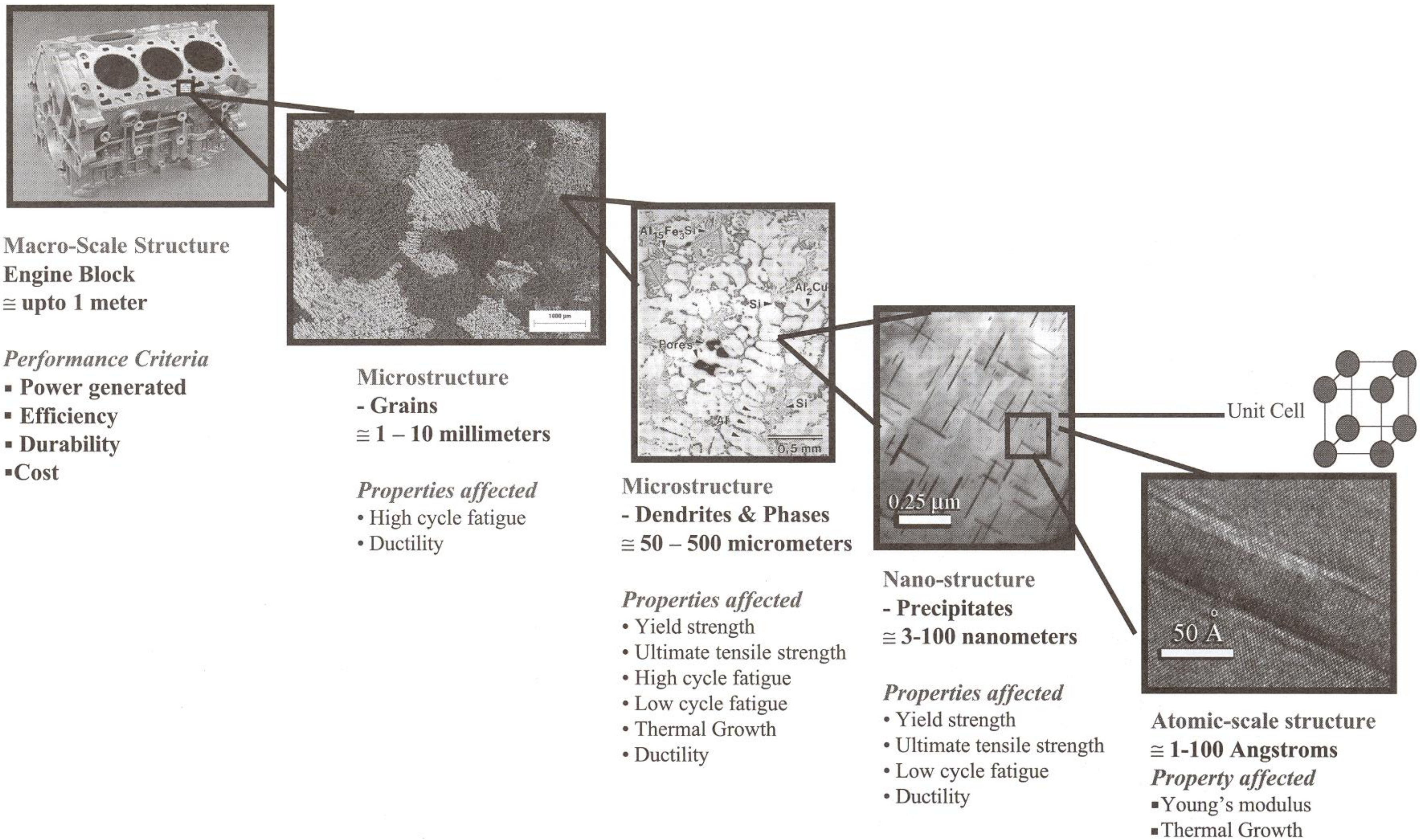
Strength – Density
Metals and polymers: yield strength, σ_y
Ceramics, glasses: modulus of rupture, MOR
Elastomers: tensile tear strength, σ_t
Composites: tensile failure, σ_t
Ceramics
Si_3N_4
SiC
Al_2O_3
Ti alloys
Steels
Metals
Ni alloys
Tungsten alloys
Tungsten carbide
Copper alloys
Composites
Al alloys
CFRP
Mg alloys
GFRP
PEEK
Polymers and elastomers
PA
PC
PMMA
PET
PP
PE
Natural materials
Woods, //
Woods, ⊥
Rigid polymer foams
Foams
Cork
Flexible polymer foams
Butyl rubber
Silicone elastomers
Concrete
Zinc alloys
Lead alloys
Guide lines for minimum mass design
$\frac{\sigma_f}{\rho}$
$\frac{\sigma_f^{2/3}}{\rho}$
$\frac{\sigma_f^{1/2}}{\rho}$
MFA, 09
Strength σ_f (MPa)
Density ρ (kg/m^3)
10,000
1000
100
10
1
0.1
0.01
10
100
1000
10,000

