Properties of Engineering Materials

Introduction

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Historical Perspective

- Materials are probably more deep-seated in our culture than most of us realize.
  - Transportation, housing, clothing, communication, recreation, and food production.
  - Virtually every segment of our everyday lives is influenced to one degree or another by materials.

- Historically, the development and advancement of societies have been intimately tied to the members' ability to produce and manipulate materials to fill their needs.
  - In fact, early civilizations have been designated by the level of their materials development (Stone Age, Bronze Age, Iron Age)

Historical Perspective

- The earliest humans had access to only a very limited number of materials,
  - Those that occur naturally: stone, wood, clay, skins, and so on.
- With time they discovered techniques for producing materials that had properties superior to those of the natural ones;
  - These new materials included pottery and various metals.
- Furthermore, it was discovered that the properties of a material could be altered by heat treatments and by the addition of other substances.

Historical Perspective

- It was not until relatively recent times that scientists came to understand the relationships between the structural elements of materials and their properties.
  - This knowledge, acquired over approximately the past 100 years, has empowered them to fashion, to a large degree, the characteristics of materials.
- Thus, tens of thousands of different materials have evolved with rather specialized characteristics that meet the needs of our modern and complex society;
  - These include metals, plastics, glasses, and fibers.

Historical Perspective

- The development of many technologies that make our existence so comfortable has been intimately associated with the accessibility of suitable materials.
- An advancement in the understanding of a material type is often the forerunner to the stepwise progression of a technology.
  - For example, automobiles would not have been possible without the availability of inexpensive steel or some other comparable substitute.
- In our contemporary era, sophisticated electronic devices rely on components that are made from what are called semiconducting materials.

Materials Science & Engineering

- It is useful to subdivide materials science from materials engineering.
  - Materials Science: materials science involves investigating the relationships that exist between the structures and properties of materials.
  - Materials Engineering: is designing or engineering the structure of a material to produce a predetermined set of properties
- So, the role of a materials scientist is to develop or synthesize new materials, whereas a materials engineer is called upon to create new products or systems using existing materials, and/or to develop techniques for processing materials.

Why Study Materials Science & Engineering?

- Many times, a materials problem is one of selecting the right material from the thousands that are available. The final decision is normally based on several criteria.
  - First of all, the in-service conditions must be characterized, for these will dictate the properties required of the material.
    - Thus, it may be necessary to trade one characteristic for another. The classic example involves strength and ductility; normally, a material having a high strength will have only a limited ductility.
  - A second selection consideration is any deterioration of material properties that may occur during service operation.
    - For example, significant reductions in mechanical strength may result from exposure to elevated temperatures or corrosive environments.

Why Study Materials Science & Engineering?

- Many times, a materials problem is one of selecting the right material from the thousands that are available. The final decision is normally based on several criteria.
  - Finally, probably the overriding consideration is that of economics: What will the finished product cost?
    - A material may be found that has the ideal set of properties but is prohibitively expensive. Here again, some compromise is inevitable.
- The more familiar an engineer or scientist is with the various characteristics and structure–property relationships, as well as processing techniques of materials, the more proficient and confident he or she will be in making judicious materials choices based on these criteria.

Classification of Materials

- Solid materials have been conveniently grouped into three basic categories: metals, ceramics, and polymers.
    - This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another.
- In addition, there are the composites, which are engineered combinations of two or more different materials.
- Another category is advanced materials—those used in high-technology applications, such as semiconductors, biomaterials, smart materials, and nanoengineered materials.

Classification of Materials

- **Metals**: Materials in this group are composed of one or more metallic elements (e.g., iron, aluminum, copper, titanium, gold, and nickel), and often also 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, and in comparison to the ceramics and polymers, are relatively dense.
  - these materials are relatively stiff and strong, yet are ductile (i.e., capable of large amounts of deformation without fracture), and are resistant to fracture.
  - Metallic materials have large numbers of nonlocalized electrons; that is, these electrons are not bound to particular atoms. Hence, metals are extremely good conductors of electricity and heat, and are not transparent to visible light; a polished metal surface has a lustrous appearance. In addition, some of the metals (i.e., Fe, Co, and Ni) have desirable magnetic properties.

