Introduction

Materials Science and Engineering

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1.HISTORICAL PERSPECTIVE

2. What are the materials science and materials engineering?

Materials science: involves investigating the relationships that exist between the structures and properties of materials.

علم المواد: هو العلم الذي يشتمل على دراسة العلاقات الموجودة بين بنية المواد وخصائصها

Materials engineering: is designing or engineering the structure of a material to produce a predetermined set of properties.

creating new products or systems using existing materials, and/or to develop techniques for processing materials.

هندسة المواد : هي تصميم وهندسة بنية المواد للحصول علي مجموعة من الخواص المطلوبة

2. Structure of a material

- **Structure of a material:** relates to the arrangement of its internal components.

بنية المادة: هي ترتيب المكونات الداخلية للمادة

- **Subatomic structure** involves electrons within the individual atoms and interactions with their nuclei (**البنية تحت الذرية**)
- **Microscopic structure** Which contains large groups of atoms that are normally agglomerated together(**البنية المجهرية**)
- **Macroscopic structural** the elements that may be viewed with the naked eye are termed.(**البنية العيانية**)

The property is a material trait in terms of the kind and magnitude of response to a specific imposed stimulus.

الخاصية هي سمةللمادةمن حيث نوع وحجم الاستجابة لمحفز محدد مفروض

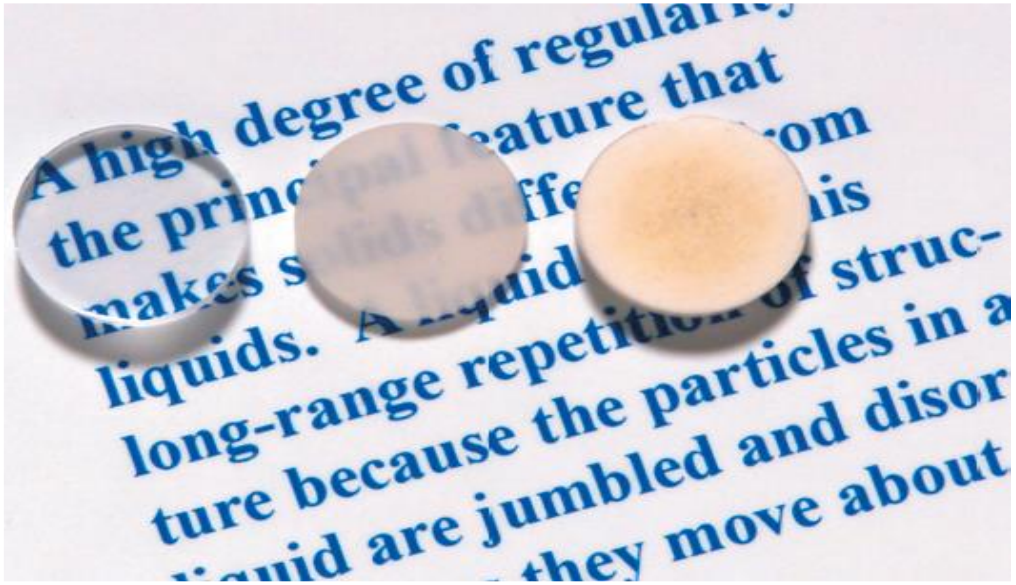
Virtually all important properties of Solid materials may be grouped into six different categories:

1) Mechanical
2) Electrical
3) Thermal
4) Magnetic
5) Optical ضوئية
6) Deteriorative تدهورية

- **Mechanical properties** relate deformation to an applied load or force; examples include elastic modulus (stiffness), strength, and toughness.
  - الخواص الميكانيكية تتعلق بالتشوهات التي تحدث في المادة نتيجة وضعها تحت حمل او قوة مثل معامل المرونة والقوة والصلابة

- **Electrical properties** such as electrical conductivity and dielectric constant.
- **The thermal properties** behavior of solids can be represented in terms of heat capacity and thermal conductivity.
- **Magnetic properties** demonstrate the response of a material to the application of a magnetic field.
- **Optical properties** index of refraction and reflectivity are representative optical properties. the stimulus is electromagnetic or light radiation.
- **Deteriorative characteristics** relate to the chemical reactivity of materials

3.The components of the discipline of materials science and engineering and their interrelationship.



light-transmittance characteristics of aluminum oxide

1. Single crystal
2. Numerous and very small single crystals
3. Composed not only of many small, interconnected crystals, but also of a large number of very small pores or void spaces.

