Week 1
INTRODUCTION

Materials Science

Material Science & Engineering

- Material -> something tangible that goes into the makeup of a physical object.
- Material Science -> involves investigating the relationships that exist between the **structures** and **properties** of materials.
- Material Engineering -> is, on the basis of these ***structure–property*** correlations, designing or engineering the structure of a material to produce a predetermined set of properties.

Material Science & Engineering

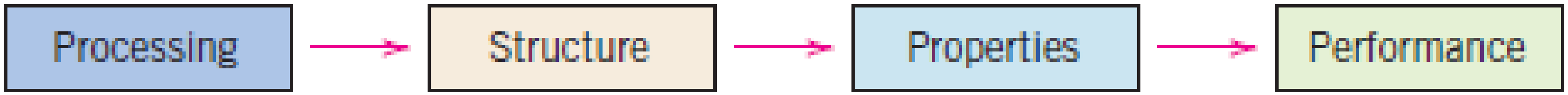
- Structure -> The structure of a material usually relates to the arrangement of its internal components
- Different levels of defining structure of a material
- Property -> A property is a material **trait** (distinguishing feature) in terms of the kind and magnitude of response to a specific imposed stimulus
- Six categories of properties -> mechanical, electrical, thermal, magnetic, optical, and deteriorative.

Material Science & Engineering

- In addition to structure and properties, two other important components are involved in the science and engineering of materials namely, "processing" and "performance."
- Processing -> preparing or putting through a prescribed procedure, e.g. the processing of ore to obtain material
- Performance -> the accomplishment relative to stated goals or objectives

Relationship Among the Four Components

- The *structure* of a material will depend on how it is *processed*.
- Furthermore, a material's *performance* will be a function of its *properties*.



processing-structure-properties-performance

- Material of all three disks -> Aluminum Oxide
- Left Disk -> a single crystal
- Center Disk ->composed of numerous and very small single crystals that are all connected
- Right Disk ->composed of many small, interconnected crystals, and large number of small pores or void spaces

WHY STUDY MATERIALS SCIENCE AND ENGINEERING?

- Being Engineers we are totally dependent upon materials, their properties and performance
- Many times, a materials problem is one of selecting the right material from the many thousands that are available
- On only rare occasions does a material possess the ideal combination of properties
- Second selection consideration ->deterioration of properties that may occur during service operation
- What will the finished product cost?

CLASSIFICATION OF MATERIALS

- Three basic classifications of **solid materials**: **metals**, **ceramics**, and **polymers.**
- In addition, there are the **composites**, combinations of two or more of the above three basic material classes

1. METALS

- Materials in this group are composed of one or more metallic elements and often also nonmetallic elements in relatively small amounts.
- Atoms in metals and their alloys are arranged in a very orderly manner and in comparison to the ceramics and polymers, are relatively dense.
- Distinguishing characteristics -> **stiff**, **strong**, **ductile**, **resistant to fracture.**
- Metallic materials have large numbers of non-localized electrons.
- Some of the metals (Fe, Co, and Ni) have desirable magnetic properties.

Metallic Objects

2. CERAMICS

- Ceramics are **compounds** between **metallic** and **nonmetallic** elements; they are most frequently oxides, nitrides, and carbides
- Traditional ceramics -> clay minerals (i.e. porcelain), as well as cement, and glass
- Common (nontraditional) ceramics -> alumina, silica, silicon carbide, silicon nitride
- Relatively stiff and strong—**stiffnesses** and **strengths** are comparable to those of the metals
- Very hard
- Thus, very brittle

2. CERAMICS *(contd…)*

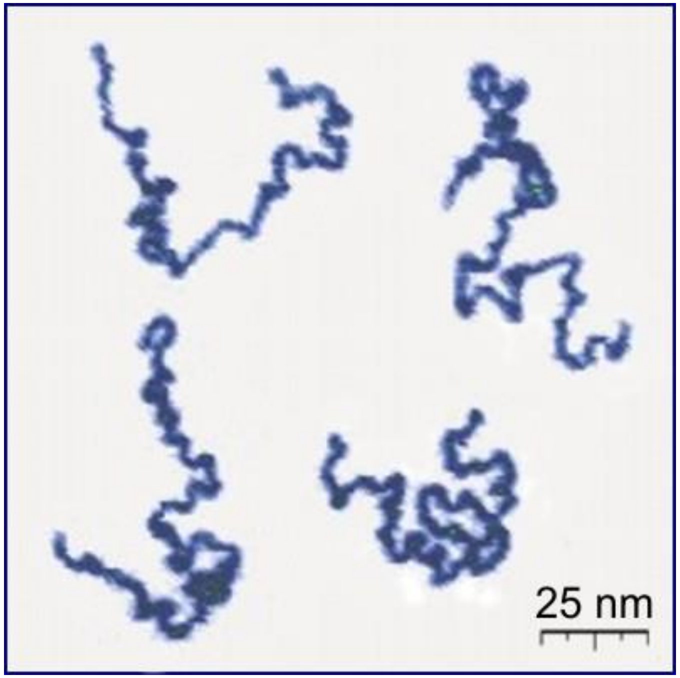
- typically insulative to the passage of heat and electricity
- more resistant to high temperatures and harsh environments than metals and polymers.
- ceramics may be transparent, translucent, or opaque
- some of the oxide ceramics (e.g., Fe_3O_4) exhibit magnetic behavior

Ceramic Objects

3. POLYMERS

- A **polymer** is a large molecule (macromolecule) composed of repeating structural units typically connected by covalent chemical bonds.
- Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (e.g. O, N and Si).
- They have very large molecular structures, often chain-like in nature that have a backbone of carbon atoms.
- Common polymers -> polyethylene (PE), nylon, poly vinyl chloride (PVC), polycarbonate (PC), polystyrene (PS), and silicon rubber.

