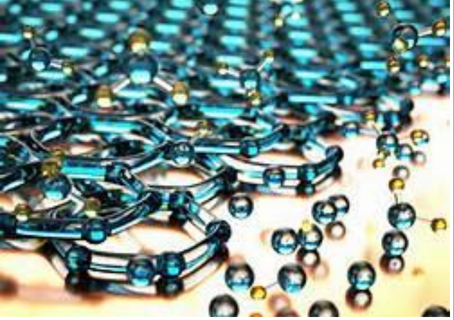

Materials Science

Lecture 2

Lebanese University - Faculty of Engineering – Branch 3

Fall 2022

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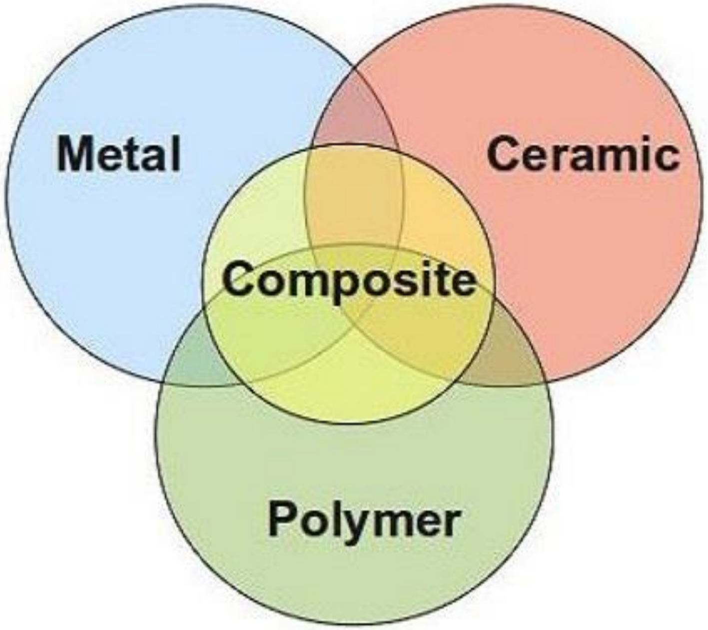
1.4.Classification of Materials

- Solid materials have been conveniently grouped into **three basic categories**: **<u>metals, ceramics, and polymers</u>**, based primarily on chemical makeup and atomic structure.

- In addition, there are the **composites** that are engineered **<u>combinations of two or more different materials.</u>**

- Another category is **advanced materials**—those used in **<u>high-technology applications</u>**, such as semiconductors, biomaterials, smart materials, and nanoengineered materials.