Optimized selection using charts



Structure-Properties Relation

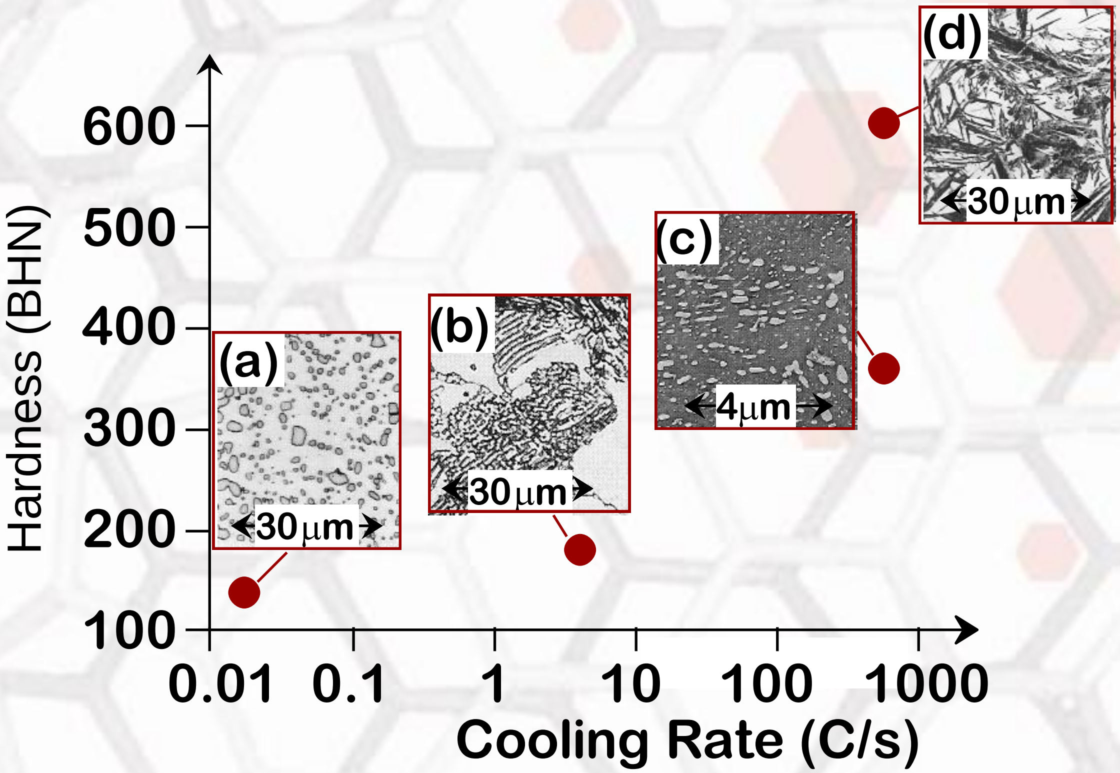
STRUCTURE –PROPERTY RELATIONS



Structure, Processing, & Properties

- Properties depend on structure