A Polymer at Macroscopic Level



Appearance of real linear polymer chains as recorded using an atomic force microscope on surface under liquid medium. Chain contour length for this polymer is ~204 nm; thickness is ~0.4 nm

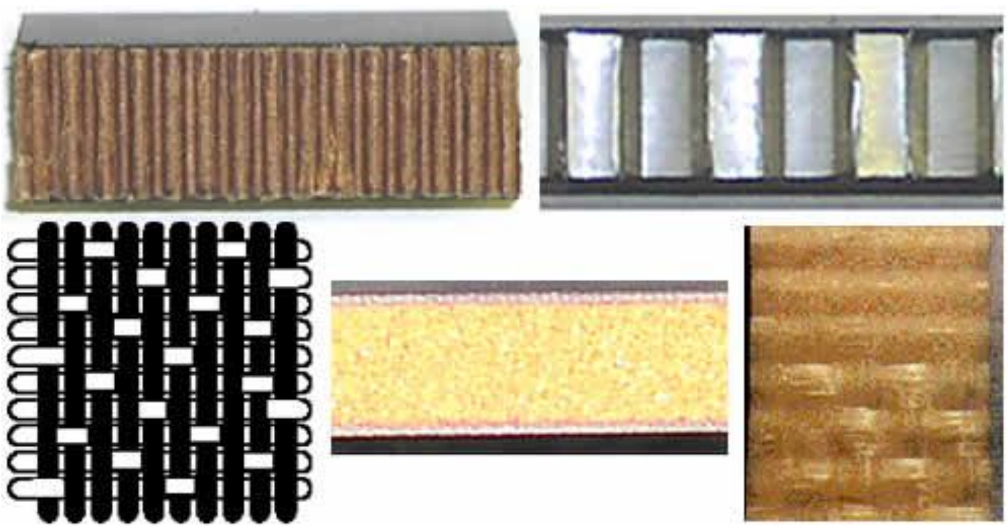
Polymers - Properties

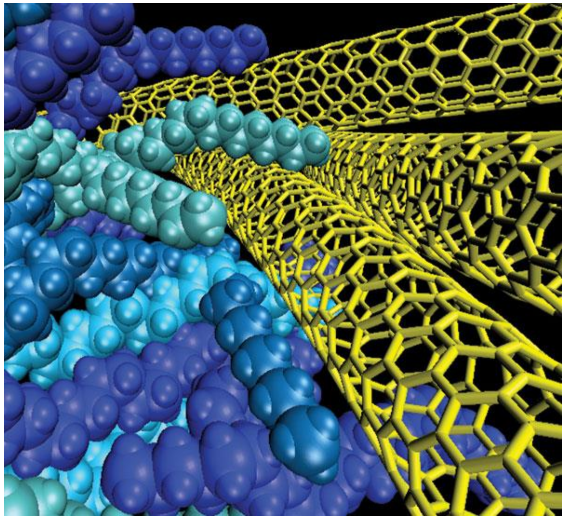
- have low densities.
- mechanical characteristics are generally dissimilar to the metallic and ceramic materials – neither **stiff** nor **strong.**
- many of the polymers are extremely ductile and pliable (i.e., plastic).
- relatively inert chemically and nonreactive in a large number of environments.
- major drawback -> tendency to soften and/or decompose at modest temperatures.
- low electrical conductivities and nonmagnetic.

Polymer Objects

COMPOSITES

- Composites are engineered materials made from two or more constituent materials with significantly different physical or chemical properties, which remain separate and distinct on a macroscopic level within the finished structure