1.4.Classification of Materials

Metals

1.4.Classification of Materials

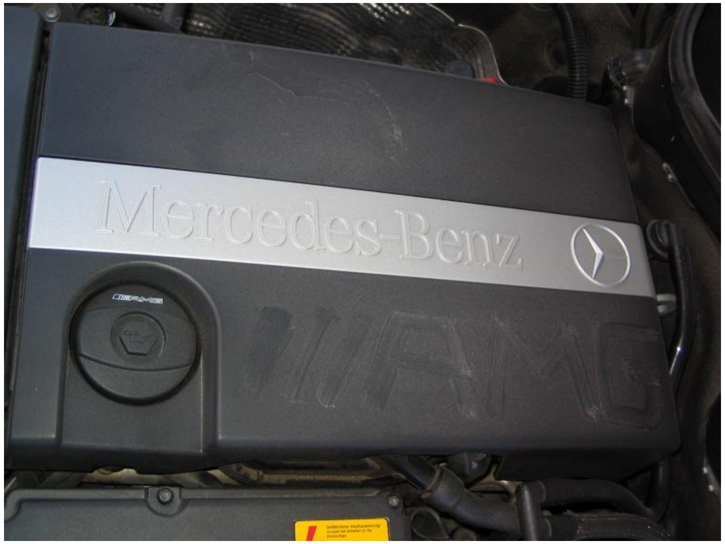
Ceramics

1.4.Classification of Materials

Polymers

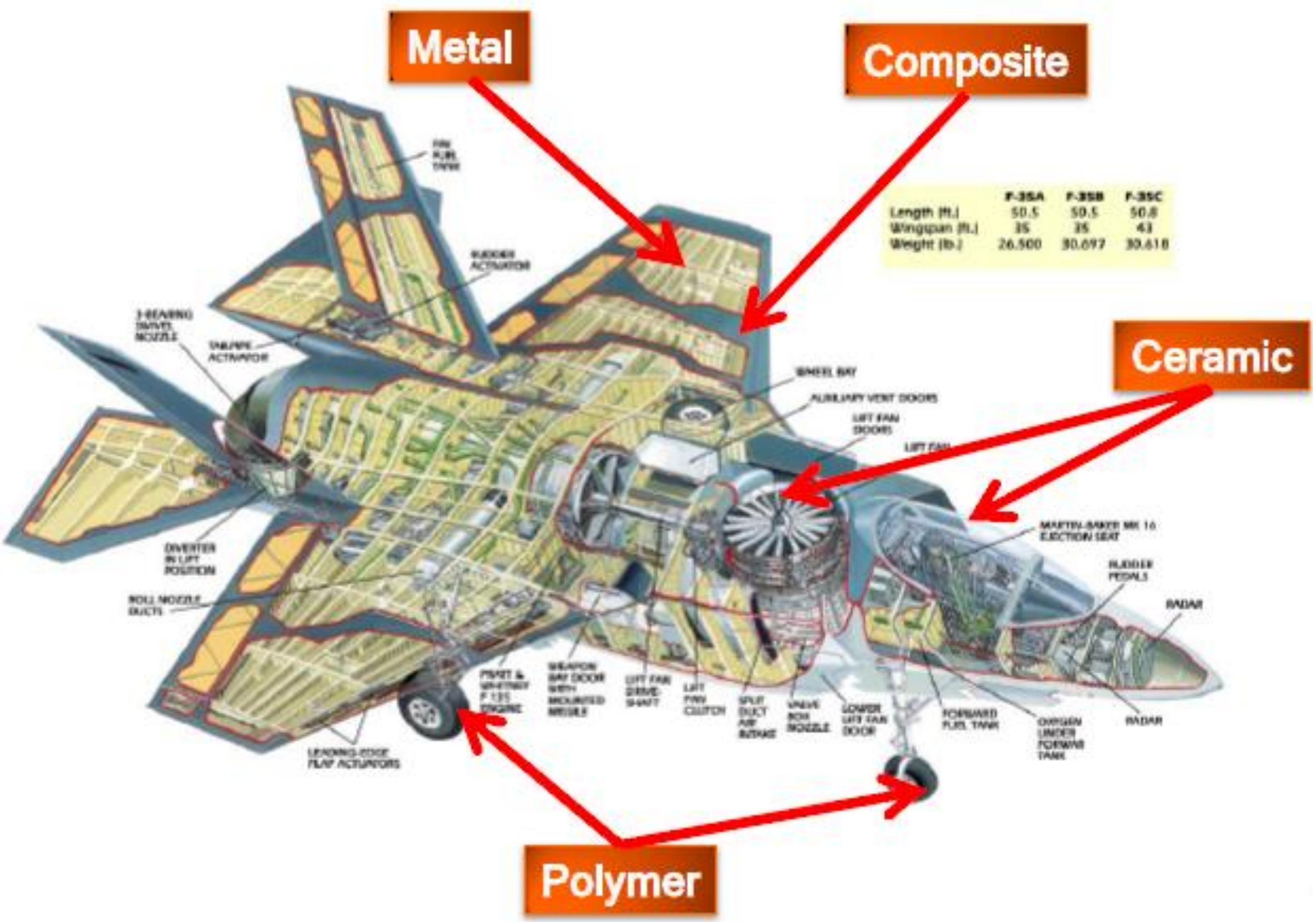
1.4.Classification of Materials

Composite Materials



1.4.Classification of Materials

Often, a device contains several categories of materials



1.4.Classification of Materials

Often, a device contains several categories of materials

Ceramic (bottle)

