Introduction to Materials Science and Engineering

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Lecture times: Tue, Thur 1:30 pm Lecture room 218
Discussion time (면담 시간): Wednesday 11:00 am

Course Content (Autumn Semester)

Text book: Materials Science and Engineering: An Introduction
7th / 8th edition, William D. Callister and David G. Rethwisch

Chapter 1.	Introduction
Chapter 2.	Atomic structure & bonding in solids
Chapter 3.	The structure of metals
Chapter 4.	Defects in solids
Chapter 5.	Diffusion in solids

Mid-term exam

Chapter 6.	Mechanical properties
Chapter 9.	Phase diagrams for metallic systems
Chapter 10.	Phase transformations
Chapter 12.	Ceramic materials
Chapter 18.	Electrical properties of materials

Final exam

Homework: 2 homeworks

Grading: Attendance 20%
Mid Term 40%
Final Exam 40%

Course Objective

Introduce fundamental concepts of Materials Science

You will learn about:

- material structure
- how structure dictates properties
- how processing can change structure

The Importance of Materials

Quality of life: Clothing, housing, transportation, communication, food production....

A definition of culture:	**Stone Age**	2.5 million years ago
	Copper Age	~5500-3000 BC
	Bronze Age	3000-1000 BC – the first alloy
	Iron Age	1200-1 BC
Pottery	10,000 BC	
Glass	4000 BC	

Over the past 100 years – understanding or the link between structure and properties.

Materials enable technological progression
e.g. Cheap steel – automobiles
Single crystal silicon - computers

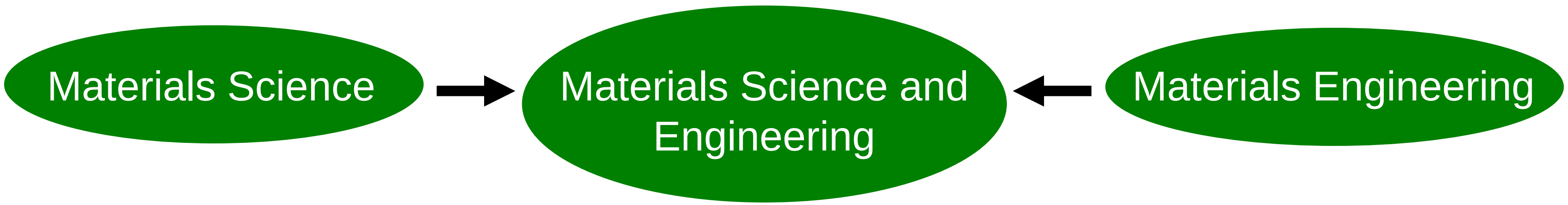
What is Materials Science and Engineering?

Materials Science: Study of the relationship between a material's structure and it's properties.

Materials Engineering: Designing / engineering a material's structure to produce the desired properties.

Materials Scientists: Develop or synthesize new materials.

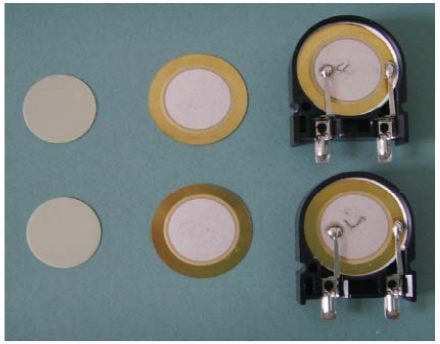
Materials Engineers: Create new products using existing materials / develop materials processing techniques.



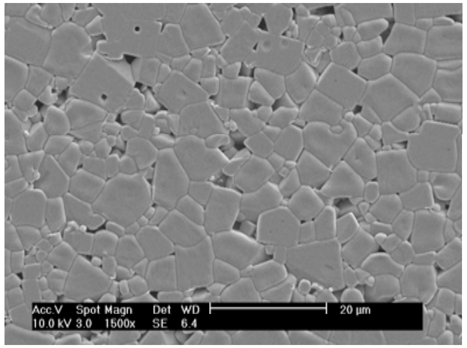
Structure

The arrangement of a material’s internal components.

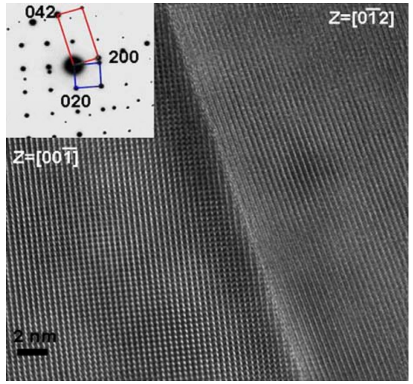
Macrostructure (>0.5mm / 500µm)



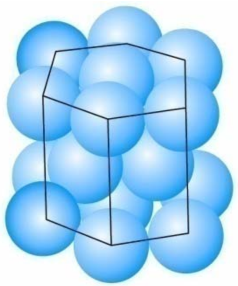
Microstructure (500µm – 0.5µm / 500nm)



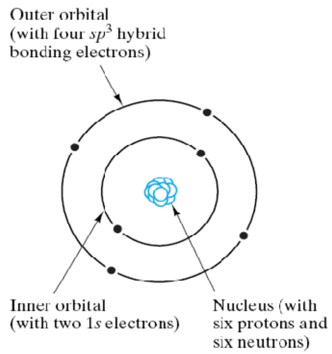
Nanostructure (500nm – 0.5nm)



Atomic structure



Subatomic structure

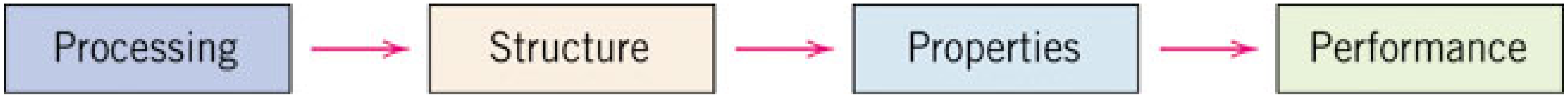


Properties

The response of a material to a stimulus e.g. force, light, electric field.

Mechanical	– response to an applied load or force
Electrical	– response to an electric field
Thermal	– response to heat
Magnetic	– response to a magnetic field
Optical	– response to electromagnetic radiation
Deteriorative	– response to chemicals

The relationship between processing, structure, properties and performance.