COMPOSITES *(contd…)*

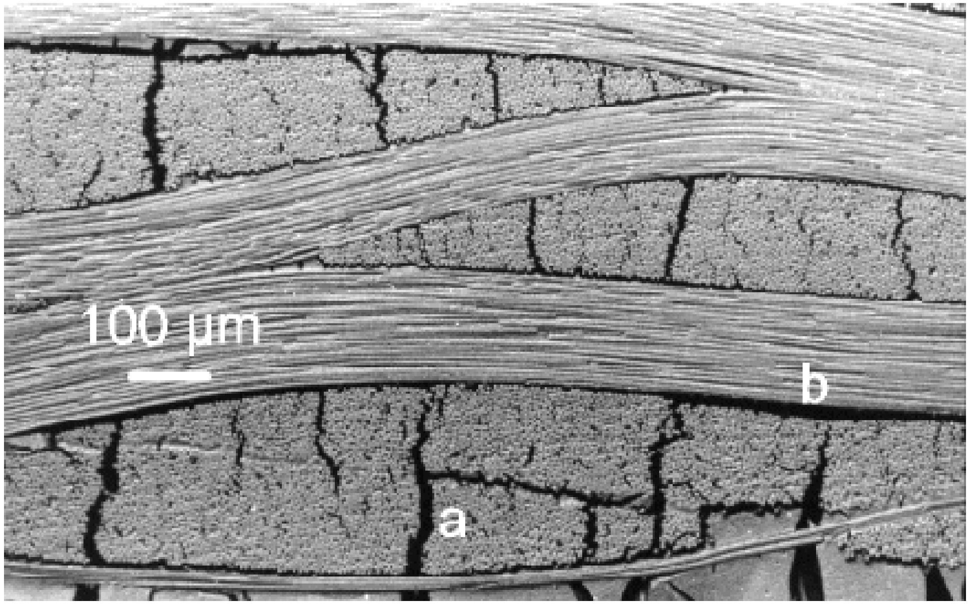
- The design goal of a composite is to achieve a combination of properties that is not displayed by any single material
- Some naturally-occurring materials are also considered to be composites
- One of the common composites is **fiberglass**, in which small glass fibers are embedded within a polymeric material
- **Glass Fiber** -> Strong + Stiff + Brittle
- **Polymer** -> Ductile + Weak + Flexible

Glass-Fiber Reinforced Polymer

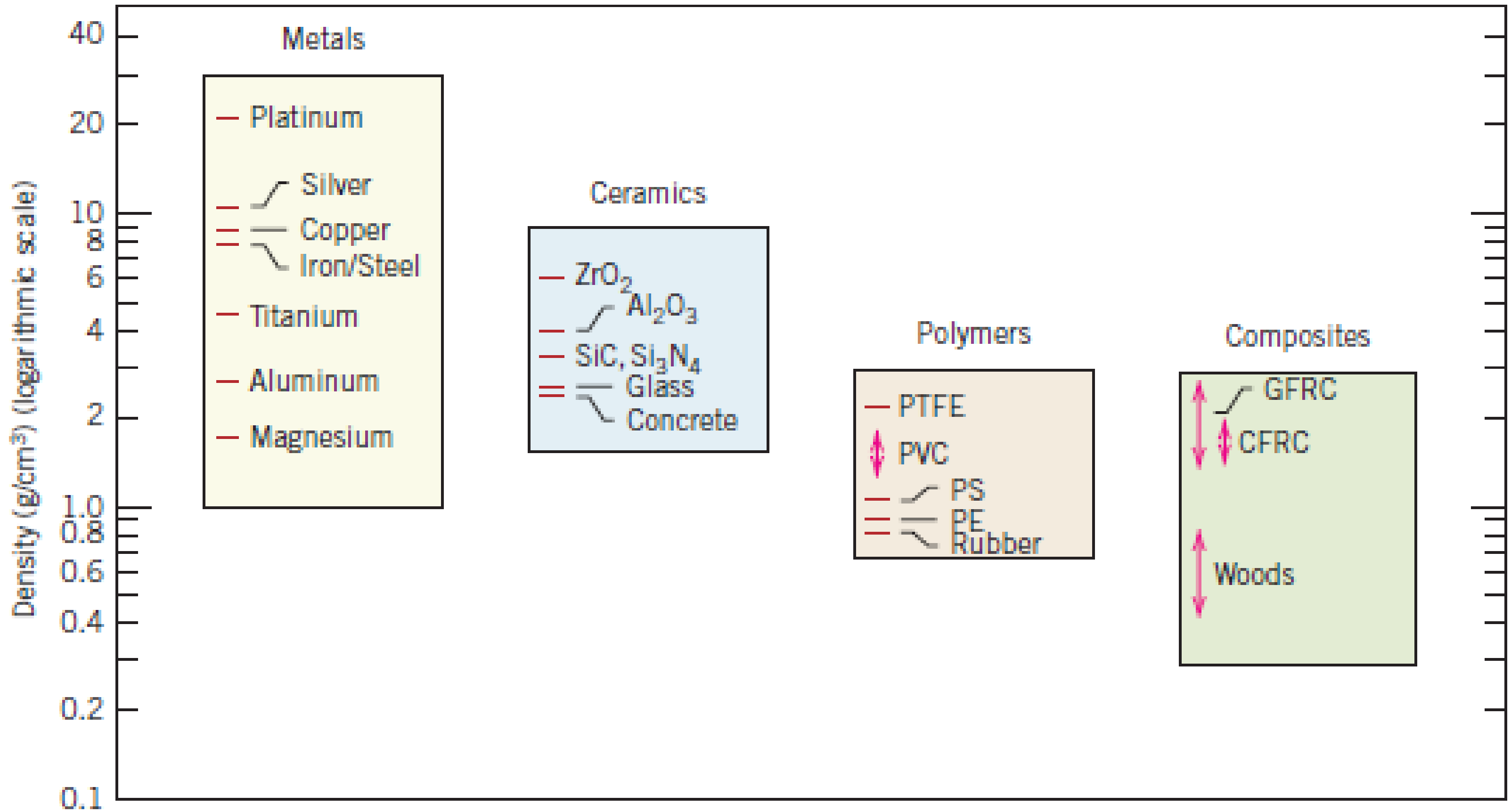
COMPOSITES *(contd…)*

- **CFRP** -> carbon fibers that are embedded within a polymer
- These materials are stiffer and stronger than the glass fiber-reinforced materials, thus they are more expensive
- CFRPs are used in some aircraft and aerospace applications, as well as high-tech sporting equipment