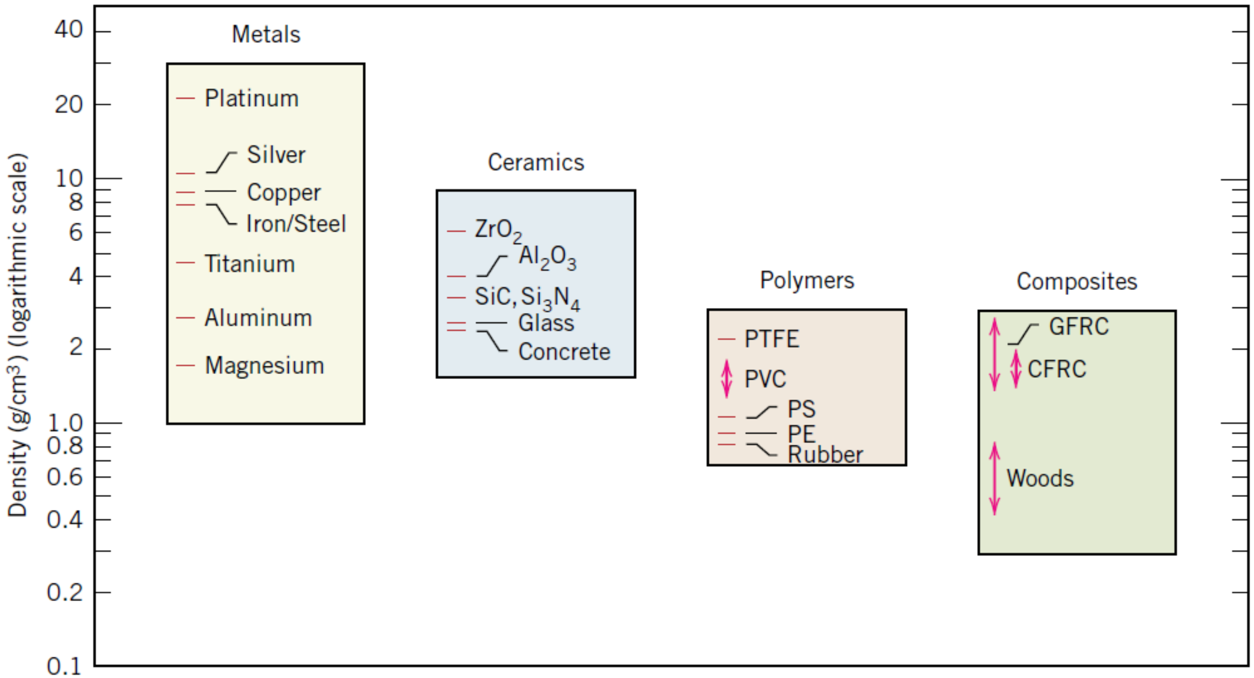
Metal(can)

Polymer

1.4.Classification of Materials

Metals

- Metals are composed of **one or more metallic elements** (e.g., iron, aluminum, copper, titanium, gold, nickel), and **often also nonmetallic elements** (e.g., carbon, nitrogen, oxygen) **in relatively small amounts**.
- **Atoms** in metals and their alloys are arranged in a very orderly manner and are relatively dense in comparison to the ceramics and polymers (figure).