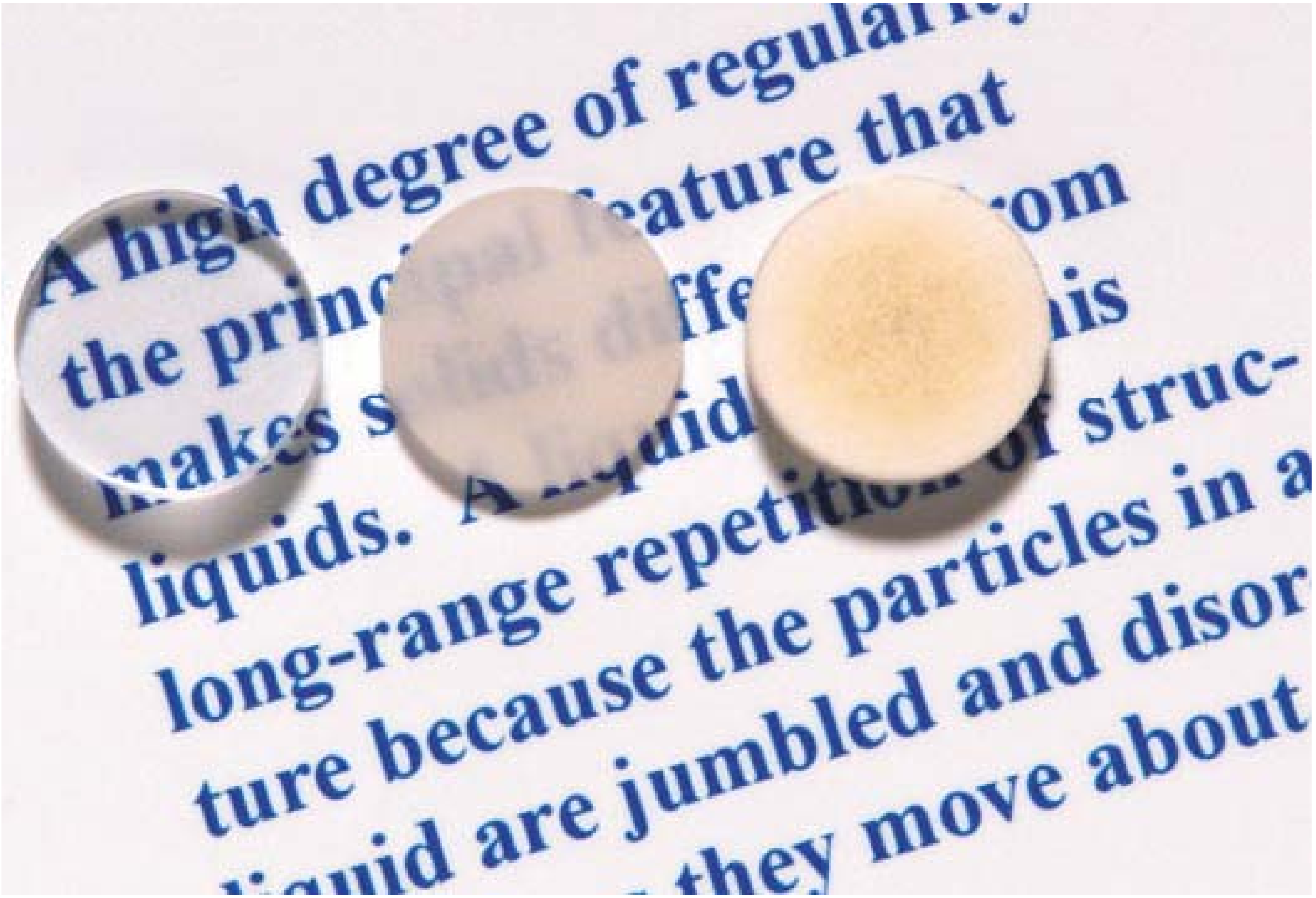


By understanding this relationship, we can:

- Predict and control the properties of materials.

- Design and develop new materials and new process technologies.

- Improve device performance by process development.



Light transmittance of (left) single crystal Al_2O_3, (centre) polycrystalline dense Al_2O_3 and (right) polycrystalline (~5% porosity) Al_2O_3

Types of Materials

Metals

Ceramics

Glasses

Polymers

Composites

Advanced Materials:	**Semiconductors** **Biomaterials**
Future Materials:	**Smart materials** **Nanoengineered materials**