Classification of Materials

- **Ceramics**: compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides.
  - These include aluminum oxide (or *alumina,* Al_2O_3), silicon dioxide (or *silica,* SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the *traditional ceramics*—those composed of clay minerals (i.e., porcelain), as well as cement and glass.
  - Ceramic materials are relatively stiff, strong and very hard, but with low ductility (brittle), thus susceptible to fracture.
  - However, newer ceramics are being engineered to have improved resistance to fracture; these materials are used for cookware, and even automobile engine parts.
  - Ceramic materials are typically insulative to the passage of heat and electricity, and are more resistant to high temperatures and harsh environments than metals and polymers.
  - Ceramics may be transparent, translucent, or opaque, and some of the oxide ceramics (e.g., Fe_3O_4) exhibit magnetic behavior.

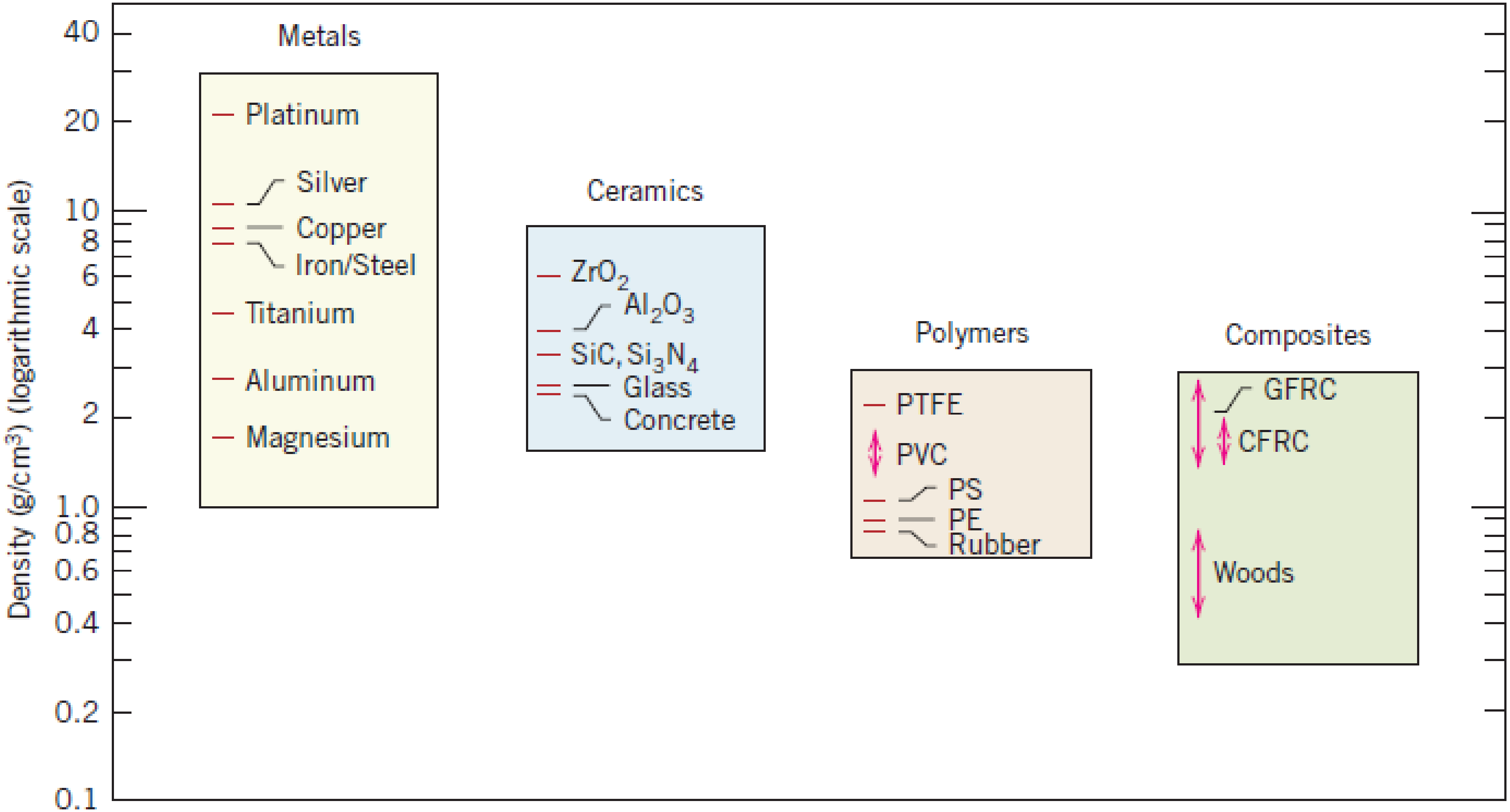
Classification of Materials

- **<u>Polymers</u>**: 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).
  - They have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms. Some of the common polymers are polyethylene (PE), nylon, poly vinyl chloride (PVC), polycarbonate (PC), polystyrene (PS).