4.WHY STUDY MATERIALS SCIENCE AND ENGINEERING?

- Designing problem involving materials
- The materials problem is one of selecting the right material from the many thousands that are available.
- Selection consideration is any deterioration of material properties that may occur during service operation.
- Economics consideration

5. CLASSIFICATION OF MATERIALS

- **Solid materials have been conveniently grouped into three basic categories:**

1) **Metals** الفلزات
2) **Ceramics** الخزفيات
3) **Polymers** البوليمرات
4) **Composites** المواد المركبة

- **The Advance materials have been categorized as follows:**

(1) **Semiconductors** اشباه الموصلات (2) **Biomaterials** المواد الحيوية

(3) **Smart materials** المواد الذكية (4) **Nano engineered materials** المواد نانوية البنية

5.1 Metals

- Materials in this group are composed of one or more metallic elements (e.g., iron, aluminum, copper, titanium, gold, and nickel).Nonmetallic elements (e.g., carbon, nitrogen, and oxygen) in relatively small amounts.
- Atoms in metals and their alloys are arranged in a very orderly manner comparison to the ceramics and polymers, are relatively dense كثيف .
- With regard to mechanical characteristics, these materials are relatively stiff صلبة and strong.
- Capable of large amounts of deformation without fracture كسر.
- Metals are extremely good conductors of electricity (Figure 1.7) and heat desirable magnetic properties.

5.2 Ceramics

- Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides.

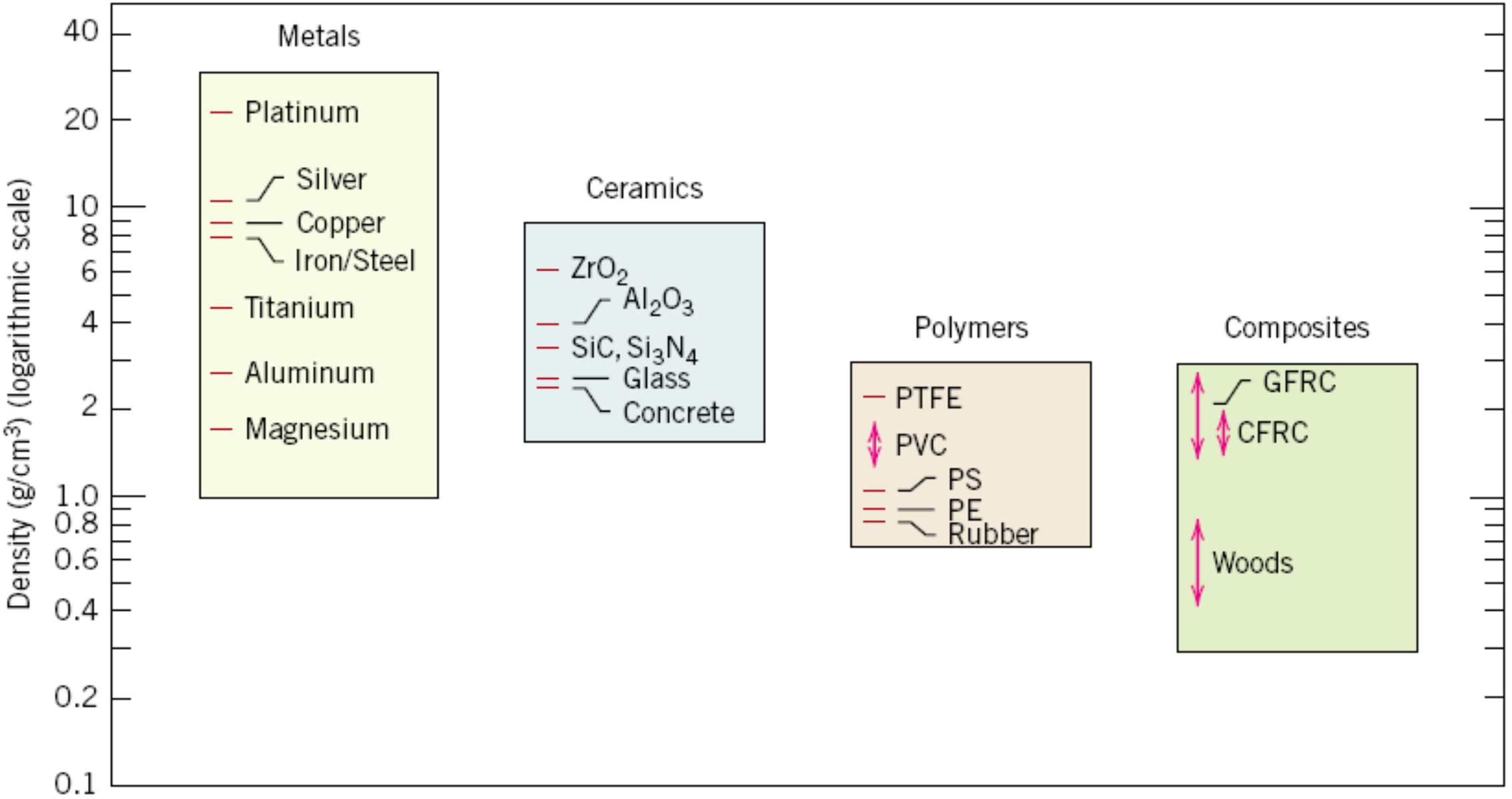
- Ceramic materials include aluminum oxide (or alumina, Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4).
- Traditional ceramics—those composed of clay minerals (i.e., porcelain), as well as cement and glass.
- Ceramic materials are relatively stiff and strong— stiffnesses and strengths are comparable to those of the metals.
- Ceramics have exhibited extreme brittleness (lack of ductility)
- Highly susceptible to fracture.
- Ceramic materials are typically insulative to the passage of heat and electricity.