  ex: hardness vs structure of steel

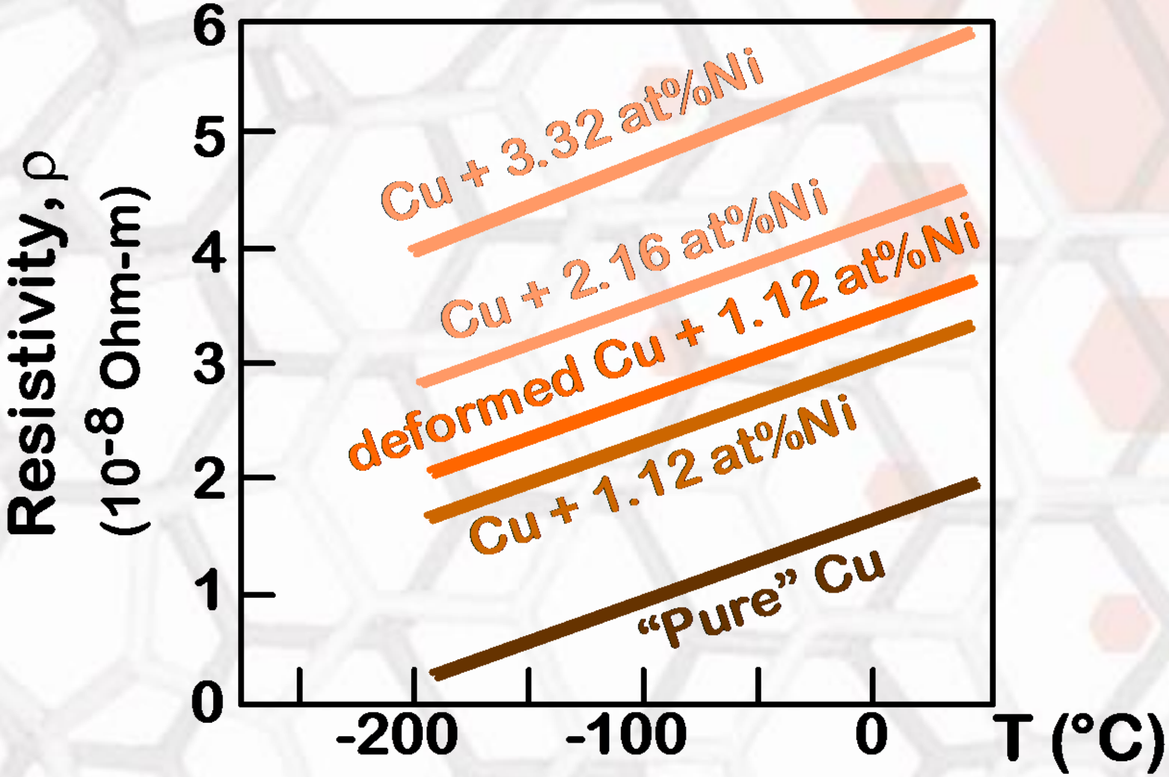


- Processing can change structure

  ex: structure vs cooling rate of steel

ELECTRICAL

- Electrical Resistivity of Copper:

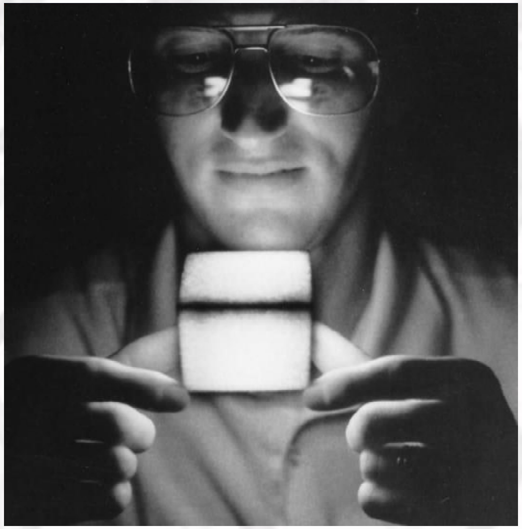


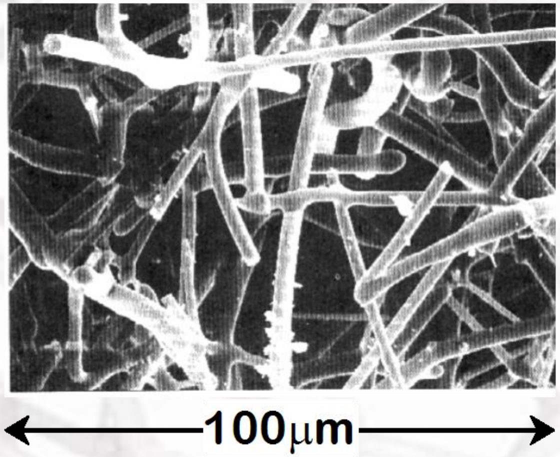
- Adding "impurity" atoms to Cu increases resistivity.
- Deforming Cu increases resistivity.

THERMAL

- Space Shuttle Tiles:

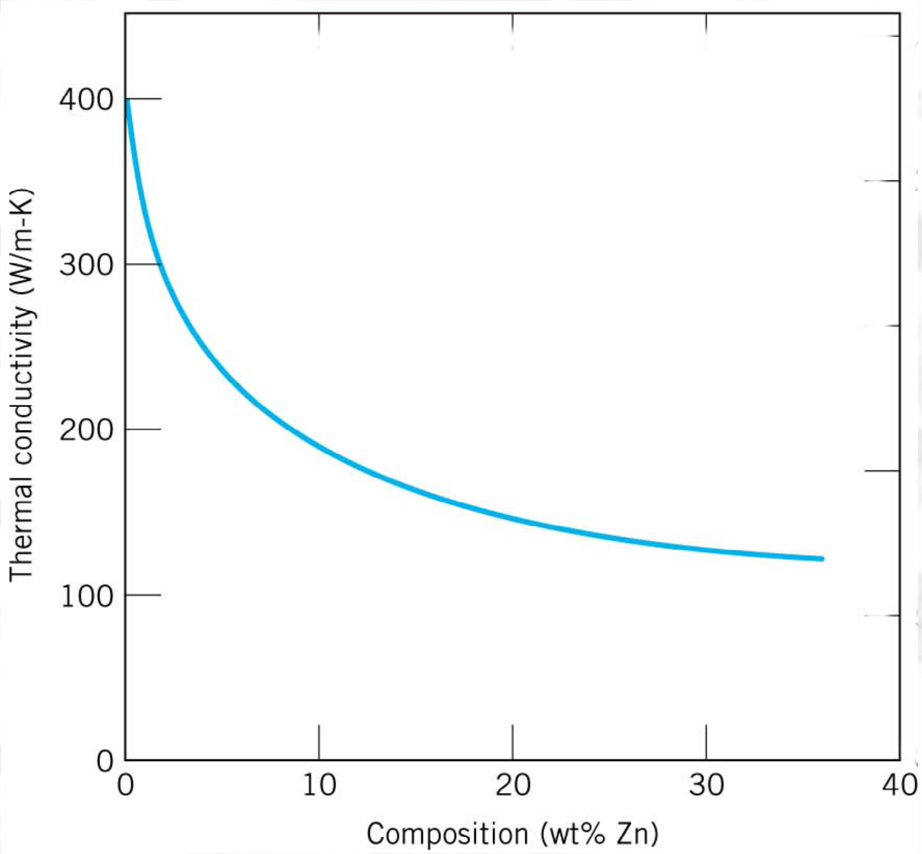
  -Silica fiber insulation offers low heat conduction.





- Thermal Conductivity of Copper:

  -It decreases when you add zinc!