Metals

Properties: strong, ductile, high thermal and electrical conductivity, shiny

Important alloy* metals: Fe, Al, Mg, Ti, Ni, Zn, Cu

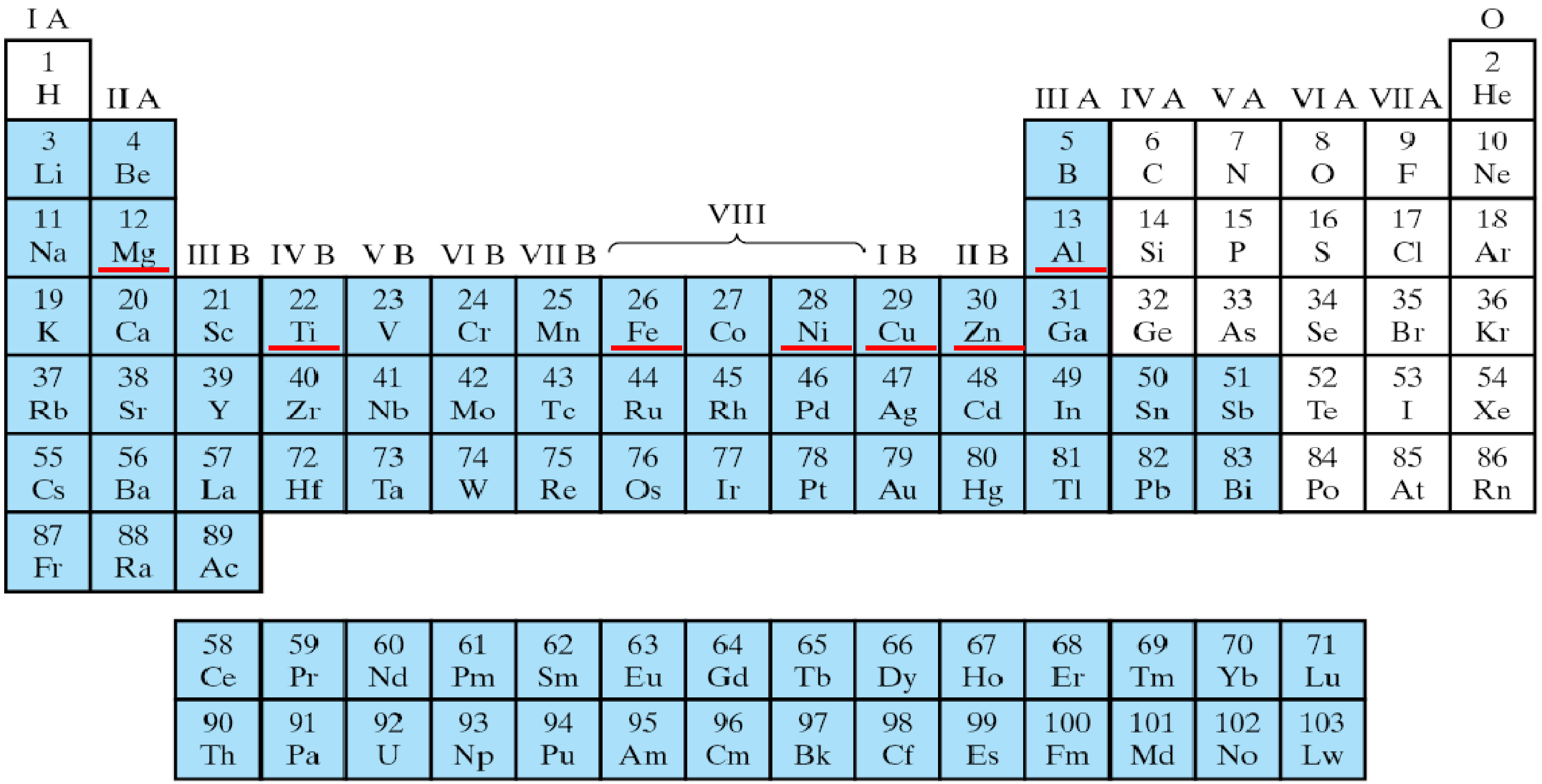


Figure 1-3 *Periodic table of the elements with those elements that are inherently metallic in nature in color.*

*alloy: a metallic material composed of two or more elements

Uses of Metals

Ceramics

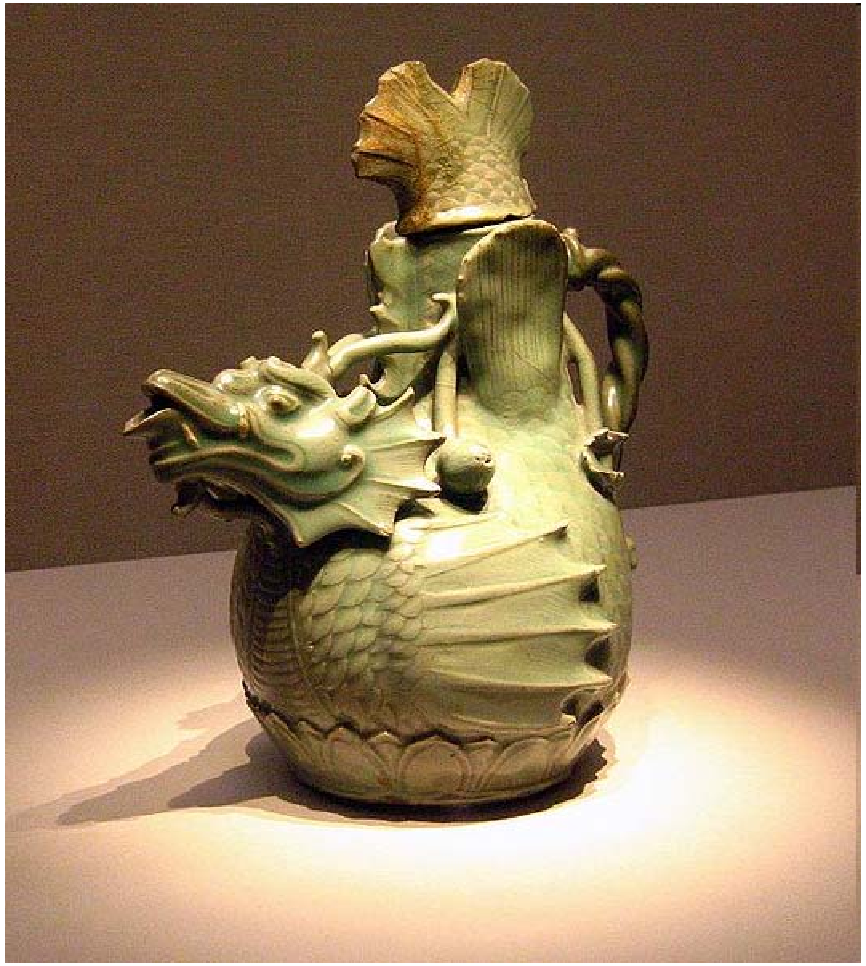
Compounds such as oxides (Al_2O_3) and carbides (WC); mostly crystalline, chemically stable, hard but brittle, usually non-conducting

I A	II A	III B	IV B	V B	VI B	VII B	VIII	VIII	VIII	I B	II B	III A	IV A	V A	VI A	VII A	O
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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
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
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
87 Fr	88 Ra	89 Ac															

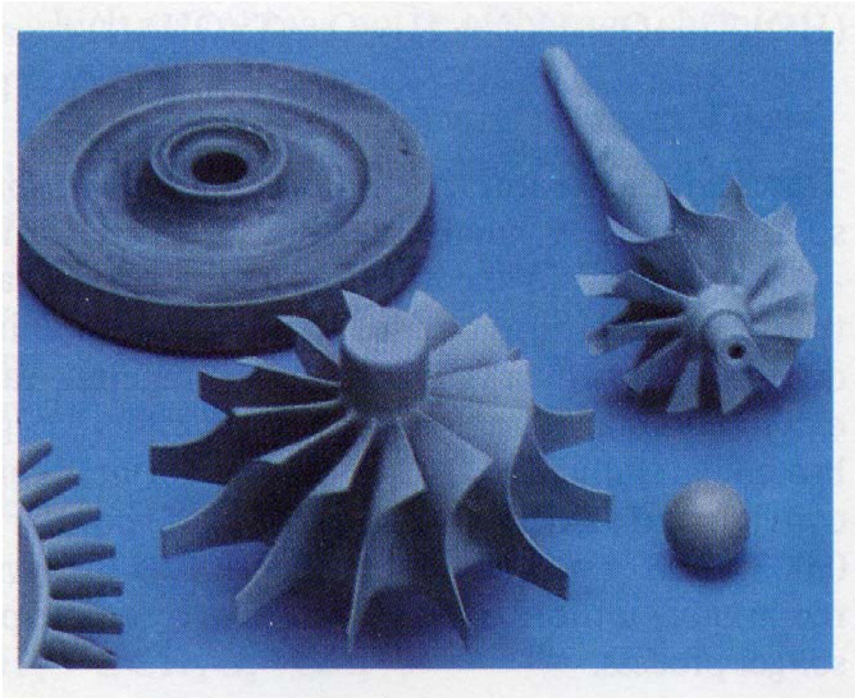
58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lw