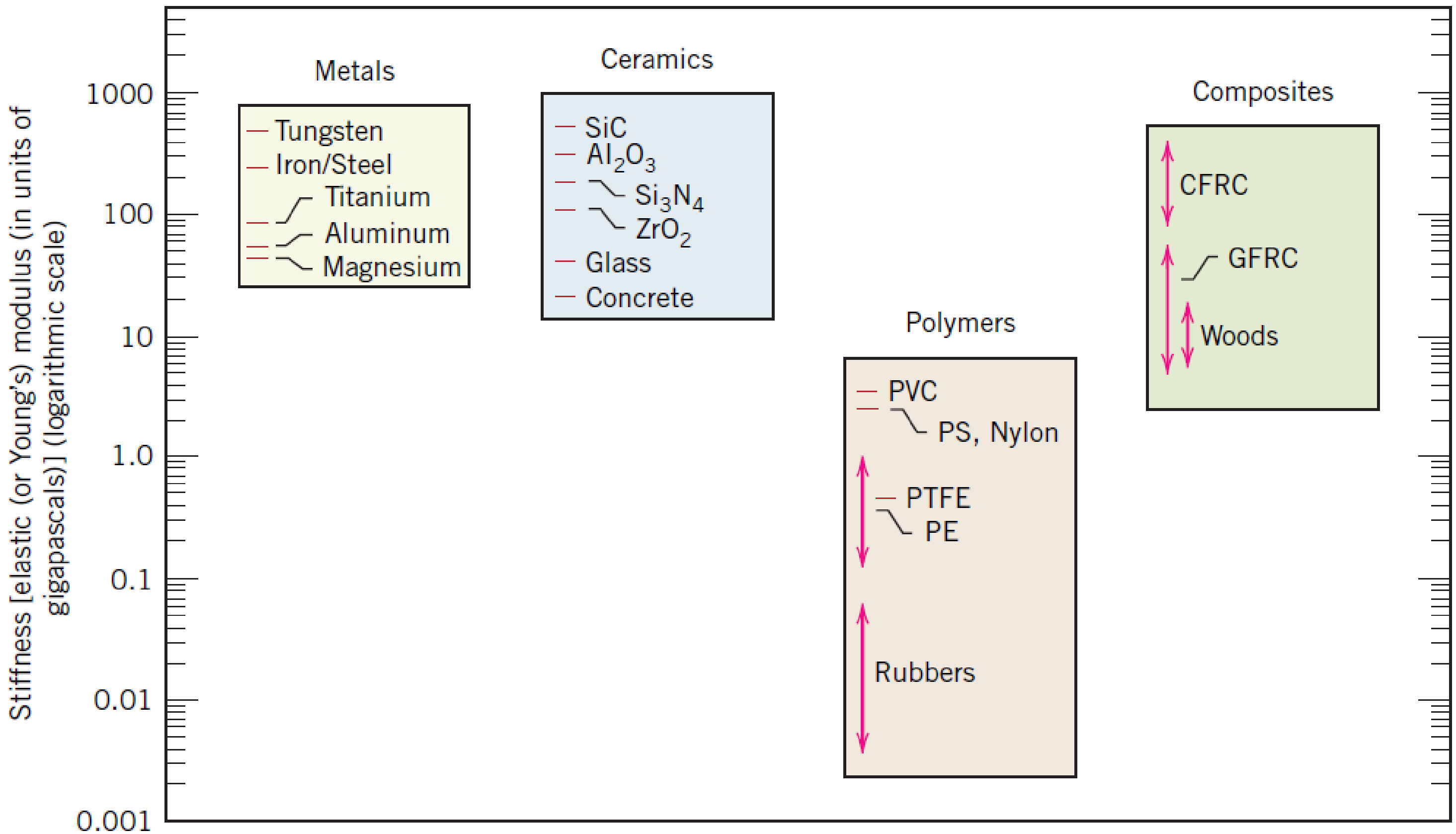


Bar chart of room-temperature density values for various metals, ceramics, polymers, and composite materials.

1.4.Classification of Materials

Metals

- With regard to **mechanical characteristics**, these materials are **relatively stiff** (figure).