Carbon Fiber Reinforced Plastics (CFRP) Microstructure

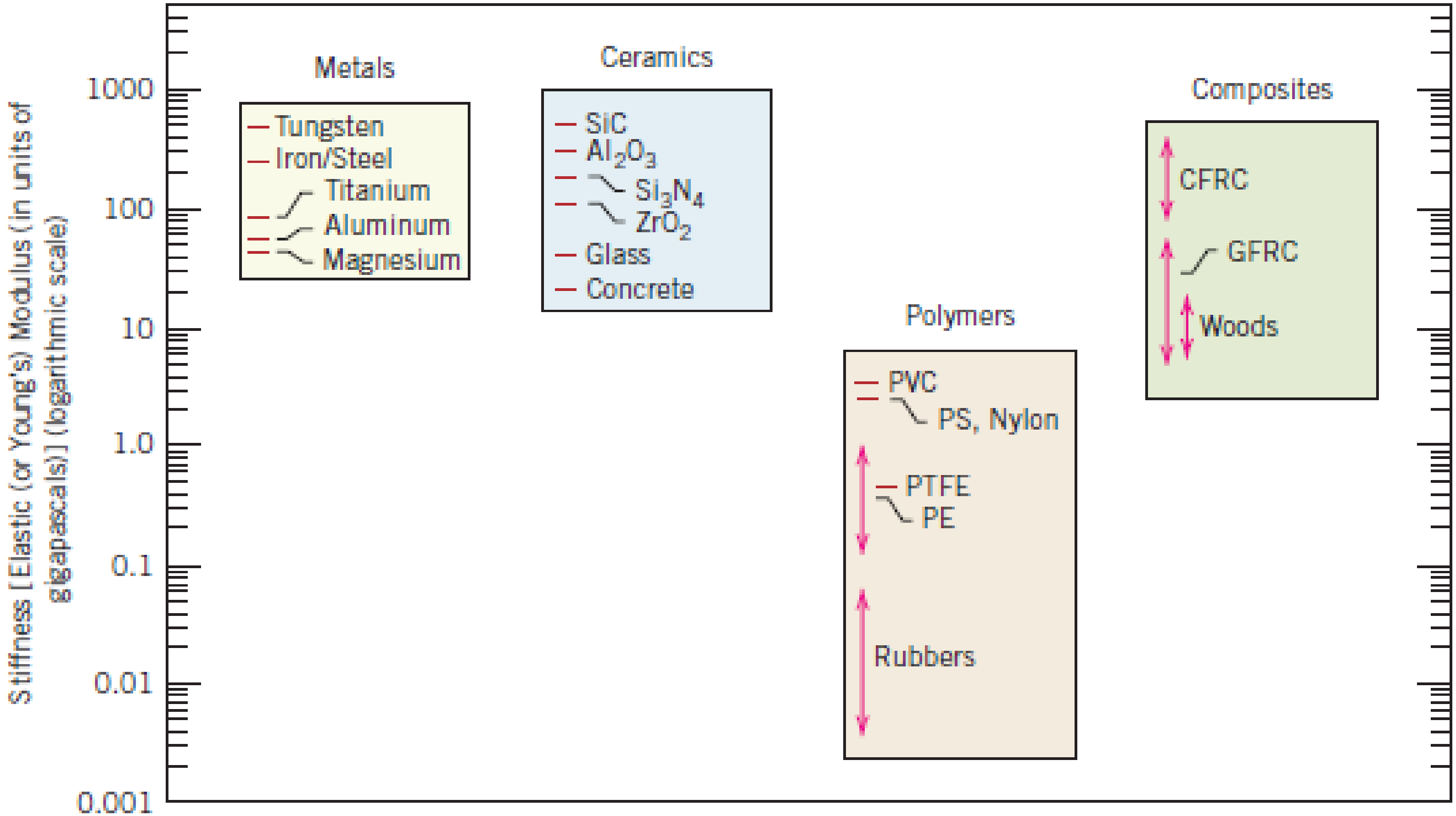


Comparison Chart - 1



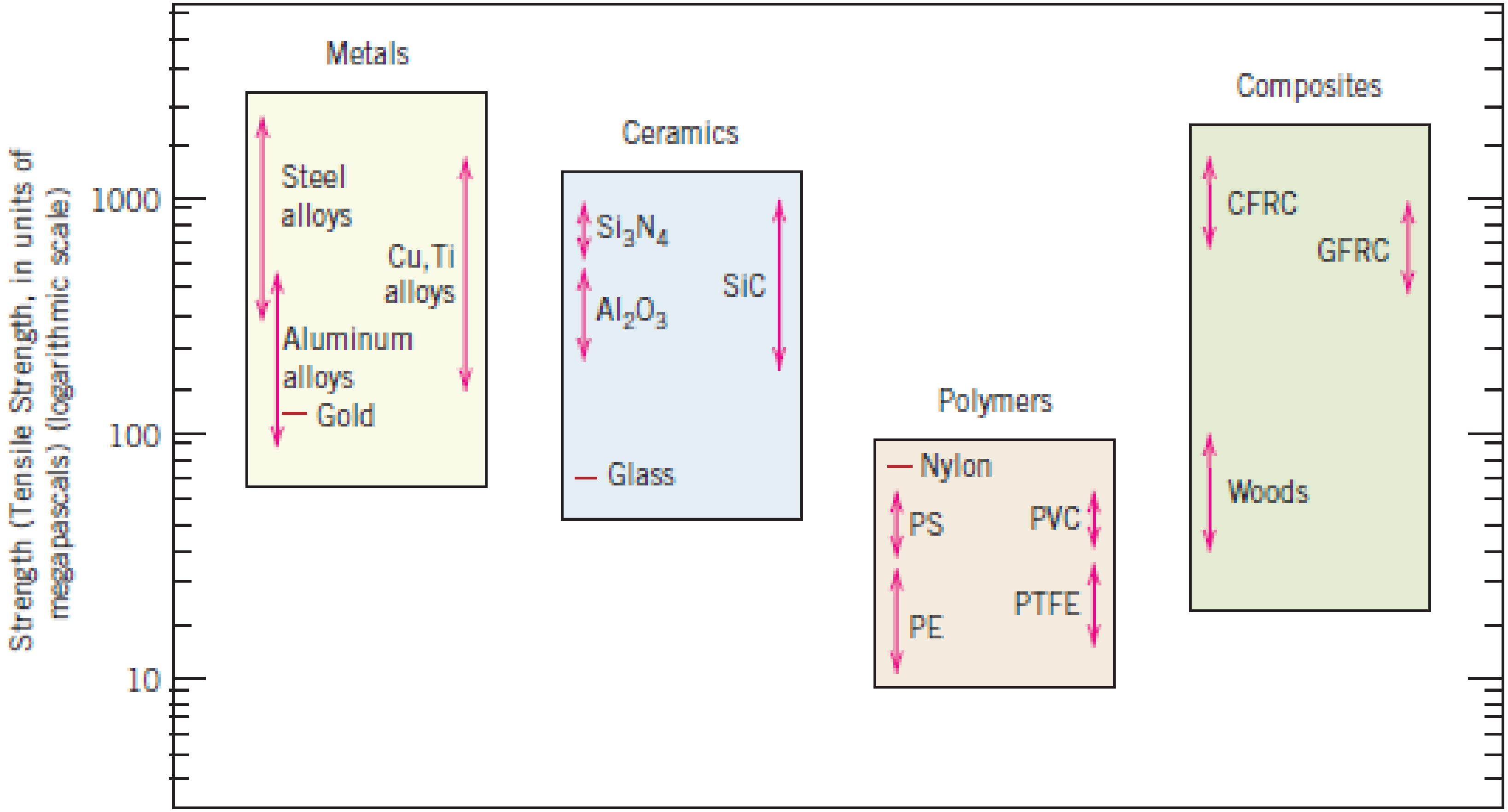