Figure 1-5 *Periodic table with ceramic compounds indicated by a combination of one or more metallic elements (in light color) with one or more nonmetallic elements (in dark color). Note that elements silicon (Si) and germanium (Ge) are included with the metals in this figure, but were not in Figure 1–3. This is because, in elemental form, Si and Ge behave as semiconductors (Figure 1–16). Elemental tin (Sn) can be either a metal or a semiconductor, depending on its crystalline structure.*

Uses of Ceramics



Korean celadon incense burner from the Goryeo period (918-1392)



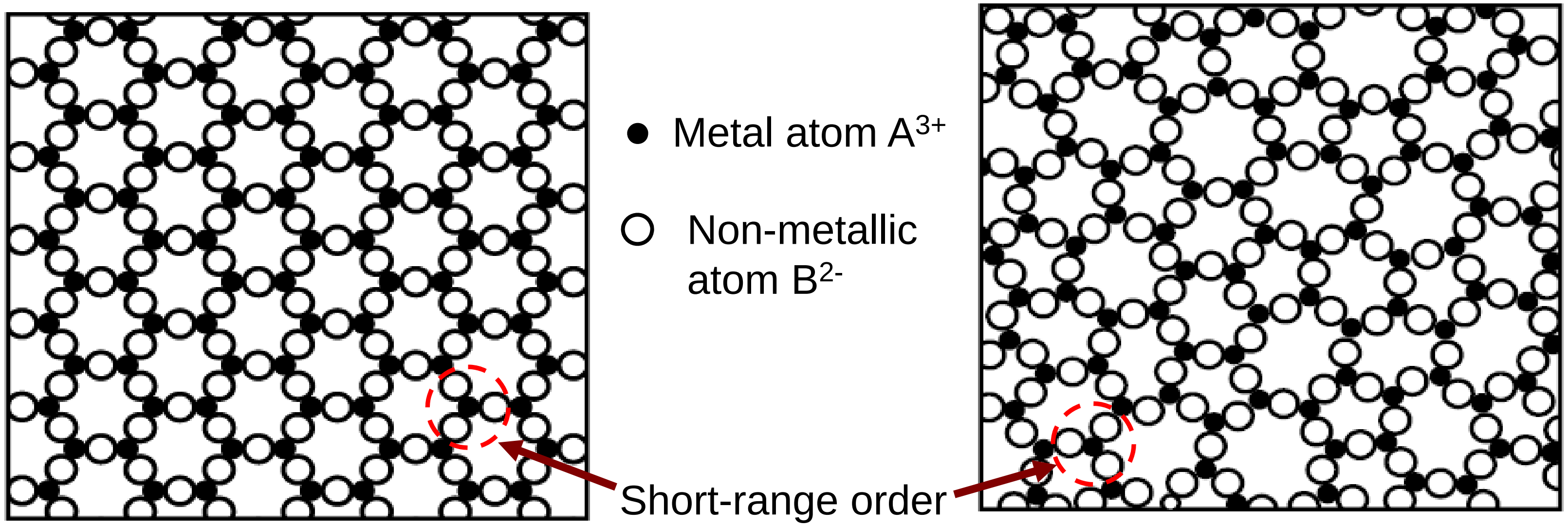
Silicon nitride parts

Glasses and Glass Ceramics

Metals and ceramics are crystalline i.e. both short and long range order.

Glasses: <u>Non-crystalline</u> i.e. short range order only.
Mostly silicate (-SiO_2); chemically stable, brittle, transparent

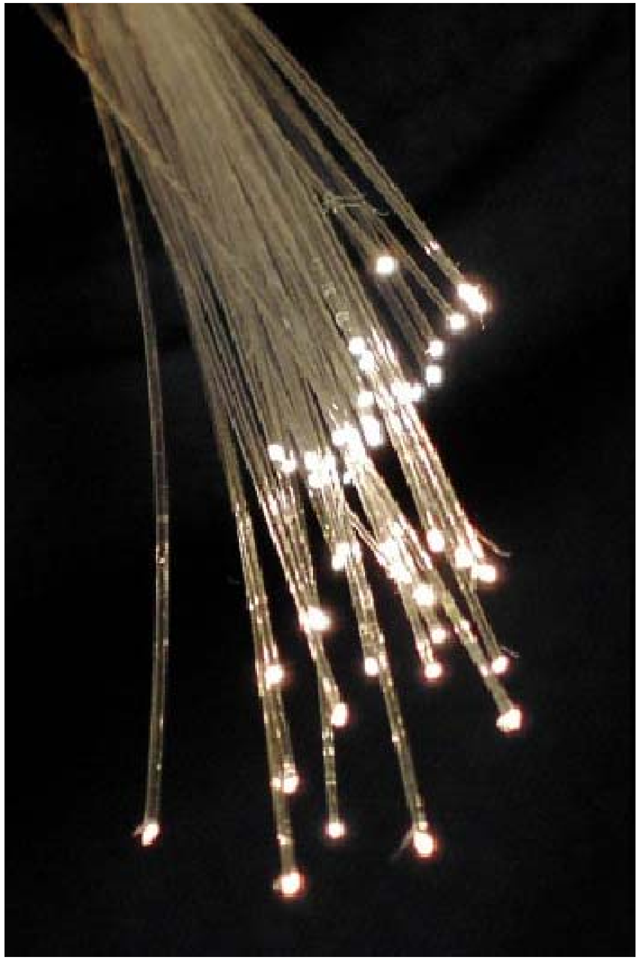
Glass ceramic: A glass which is heat treated to cause devitrification.
High strength, low thermal expansion coefficient (lithium aluminosilicate).



Crystalline ceramic A_2B_3 — Non-crystalline glass A_2B_3

Uses of Glasses

Glasshouse



Optical fibres

Polymers

Polymers (plastics) are organic materials.
Single hydrocarbon molecules (mer) are joined together to form long-chain molecules.

e.g. Ethylene (C_2H_4) $\rightarrow$ Polyethylene $-\!\!\left(C_2H_4\right)\!\!-_n$, where n = ~100-1000

Properties: ductile, low strength, low T_m, light, cheap!