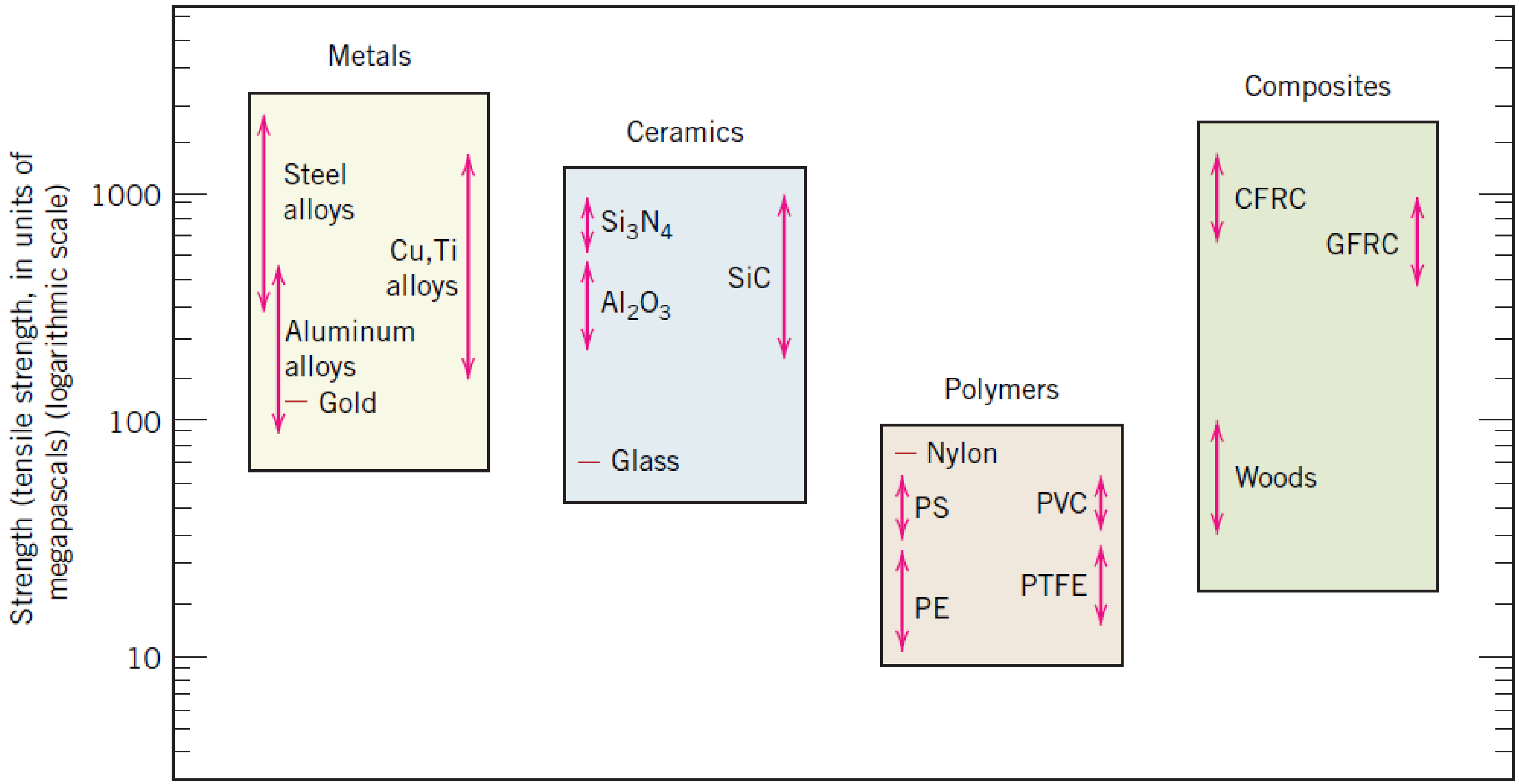


Bar chart of room-temperature stiffness (i.e., elastic modulus) values for various metals, ceramics, polymers, and