  - They 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 (i.e., plastic), which means they are easily formed into complex shapes.
  - they are relatively inert chemically and unreactive in a large number of environments. One major drawback to the polymers is their tendency to soften and/or decompose at modest temperatures, which, in some instances, limits their use. Furthermore, they have low electrical conductivities and are nonmagnetic.

Classification of Materials

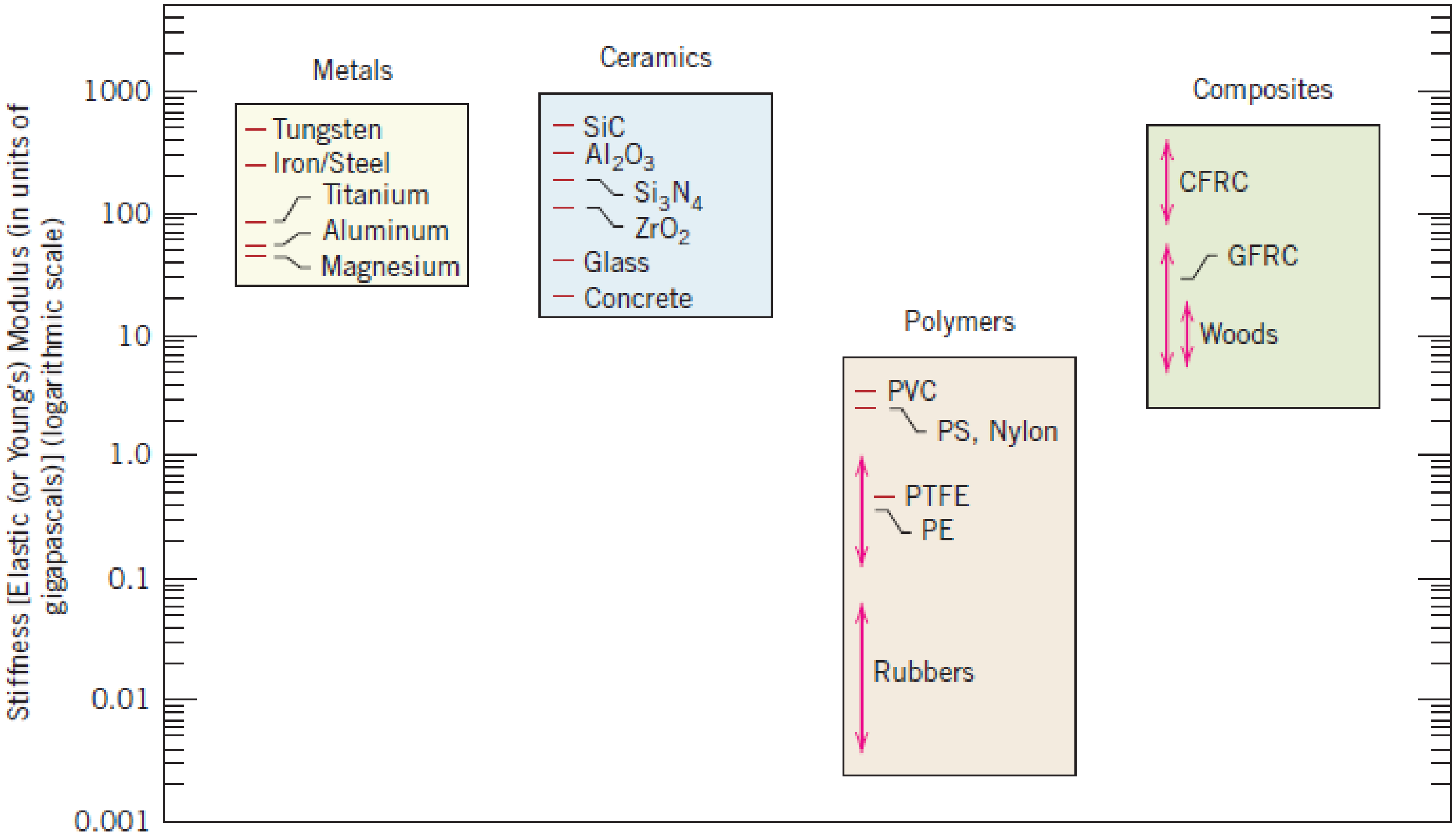
- **<u>Composites</u>**: composed of two (or more) individual materials, which come from metals, ceramics, and polymers.
  - The design goal of a composite is to achieve a combination of properties that is not displayed by any single material.
  - A large number of composite types are represented by different combinations of metals, ceramics, and polymers. Furthermore, some naturally occurring materials are composites—for example, wood and bone.
  - One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material.
  - The glass fibers are relatively strong and stiff (but also brittle), whereas the polymer is more flexible. Thus, fiberglass is relatively stiff, strong, and flexible.
  - Composites have good applications in aerospace industry.