OPTICAL

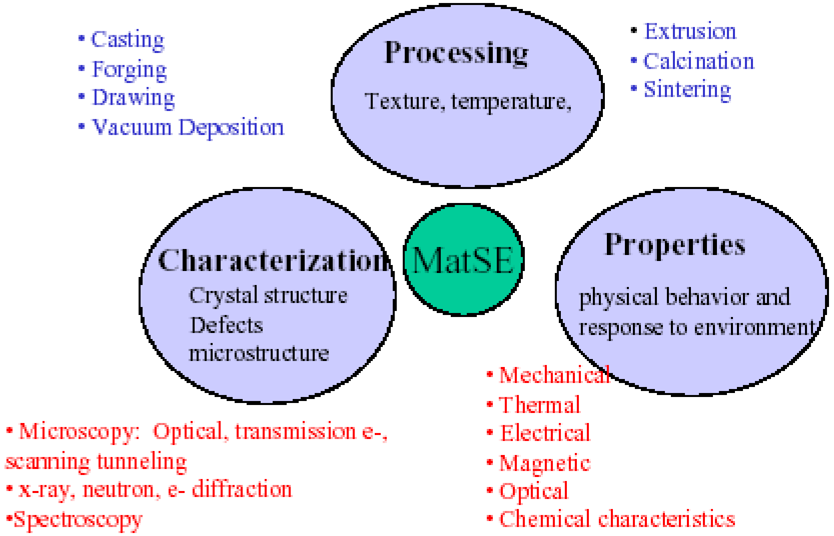
- Transmittance:
  --Aluminum oxide may be transparent, translucent, or opaque depending on the material structure.

single crystal

polycrystalline: low porosity

polycrystalline: high porosity

SYNTHESIS & PROCESSING



"Synthesis": how materials are made from chemicals.

<u>Examples:</u>

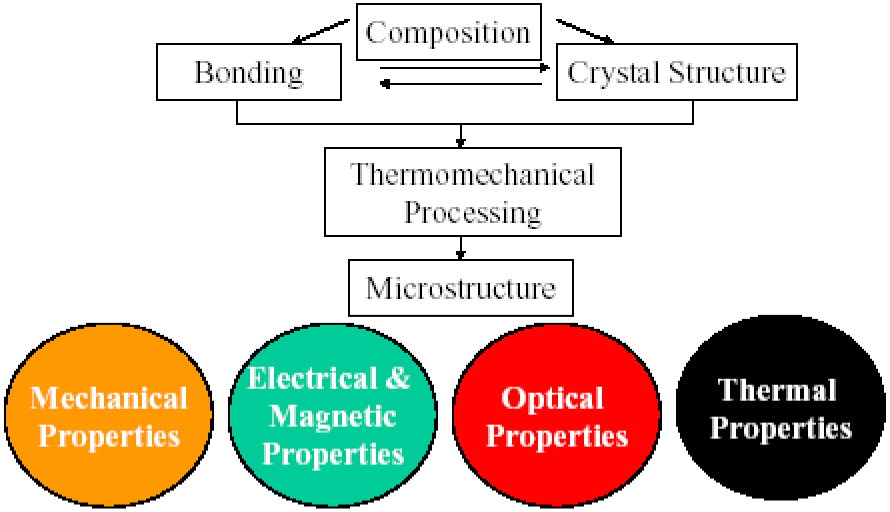
- Reaction Sintering (RS)
- Chemical Vapor Deposition (CVD)
- Combustion Synthesis (CS)

"Processing": how materials are shaped into useful components to cause changes in their properties.