composite materials.

1.4.Classification of Materials

Metals

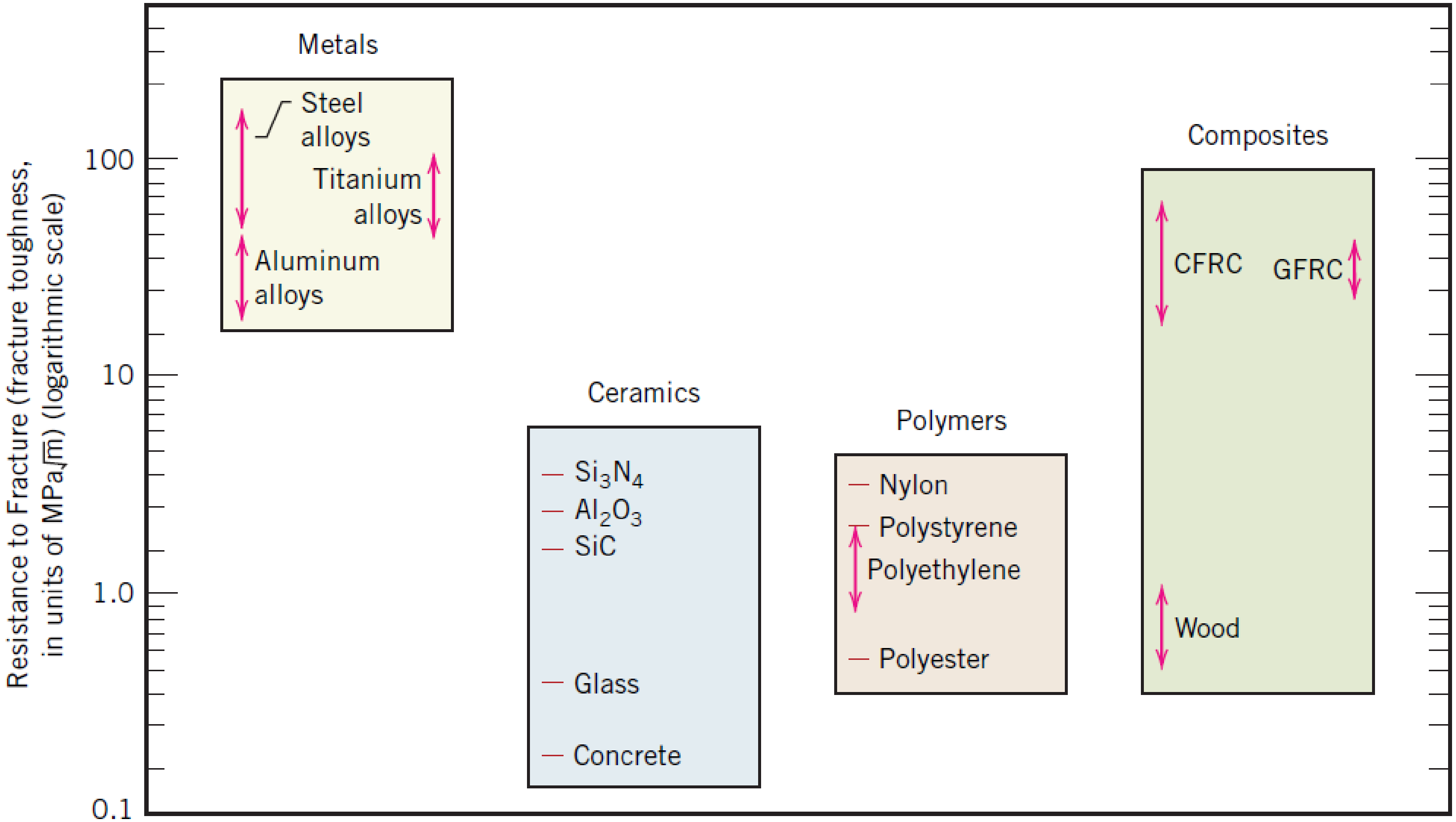
- They are **strong** (figure).