Properties of Different Materials



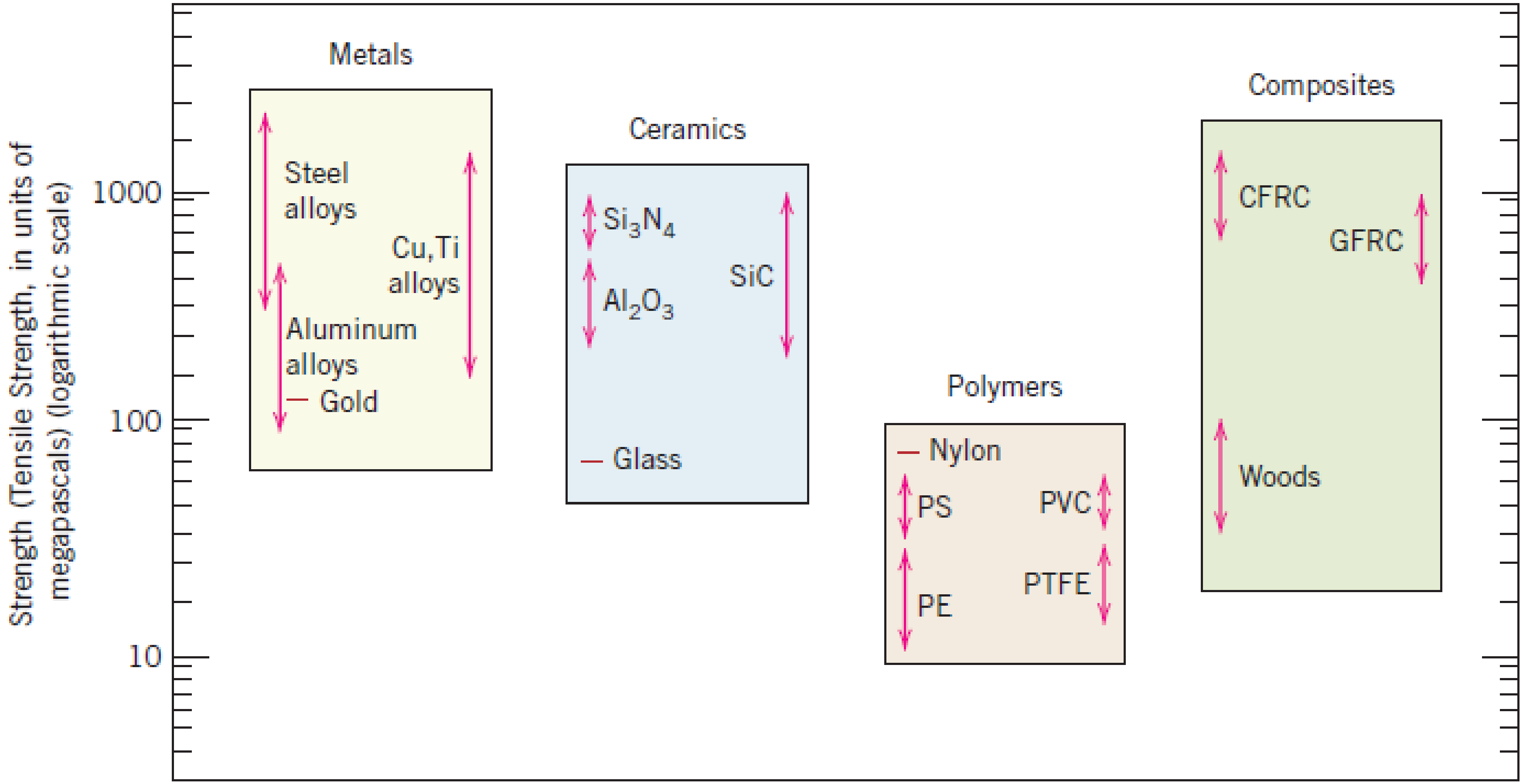
Bar chart of room temperature density values for various metals, ceramics, polymers, and composite materials.