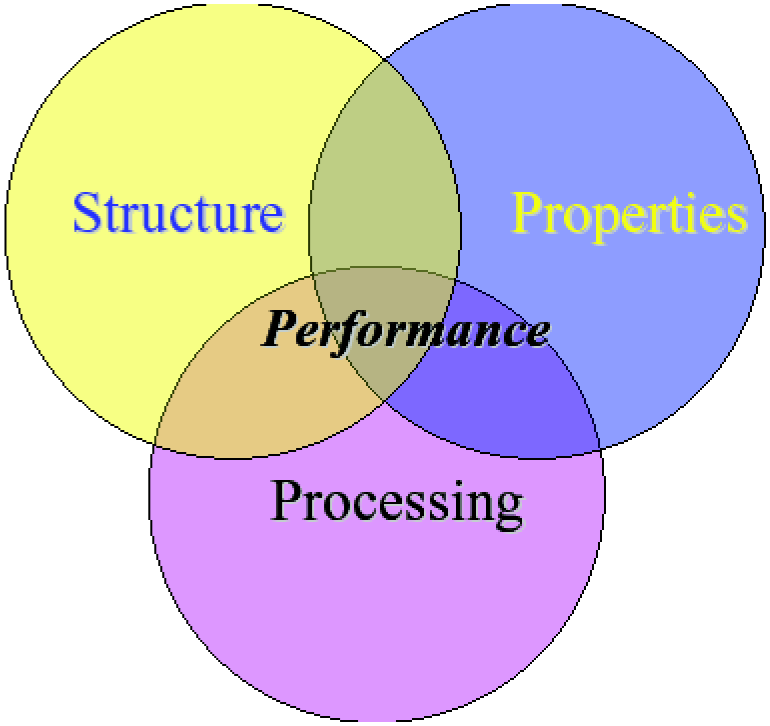
<u>Examples:</u> metal casting, cold work.

Composition, atomic, crystalline and microstructures **<u>define</u>** material properties, but also processing does!

What is MSE?



Composition
Bonding
Crystal Structure
Thermomechanical Processing
Microstructure
Mechanical Properties
Electrical & Magnetic Properties
Optical Properties
Thermal Properties

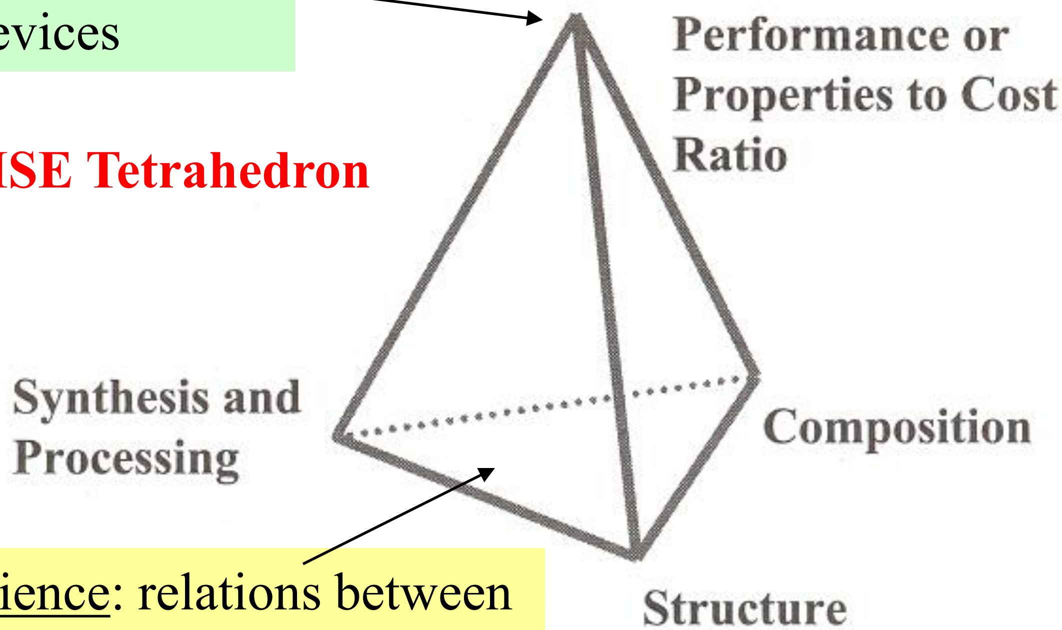


Structure
Properties
Performance
Processing

WHAT IS MATERIALS SCIENCE & ENGINEERING (MSE)?

Materials Engineering: material transformation to useful devices

MSE Tetrahedron



Materials Science: relations between synthesis/processing parameters and material composition/structure and its properties

Conclusion

- ***MSE*** an interdisciplinary field of science concerned with ***inventing new*** and improving previously known materials by developing a ***deeper*** understanding of the ***microstructure-composition-synthesis-processing*** relationship.