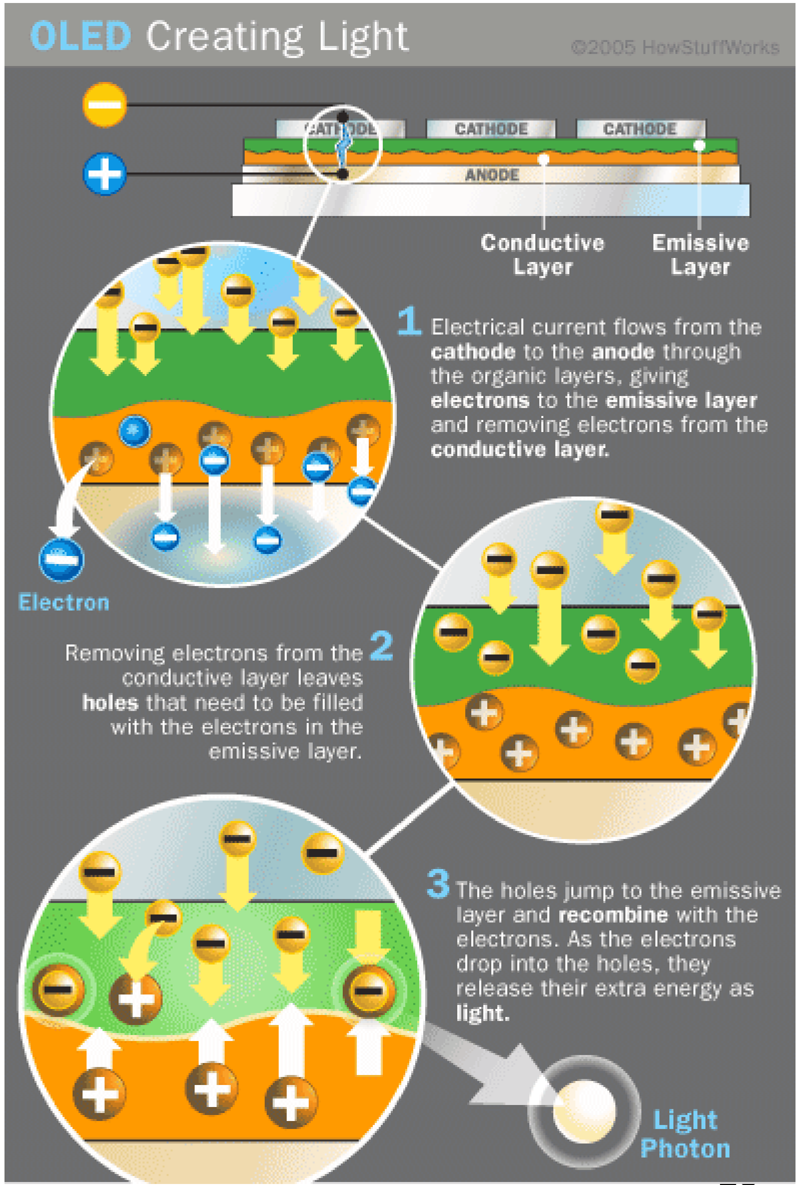
Acrylics (C, H, O); Nylons (C, H, N), fluoroplastics (C, H, F e.g. Teflon), Silicones (C, H, O, Si)

I A	II A	III B	IV B	V B	VI B	VII B	VIII	VIII	VIII	I B	II B	III A	IV A	V A	VI A	VII A	O
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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
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
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
87 Fr	88 Ra	89 Ac															

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
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 Lw

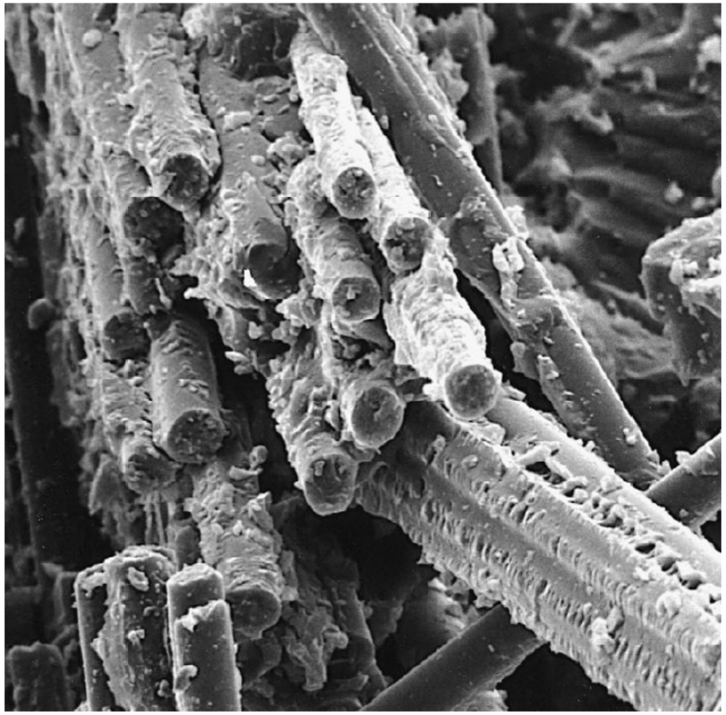
Figure 1-12 *Periodic table with the elements associated with commercial polymers in color.*