Properties of Different Materials



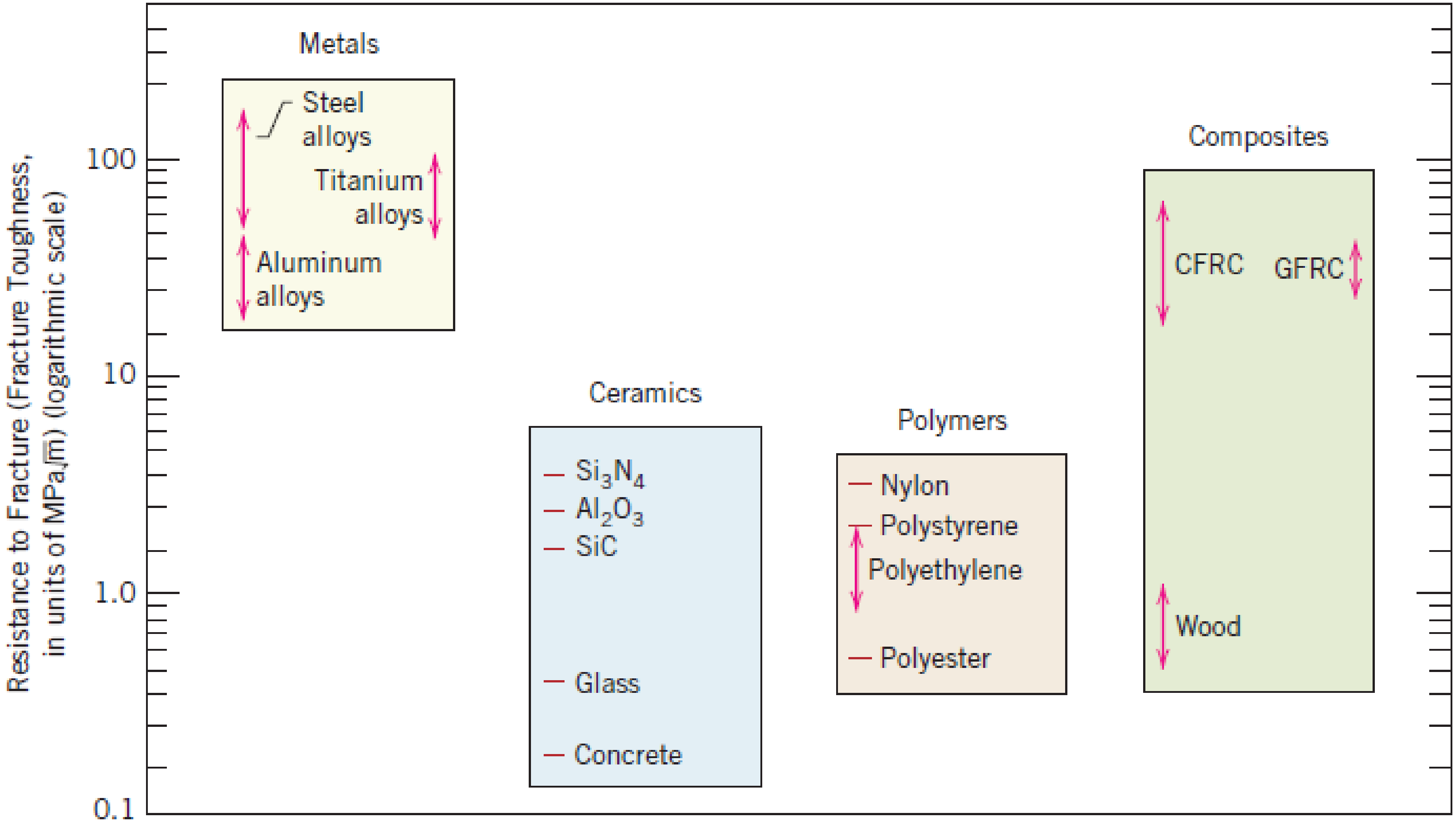
Bar chart of room temperature stiffness (i.e., elastic modulus) values for various metals, ceramics, polymers, and composite materials.