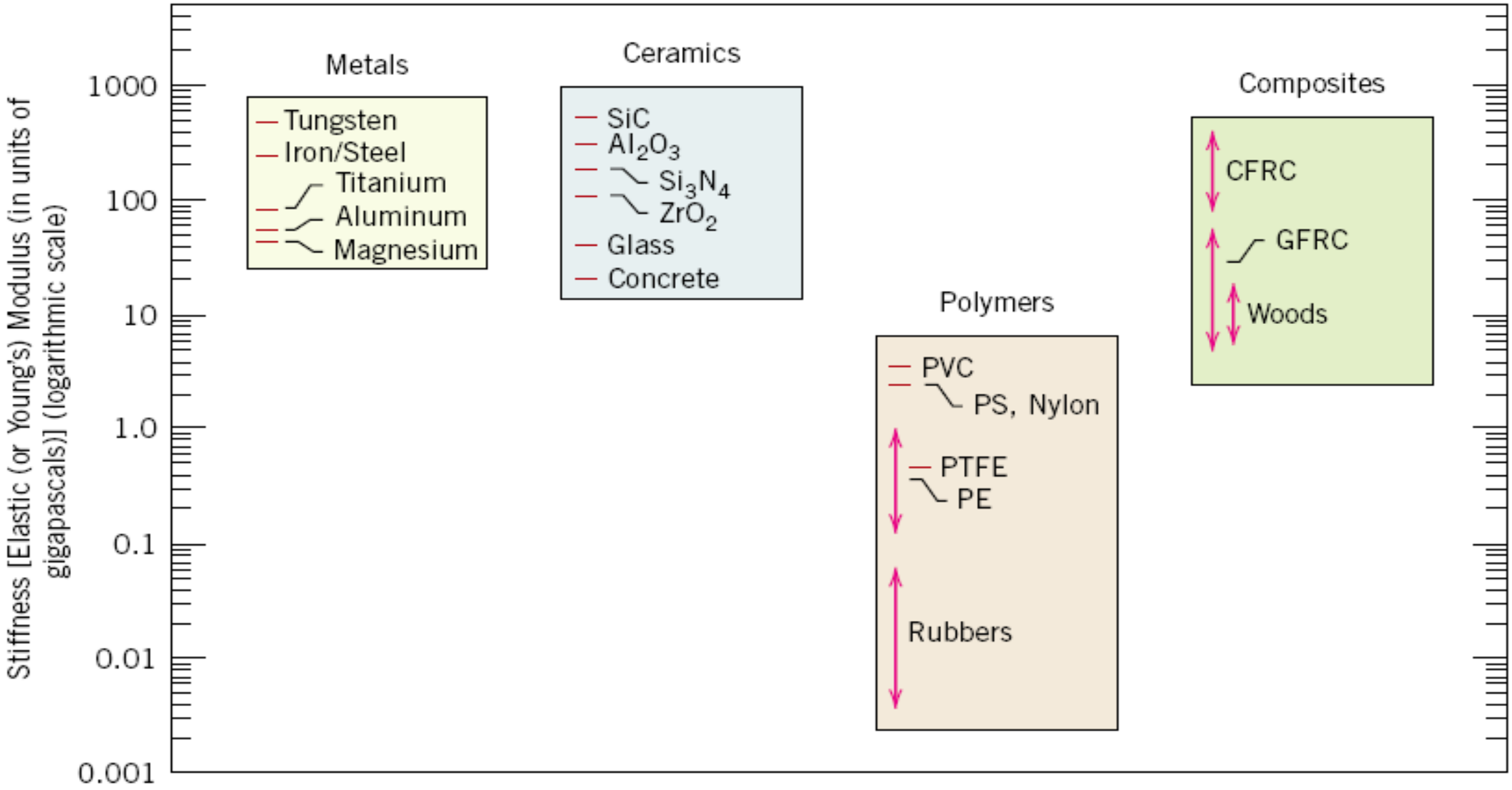
5.2 Polymers

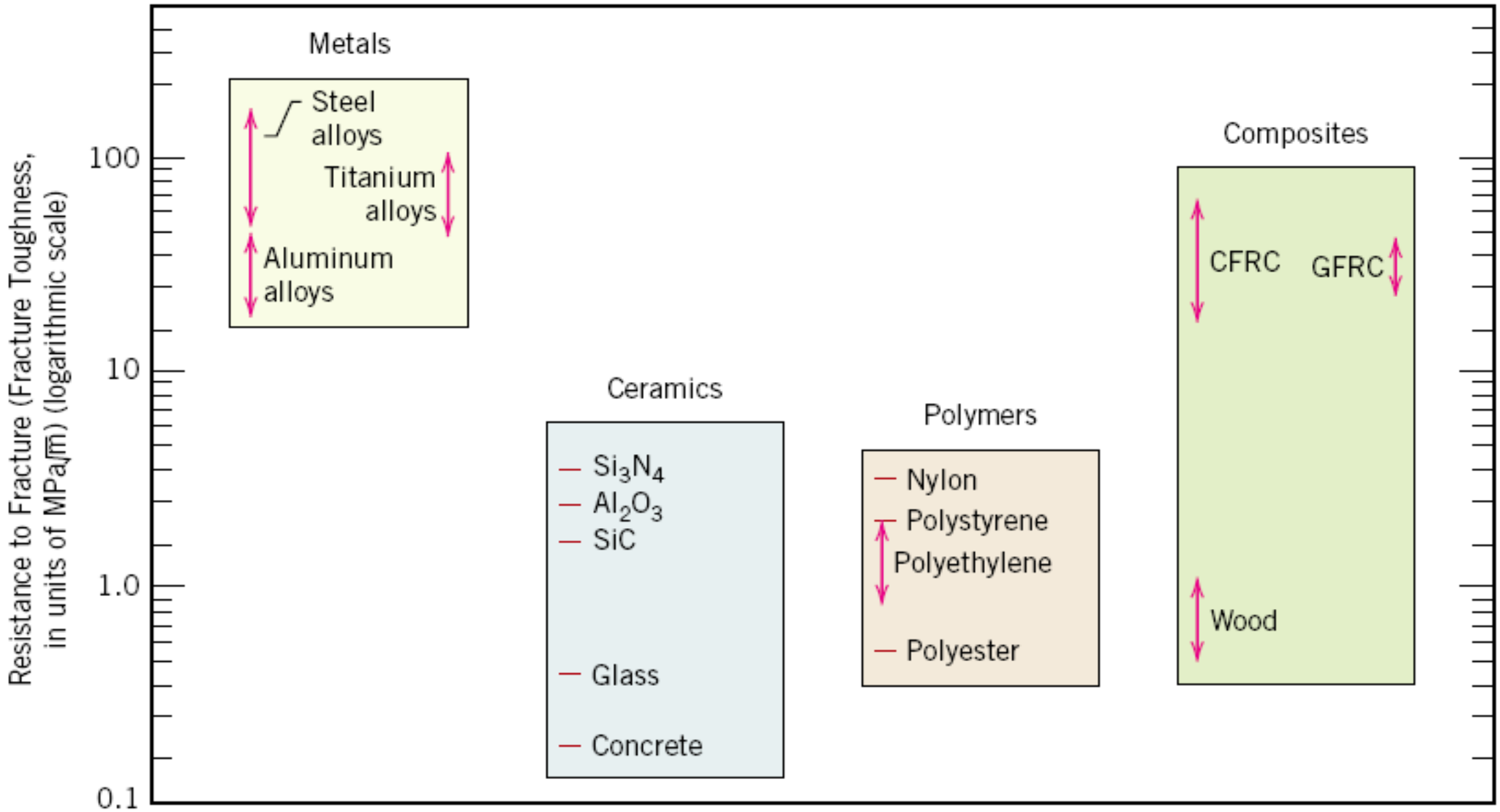
- Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (i.e., O, N, and Si).
- Polymers have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms.
- These materials typically have low densities whereas their mechanical characteristics are generally dissimilar to the metallic and ceramic materials—they are not as stiff nor as strong as these other material types.
- many of the polymers are extremely ductile and pliable (i.e., plastic).
- Polymers relatively inert chemically and One major drawback to the polymers is their tendency to soften and/or decompose at modest temperatures
- unreactive in a large number of environments
- Polymers have low electrical conductivities and are nonmagnetic.