Bar-chart of room temperature density

Comparison Chart - 2



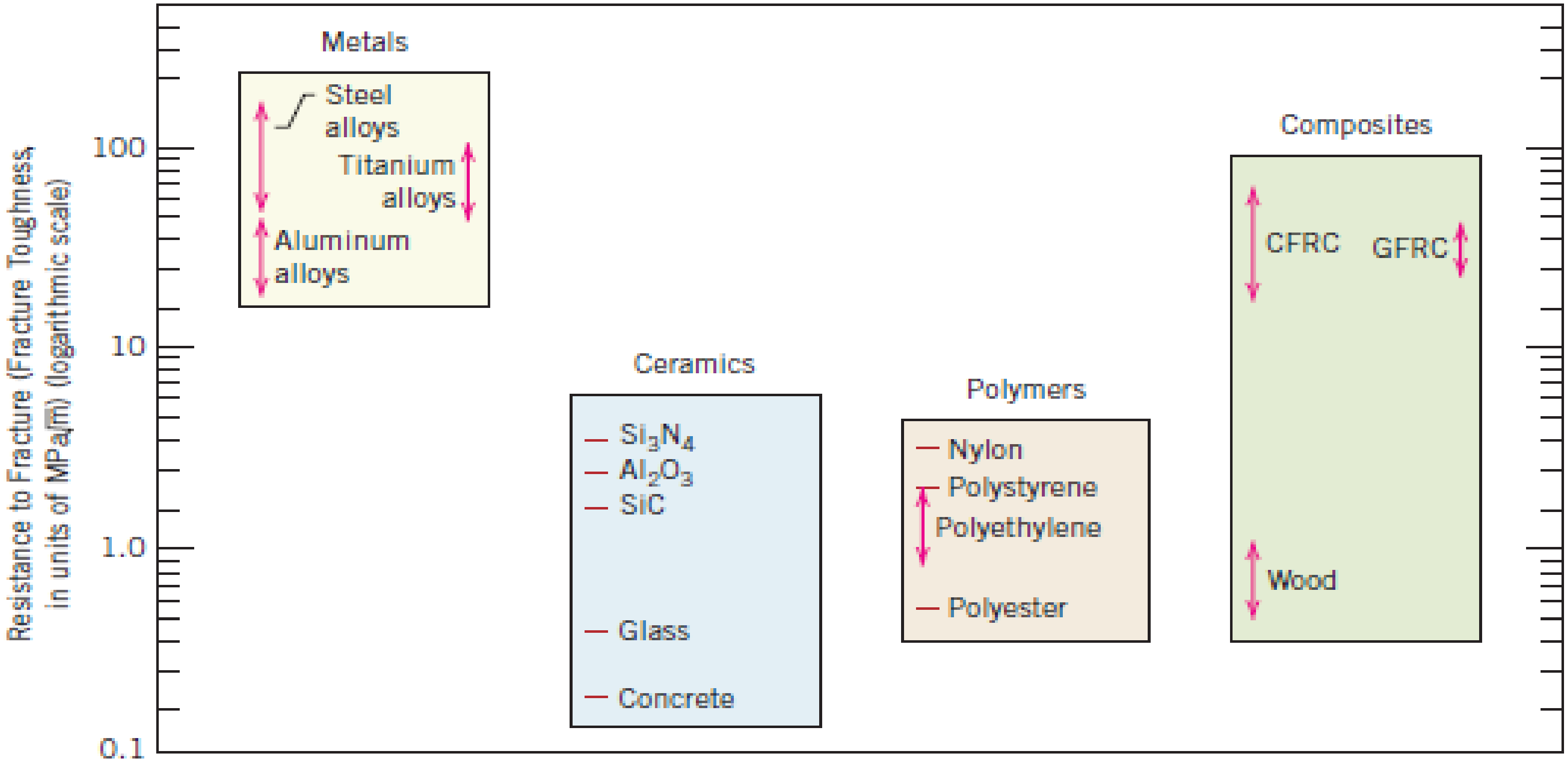
Bar-chart of room temperature