Uses of Polymers



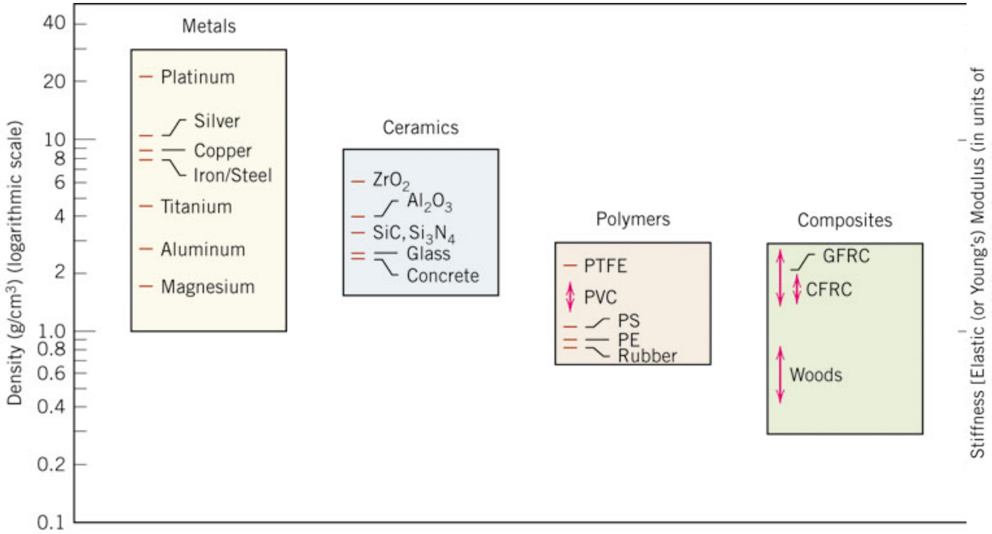
Composites

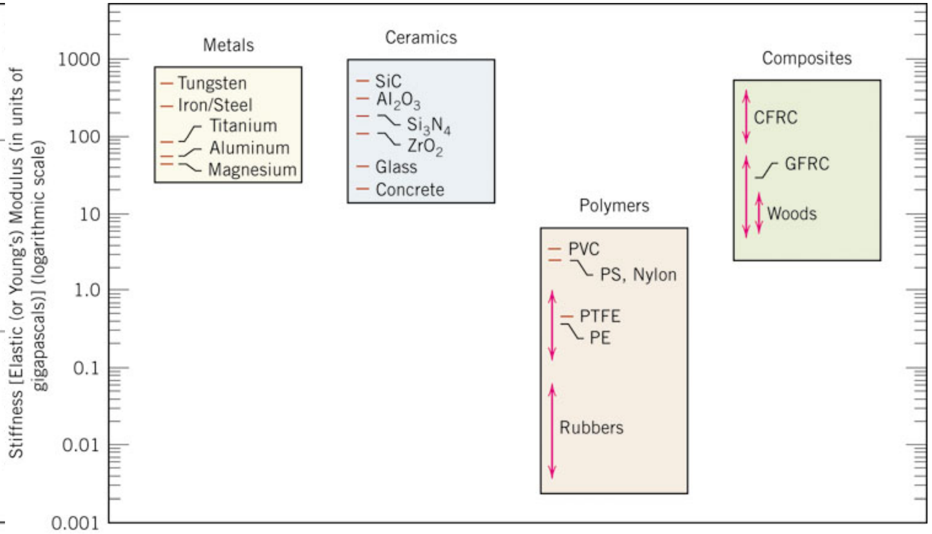
Composites: fiberglass (FRP) (glass fiber and polymer matrix), wood, concrete: a combination of materials, combining the desirable properties of each one.

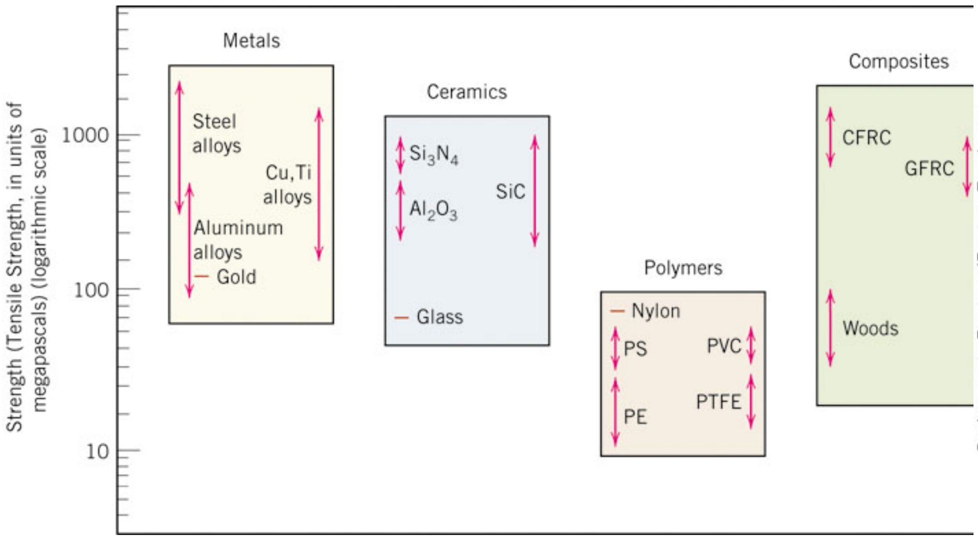


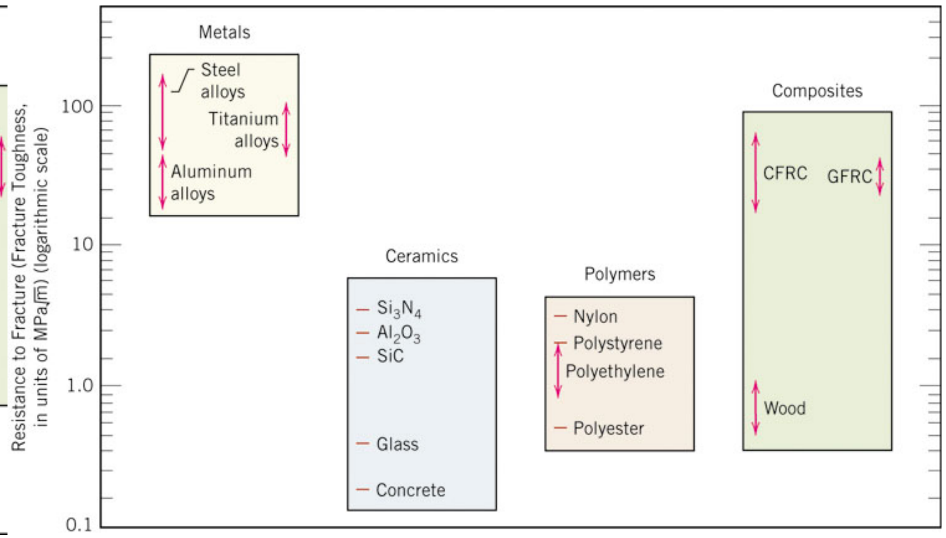
Fibreglass composite

Graphite fibre epoxy composite


Density (g/cm³) (logarithmic scale)
40
20
10
8
6
4
2
1.0
0.8
0.6
0.4
0.2
0.1
Metals
Platinum
Silver
Copper
Iron/Steel
Titanium
Aluminum
Magnesium
Ceramics
ZrO_2
Al_2O_3
SiC, Si_3N_4
Glass
Concrete
Polymers
PTFE
PVC
PS
PE
Rubber
Composites
GFRC
CFRC
Woods


Stiffness [Elastic (or Young's) Modulus (in units of gigapascals)] (logarithmic scale)
1000
100
10
1.0
0.1
0.01
0.001
Metals
Tungsten
Iron/Steel
Titanium
Aluminum
Magnesium
Ceramics
SiC
Al_2O_3
Si_3N_4
ZrO_2
Glass
Concrete
Polymers
PVC
PS, Nylon
PTFE
PE
Rubbers
Composites
CFRC
GFRC
Woods


Strength (Tensile Strength, in units of megapascals) (logarithmic scale)
1000
100
10
Metals
Steel alloys
Cu,Ti alloys
Aluminum alloys
Gold
Ceramics
Si_3N_4
SiC
Al_2O_3
Glass
Polymers
Nylon
PS
PVC
PE
PTFE
Composites
CFRC
GFRC
Woods


Resistance to Fracture (Fracture Toughness, in units of MPa$\sqrt{m}$) (logarithmic scale)
100
10
1.0
0.1
Metals
Steel alloys
Titanium alloys
Aluminum alloys
Ceramics
Si_3N_4
Al_2O_3
SiC
Glass
Concrete
Polymers
Nylon
Polystyrene
Polyethylene
Polyester
Composites
CFRC
GFRC
Wood

Advanced Materials

Utilized in high-technology applications e.g. computers, fibre-optic systems, aircraft

Can be: traditional materials with enhanced properties

newly developed, high performance materials

Made from all material types.