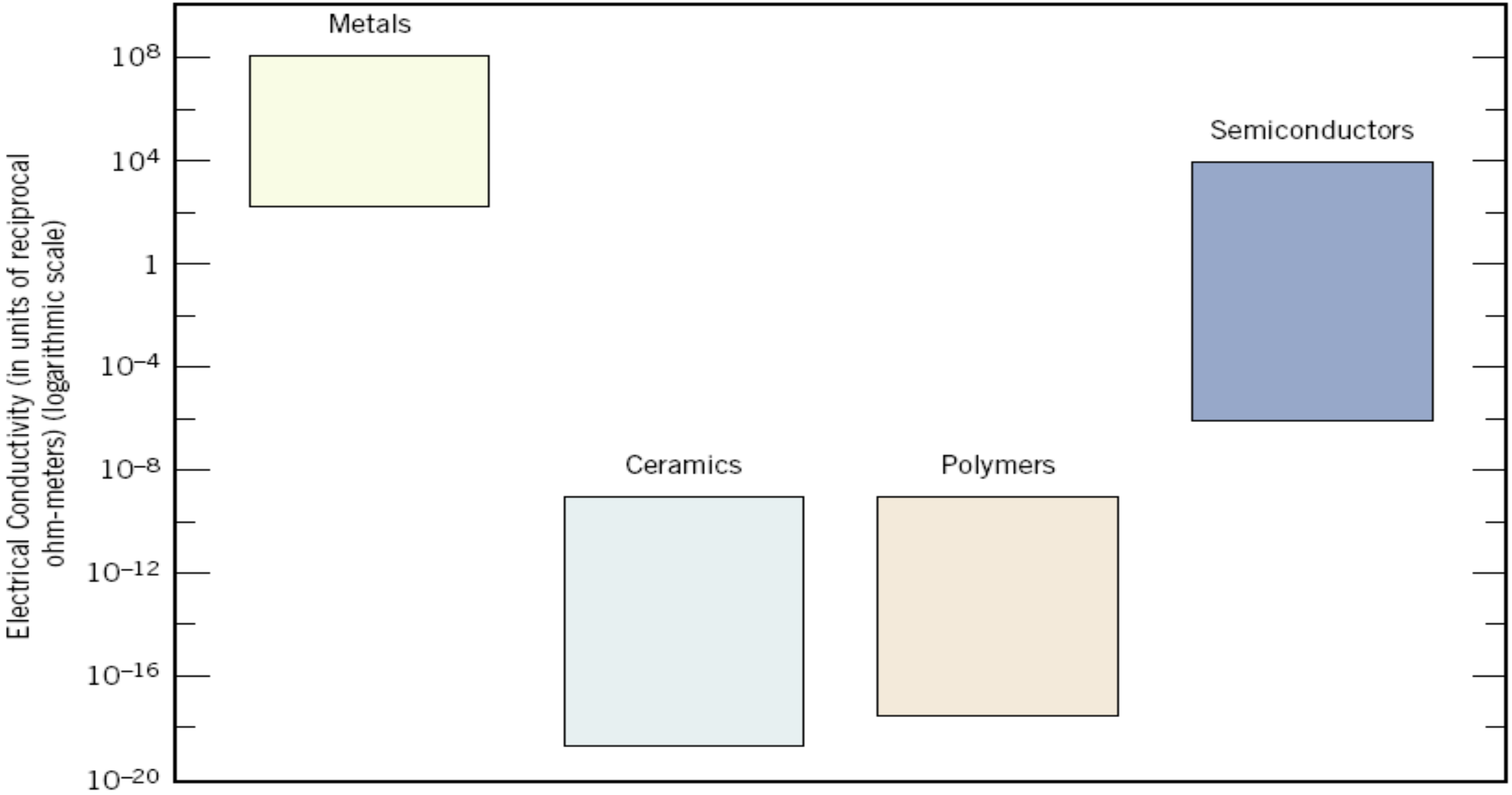
5.3 Composites

- A composite is composed of two (or more) individual materials, which come from the categories previously discussed—metals, ceramics, and polymers).
- The design goal of a composite is to achieve a combination of properties that is not displayed by any single material, and also to incorporate the best characteristics of each of the component materials.
- One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material (normally an epoxy or polyester). The glass fibers are relatively strong and stiff (but also brittle), whereas the polymer is more flexible. Thus, fiberglass is relatively stiff, strong and and flexible. In addition, it has a low density.
- Another material is the carbon fiber–reinforced polymer (CFRP) composite—carbon fibers that are embedded within a polymer. These materials are stiffer and stronger than glass fiber–reinforced materials, but more expensive. CFRP composites are used in some aircraft.


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
ZrO2
Al2O3
SiC, Si3N4
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


Resistance to Fracture (Fracture Toughness, in units of MPa√m) (logarithmic scale)
100
10
1.0
0.1
Metals
Steel alloys
Titanium alloys
Aluminum alloys
Ceramics
Si3N4
Al2O3
SiC
Glass
Concrete
Polymers
Nylon
Polystyrene
Polyethylene
Polyester
Composites
CFRC
GFRC
Wood


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

6. ADVANCED MATERIALS

Another materials category is the advanced materials that are used in high-tech applications which are:

1) Semiconductors (having electrical conductivities intermediate between conductors and insulators).
2) Biomaterials (which must be compatible with body tissues)
3) Smart materials (those that sense and respond to changes in their environments in predetermined manners)
4) Nano-materials (those that have structural features on the order of a nanometer, some of which may be designed on the atomic/molecular level).

6.1 Semiconductors

- Semiconductors have electrical properties that are intermediate between the electrical conductors (i.e., metals and metal alloys) and insulators(i.e., ceramics and polymers)
- The electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms, for which the concentrations may be controlled over very small spatial regions.

6.2 Biomaterials

- Biomaterials are employed in components implanted into the human body to replace diseased or damaged body parts.