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

Metals

- They are **ductile** (i.e., capable of large amounts of deformation without fracture), and **are resistant to fracture** (figure), which accounts for their widespread use in structural applications.



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

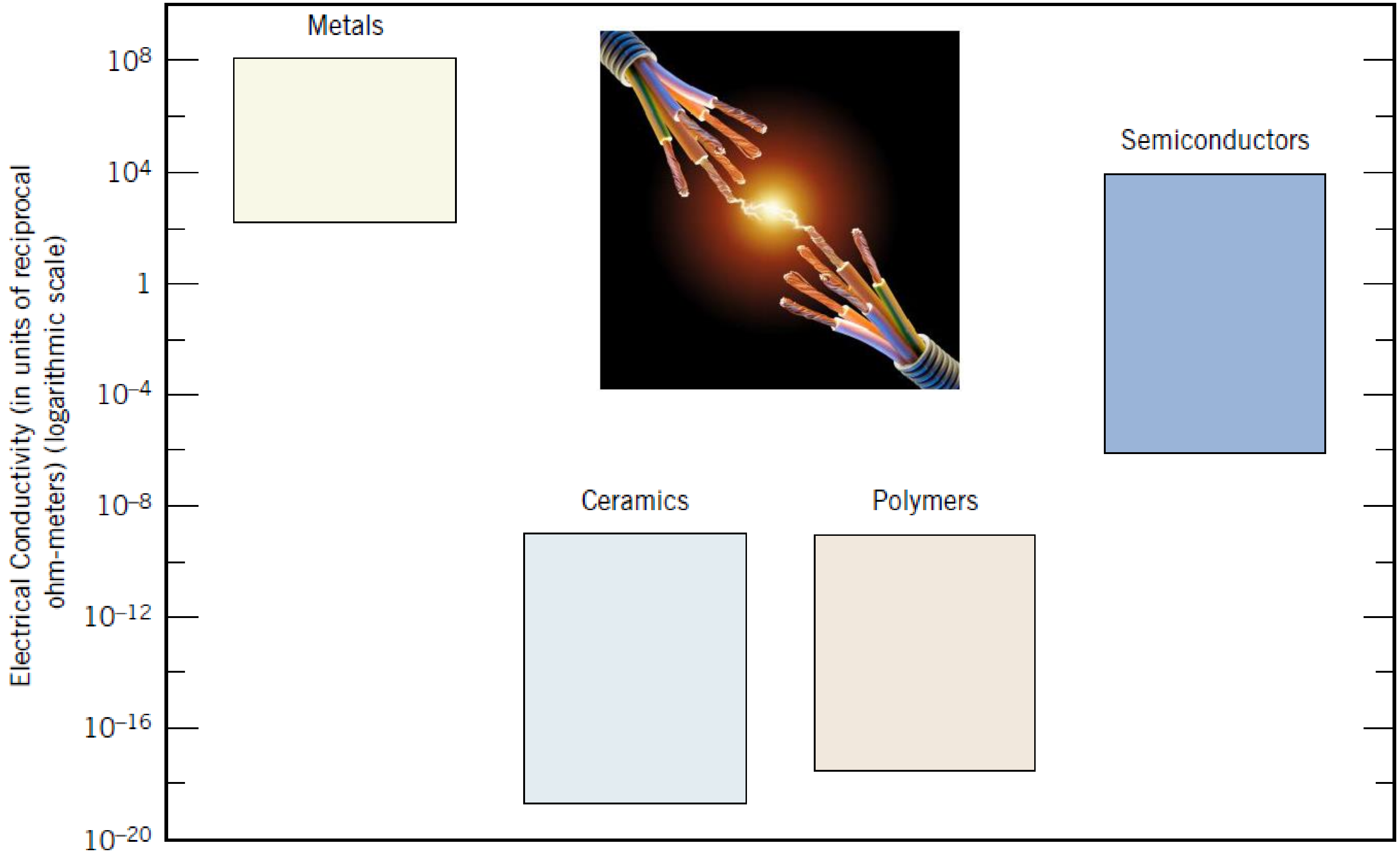
1.4.Classification of Materials

Metals

- Metallic materials have **large numbers of nonlocalized electrons—that is, these electrons are not bound to particular atoms.**
- Many properties of metals are directly attributable to these electrons. **For example**, 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.**

1.4.Classification of Materials

Metals



Bar chart of room-temperature electrical ***conductivity*** *ranges for metals, ceramics, polymers, and semiconducting materials.*

1.4.Classification of Materials

Ceramics

- Ceramics are compounds **between metallic and nonmetallic elements**.
- They are most frequently **oxides (oxygen), nitrides (nitrogen), and carbides (carbon)**.
- **For example**, common ceramic materials include aluminum oxide (or alumina, Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4).
- In addition, some refer to as the traditional ceramics—those composed of **clay minerals (e.g., porcelain), as well as cement and glass.**
- With regard to mechanical behavior, ceramic materials **are relatively stiff and strong—stiffnesses and strengths are comparable to those of the metals** (Previous figures).
- They are typically very hard.

1.4.Classification of Materials

Ceramics

- Historically, ceramics have exhibited **extreme brittleness (lack of ductility)** and are **highly susceptible to fracture** (Previous figure). However, **newer ceramics are being engineered to have improved resistance to fracture.**

- These materials are used for **cookware, cutlery, and even automobile engine parts.**

- Furthermore, ceramic materials are typically **insulative to the passage of heat and electricity** (i.e., have low electrical conductivities, Previous figure) and are **more resistant to high temperatures and harsh environments than are metals and polymers.**

- With regard to optical characteristics, ceramics **may be transparent, translucent, or opaque, and some of the oxide ceramics (e.g., Fe_3O_4) exhibit magnetic behavior.**

1.4.Classification of Materials

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).

- Furthermore, they have **very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms.**

- Some common and familiar polymers are polyethylene (PE), nylon, poly(vinyl chloride) (PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber.

- These materials typically have **low densities** (Previous figure), whereas their **mechanical characteristics are generally dissimilar to those of the metallic and ceramic materials**—they are **not as stiff or strong as these other material types** (Previous figures).

1.4.Classification of Materials

Polymers

- Many of the polymers are **extremely ductile** and **pliable** (i.e., plastic), which means they are **easily formed into complex shapes**.
- In general, 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** (Previous figure) and are **nonmagnetic**.

1.4.Classification of Materials

Composites

- A composite is composed of **two (or more) individual materials** that 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 materia**ls.

- 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**.

- However, most of those we consider in our discussions are **synthetic** (or human-made) composites.

1.4.Classification of Materials

Composites

- 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 (Previous figures), and flexible.

- In addition, it has a low density (Previous figure).

- **Another technologically** important material is the **carbon fiber–reinforced polymer CFRP) composite**—carbon fibers that are embedded within a polymer.