Usually expensive.

Semiconductors

Semiconductors: Si, Ge, GaAs, CdS: intermediate between electrical conductors and insulators

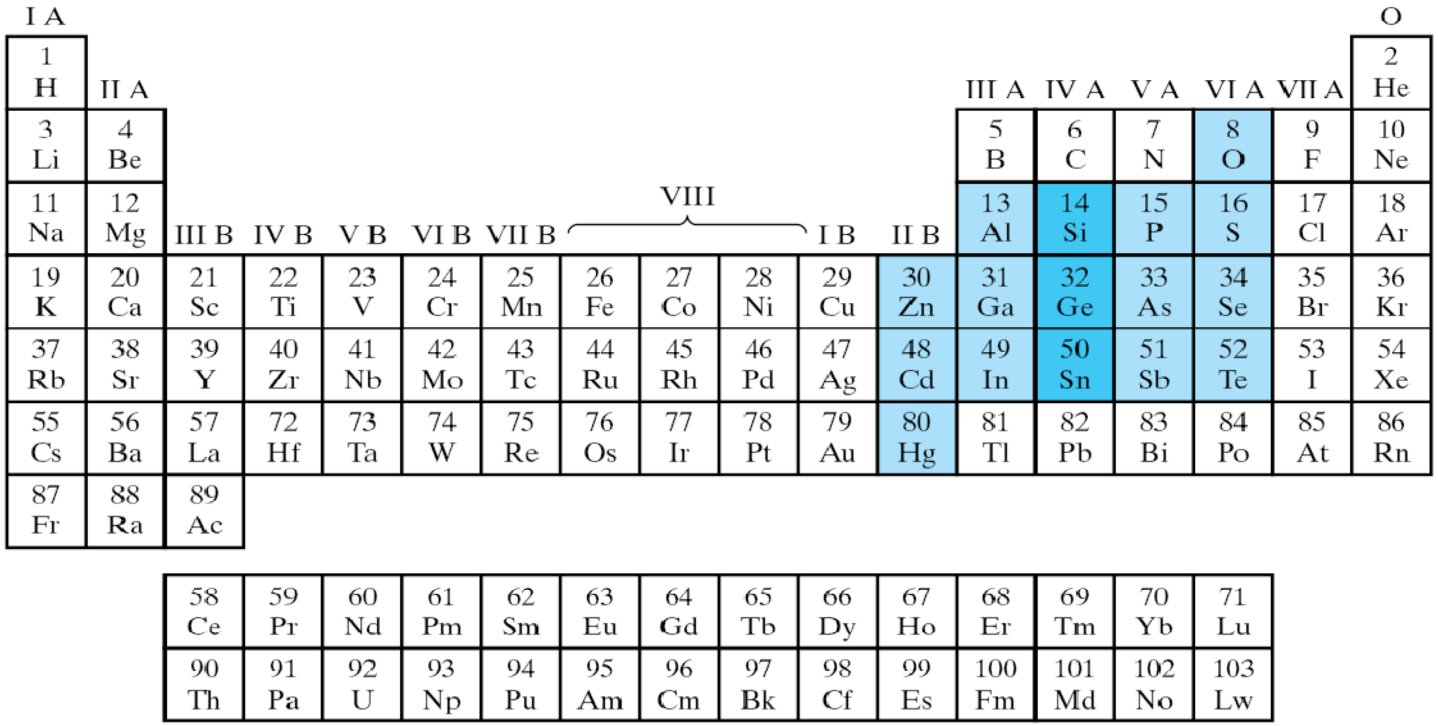
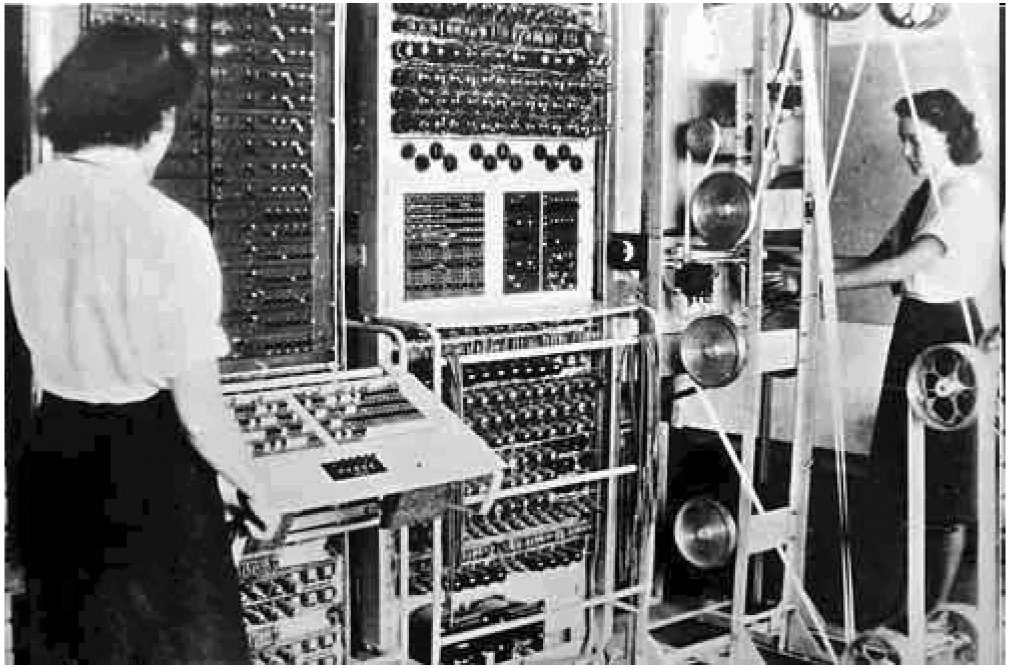


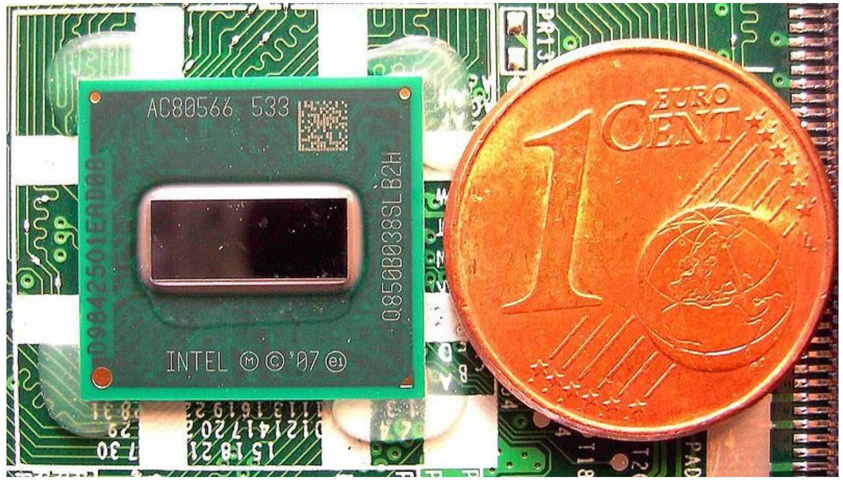
Figure 1-16 *Periodic table with the elemental semiconductors in dark color and those elements that form semiconducting compounds in light color. The semiconducting compounds are composed of pairs of elements from columns III and V (e.g., GaAs) or from columns II and VI (e.g., CdS).*