stiffness (elastic modulus)

Comparison Chart - 3



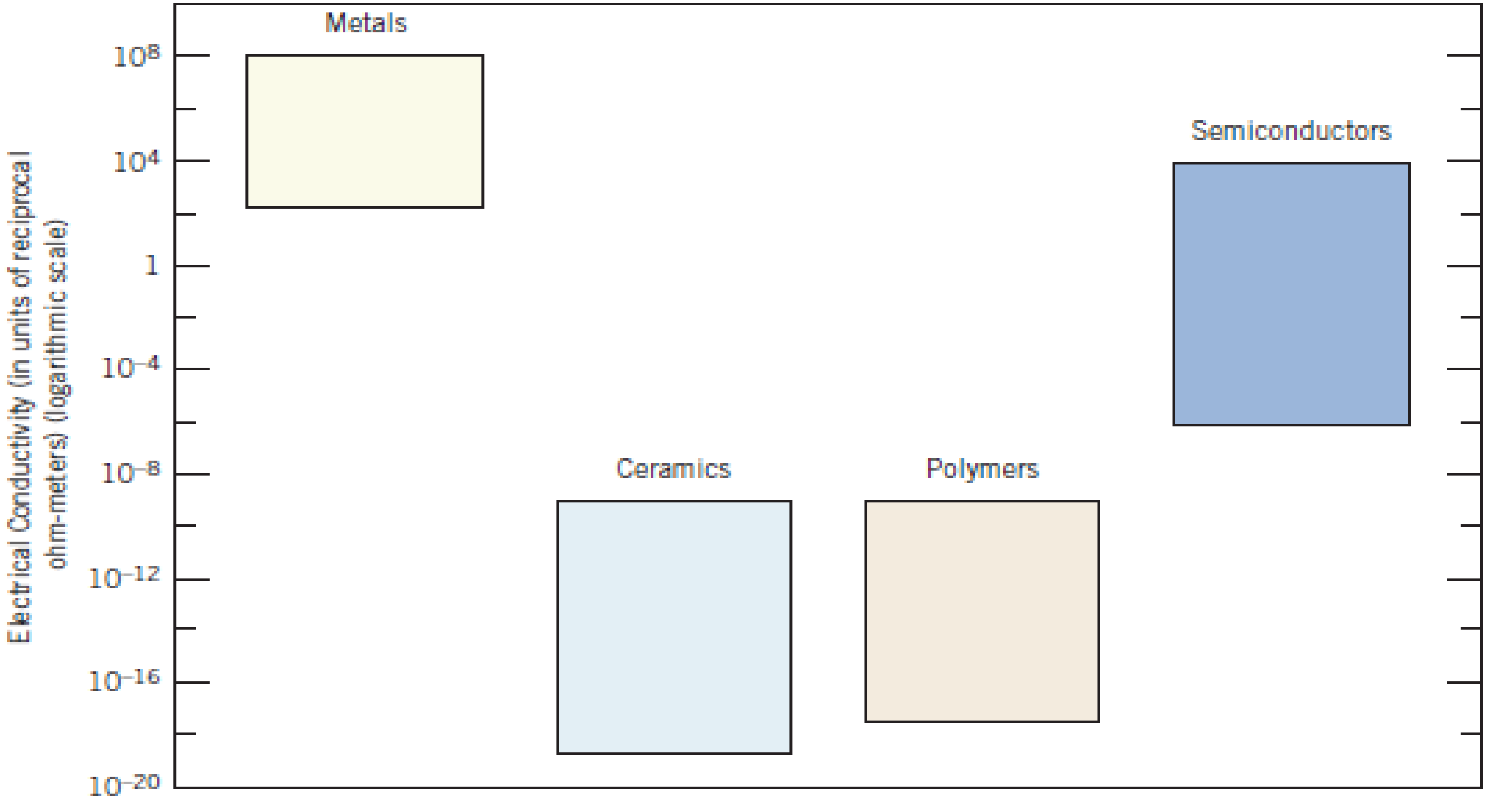
Bar-chart of room temperature strength (tensile strength)