Properties of Different Materials



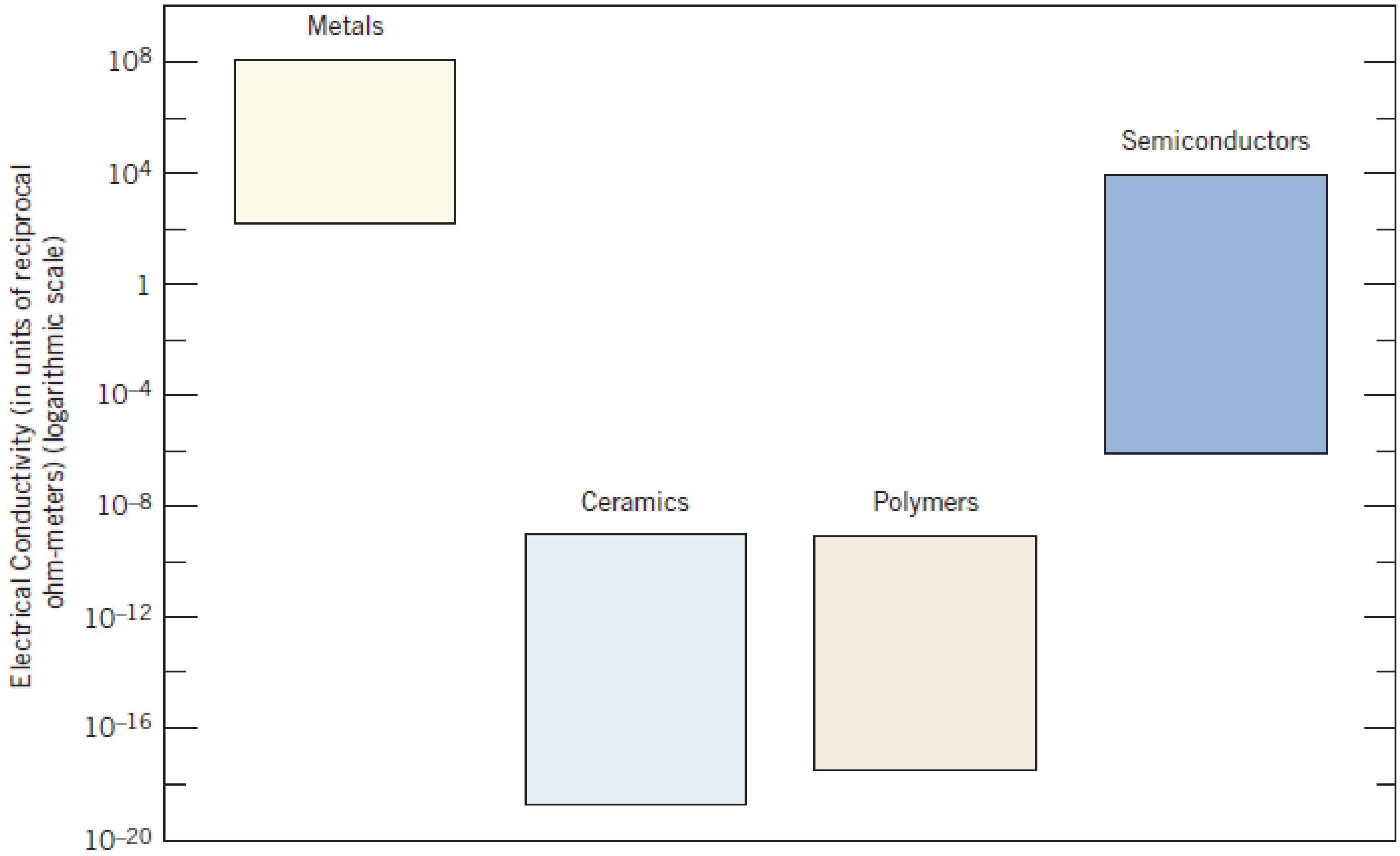
Bar chart of room temperature strength (i.e., tensile strength) values for various metals, ceramics, polymers, and composite materials.

Properties of Different Materials



Bar chart of room temperature resistance to fracture (i.e., fracture toughness) values for various metals, ceramics, polymers, and composite materials.

Properties of Different Materials



Bar chart of room temperature electrical conductivity ranges for various metals, ceramics, polymers, and composite materials.