Impact of Semiconductors

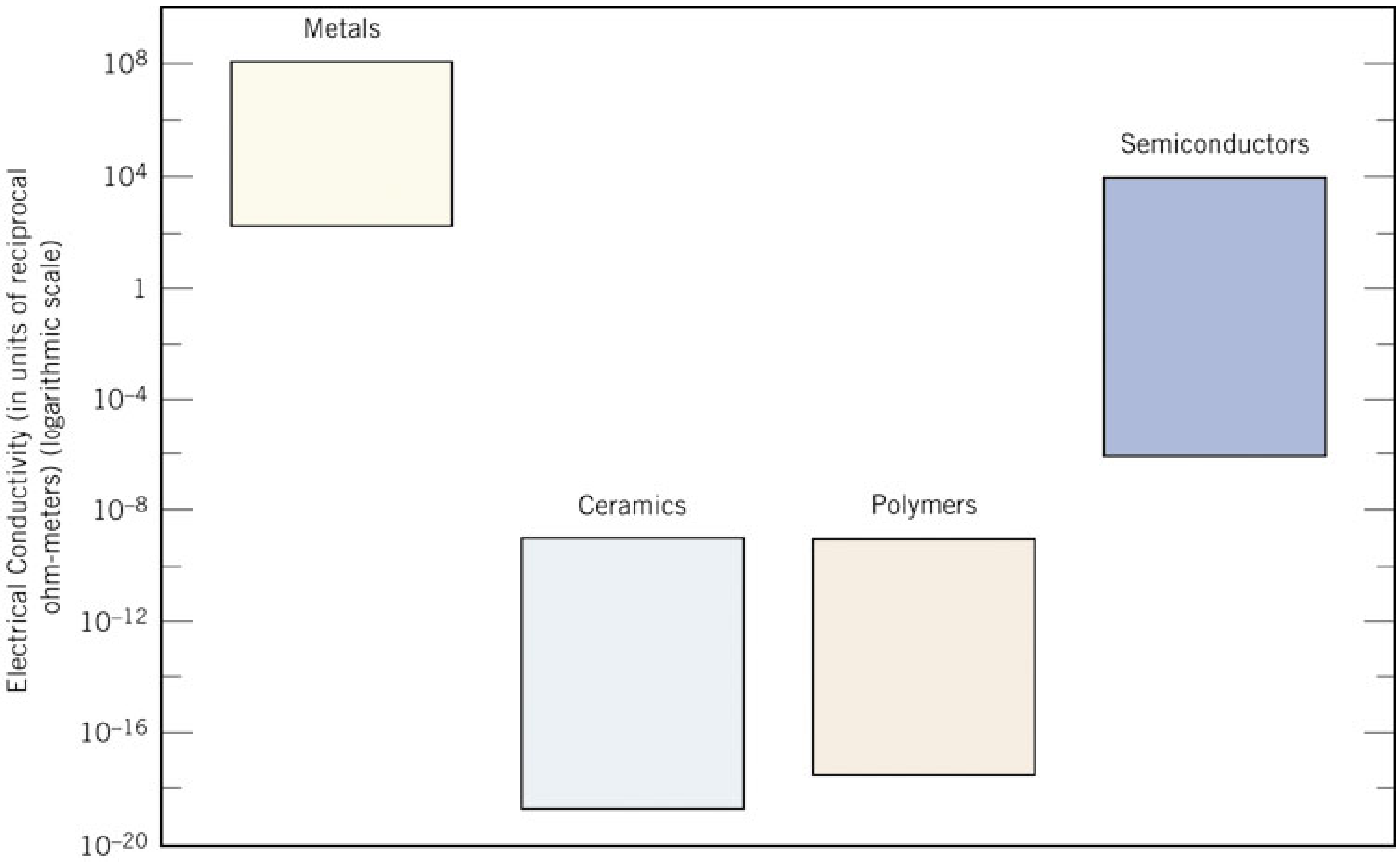


Colossus Mk 2 computer

Subnotebook



Intel Atom processor


Metals
Semiconductors
Ceramics
Polymers
Electrical Conductivity (in units of reciprocal ohm-meters) (logarithmic scale)
10^{8}
10^{4}
1
10^{-4}
10^{-8}
10^{-12}
10^{-16}
10^{-20}

Biomaterials

- Used in components placed in the human body for replacement of diseased / damaged parts.
- Used in controlled drug release systems.
- Must be non-toxic and compatible (i.e. no adverse biological reactions) with body tissues.
- All material types are used as biomaterials

(b)

Smart Materials

Materials or systems that can sense changes in the environment and respond to them.

Smart material / system:	sensor (detects input signal e.g. temp, electric or magnetic field)
	actuator (responds to input e.g. change in shape, position)

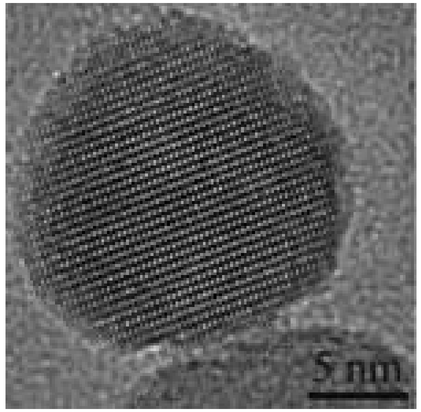
Sensor material:	optical fibres
	piezoelectric materials
	microelectromechanical systems
Actuator materials:	shape memory alloys
	piezoelectric ceramics
	magnetorestrictive materials
	electrorheological / magnetorheological fluids

Nanoengineered Materials

Materials with structural units < 100 nm in size.

Properties can differ significantly from regular materials.

Possible to arrange individual atoms to create materials with new mechanical, electrical and optical properties.



Fe_3O_4 nanoparticle

(N. Pinna *et al.* (2005), *Chem. Mater.* **17**: 3044.)

Iron atoms arranged on a copper (111) surface. These Hanja characters represent the word "atom".

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