Comparison Chart - 4



Bar-chart of room temperature resistance to fracture (fracture toughness)

Comparison Chart - 5



Bar-chart of room temperature electrical conductivity ranges

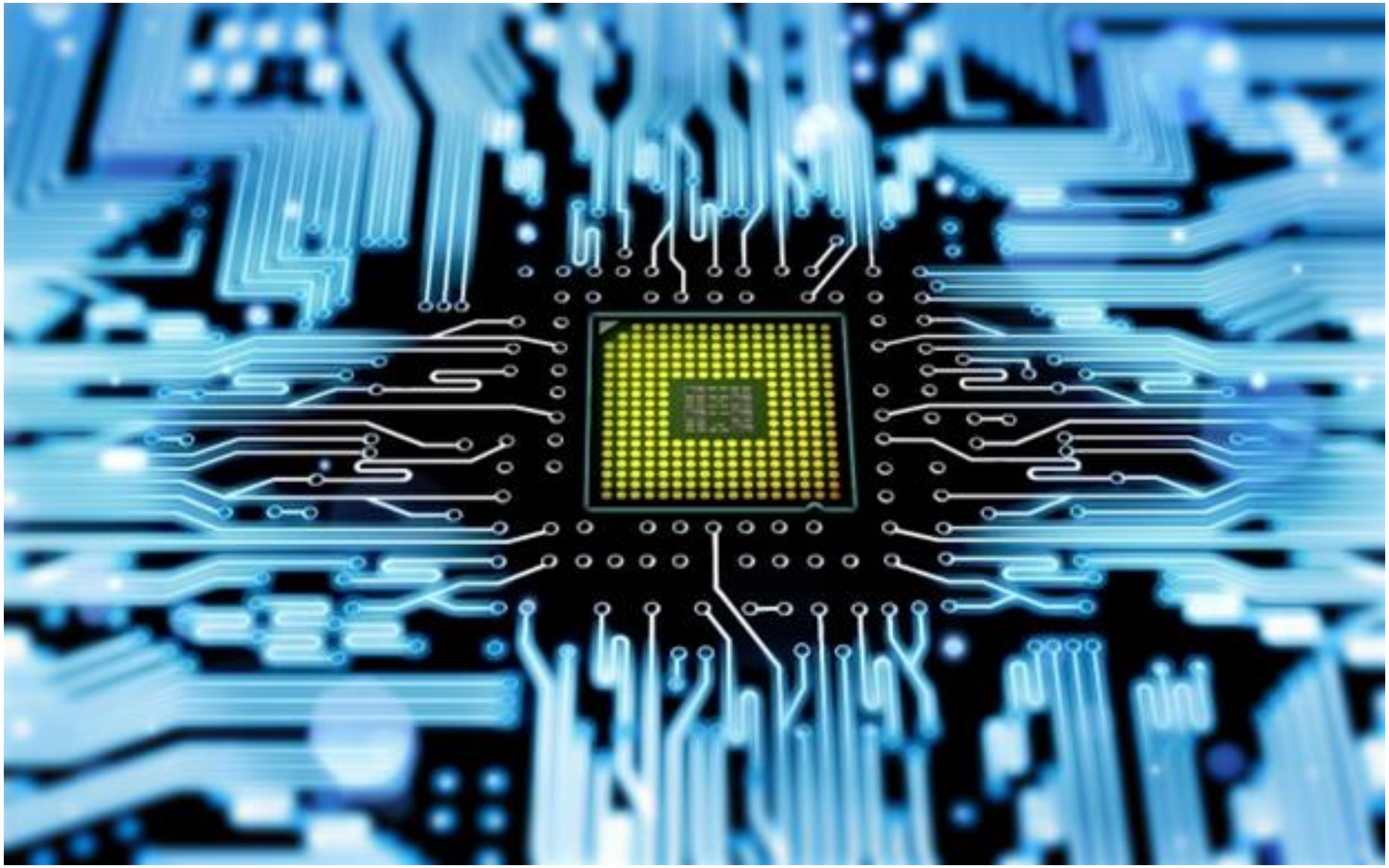
Advanced Materials

- Materials that are utilized in high-tech applications
- Hi-Tech -> device or product that operates or functions using relatively intricate and sophisticated principles
- These advanced materials are typically traditional materials whose properties have been enhanced, and also newly developed, high-performance materials.
- include **semiconductors**, **biomaterials**, and **materials of the future** (i.e. smart materials and nano-engineered materials).