- These materials must not produce toxic substances and must be compatible with body tissues (i.e., must not cause adverse biological reactions).
- All of the preceding materials—metals, ceramics, polymers, composites, and semiconductors—may be used as biomaterials.
- For example, some of the biomaterials that are utilized in artificial hip replacements are discussed in the online Biomaterials Module.

6.3 Smart Materials

- Materials are able to sense changes in their environment and then respond to these changes in predetermined manners.
- Components of a smart material (or system) include some type of sensor (that detects an input signal), and an actuator (that performs a responsive and adaptive function). Actuators may be called upon to change shape, position, natural frequency, or mechanical characteristics in response to changes in temperature, electric fields, and/or magnetic fields.
- Four types of materials are commonly used for actuators: shape-memory alloys سبائك ذاكرة الشكل piezoelectric ceramics، الخزفيات الكهرواجهادية magnetostrictive materials المواد المغناطيسية, and electrorheological/magnetorheological fluid السوائل الكهربية / المغنطيسية

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6.3 Smart Materials

- Shape-memory alloys are metals that, after having been deformed, revert back to their original shape when temperature is changed.
- Piezoelectric ceramics expand and contract in response to an applied electric field (or voltage); conversely, they also generate an electric field when their dimensions are altered.
- The behavior of magnetostrictive materials is analogous to that of the piezoelectrics, that they are responsive to magnetic fields.
- Electrorheological and magnetorheological fluids are liquids that experience dramatic changes in viscosity upon the application of electric and magnetic fields, respectively.

6.4 Nanomaterial

- Nanomaterials may be any one of the four basic types—metals, ceramics, polymers, and composites. However, unlike these other materials, they are not distinguished on the basis of their chemistry, but rather, size; the *nano*-prefix denotes that the dimensions of these structural entities are on the order of a nanometer (10^{-9} m)—as a rule, less than 100 nanometers (equivalent to approximately 500 atom diameters)

top-down" science

- The development of scanning probe microscopes, which permit observation of individual atoms and molecules, it has become possible to design and build new structures from their atomiclevel constituents, one atom or molecule at a time