1. Semiconductors

- Semiconductors have electrical properties that are intermediate between the conductors (e.g. metals and metal alloys) and insulators (e.g. ceramics and polymers).
- Common semiconducting materials are crystalline solids but amorphous and liquid semiconductors are known. These include hydrogenated amorphous silicon and mixtures of arsenic, selenium and tellurium in a variety of proportions.
- Electrical characteristics are extremely sensitive to the presence of minute concentrations of impurity atoms.
- Semiconductors have caused the advent of integrated circuitry.

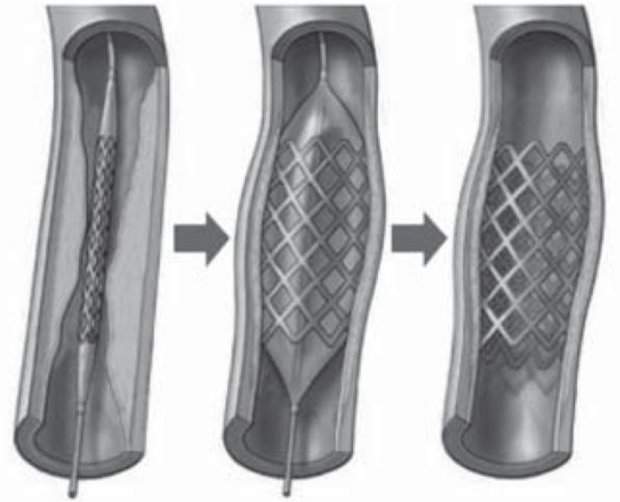
1. Semiconductors

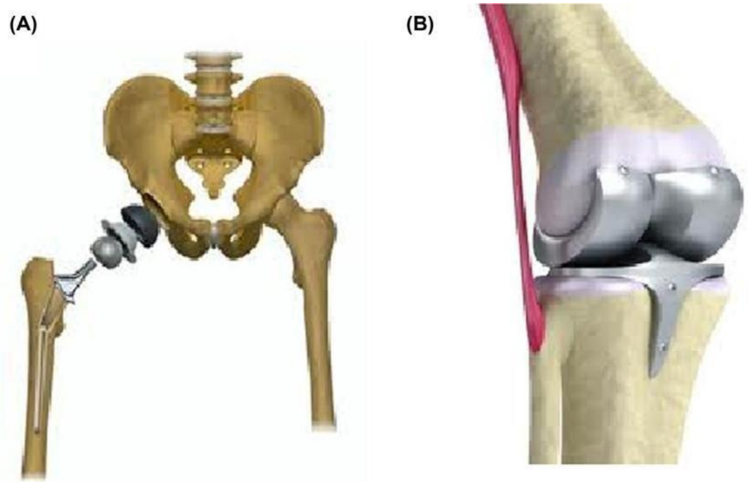


2. Biomaterials

- A biomaterial is any material, natural or man-made, that comprises whole or part of a living structure or biomedical device which performs, augments or replaces a natural function.
- must not produce toxic substances and must be compatible with body tissues.
- All of the above materials—metals, ceramics, polymers, composites, and semiconductors—may be used as biomaterials.
- Examples -> Artificial hip, bone plates, heart valves, contact lenses, dental implants, etc.

2. Biomaterials





Materials of the Future – Smart Materials

- **Smart materials** are materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields.
- Smart material (or system) include some type of **sensors**, and an **actuators.**
- Four types -> shape memory alloys, piezoelectric ceramics, magnetostrictive materials and electrorheological/magnetorheological fluids.

Smart Materials (*contd…*)

- **Shape Memory Alloys** -> alloy that "remembers" its original shape and returns the pre-deformed shape by heating.
- Main types of shape memory alloys are the copper-zinc-aluminum-nickel, copper-aluminum-nickel, and nickel-titanium alloys.
- **Piezoelectric ceramics** -> produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample

Smart Materials (*contd…*)

- **Magnetostrictive materials** -> analogous to piezoelectrics, except that they are responsive to **magnetic** fields.
- **Electrorheological and Magnetorheological fluids** -> liquids that experience dramatic changes in viscosity upon the application of electric and magnetic fields, respectively.
- **Materials for sensors** -> Optical fibers, Piezoelectrics, Microelectromechanical devices.

Materials of the Future – Nano-engineered Materials

- It has become possible to manipulate and move atoms and molecules to form new structures and design new materials that are built from simple atomic-level constituents.
- This ability to carefully arrange atoms provides opportunities to develop mechanical, electrical, magnetic, and other properties that are not otherwise possible
- One example of a material of this type is the carbon nanotube