1.4.Classification of Materials

Composites

- **These materials are stiffer and stronger** than glass fiber–reinforced materials but **more expensive**.

- **CFRP composites are used in some aircraft and aerospace applications**, as well as in **high-tech sporting equipment** (e.g., bicycles, golf clubs, tennis rackets, skis/ snowboards) and recently in **automobile bumpers**.

- The new Boeing 787 fuselage (body) is primarily made from such CFRP composites.

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1.5.Advanced Materials

- Materials **utilized in high-technology (or high-tech)** applications are sometimes termed **advanced materials**.

- By **high technology**, we mean a device or **product that operates or functions using relatively intricate and sophisticated principles**, including **electronic** equipment (camcorders, CD/DVD players), **computers**, **fiber-optic** systems, **spacecraft**, **aircraft**, and **military rocketry**.

- These advanced materials are typically **traditional materials whose properties have been enhanced** and also **newly developed, high-performance materials.**

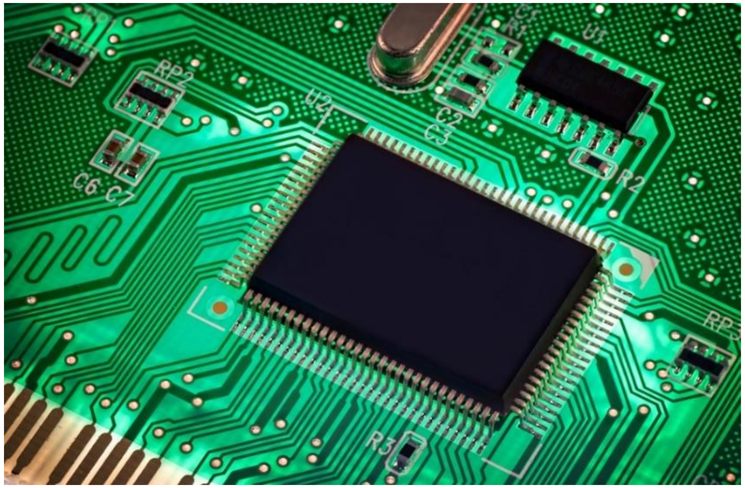
- Furthermore, **they may be of all material types** (e.g., metals, ceramics, polymers) and are normally expensive.

- Advanced materials include **semiconductors, biomaterials, and what we may term materials of the future (i.e., smart materials and nanoengineered materials).**

1.5.Advanced Materials

Semiconductors

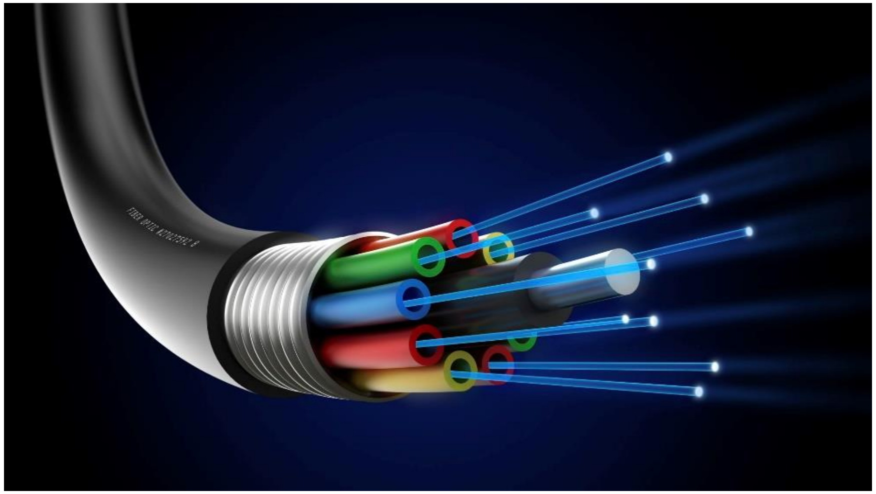
- Semiconductors have **electrical properties that are intermediate between those of electrical conductors** (i.e., metals and metal alloys) **and insulators** (i.e., ceramics and polymers).
- Furthermore, the **electrical characteristics** of these materials are **extremely sensitive** to the **presence of minute concentrations of impurity atoms**.
- Semiconductors have made possible **the advent of integrated circuitry** that has totally revolutionized **the electronics and computer industries** (and our lives) over the past three decades.



1.5.Advanced Materials

Photonic or Optical Materials

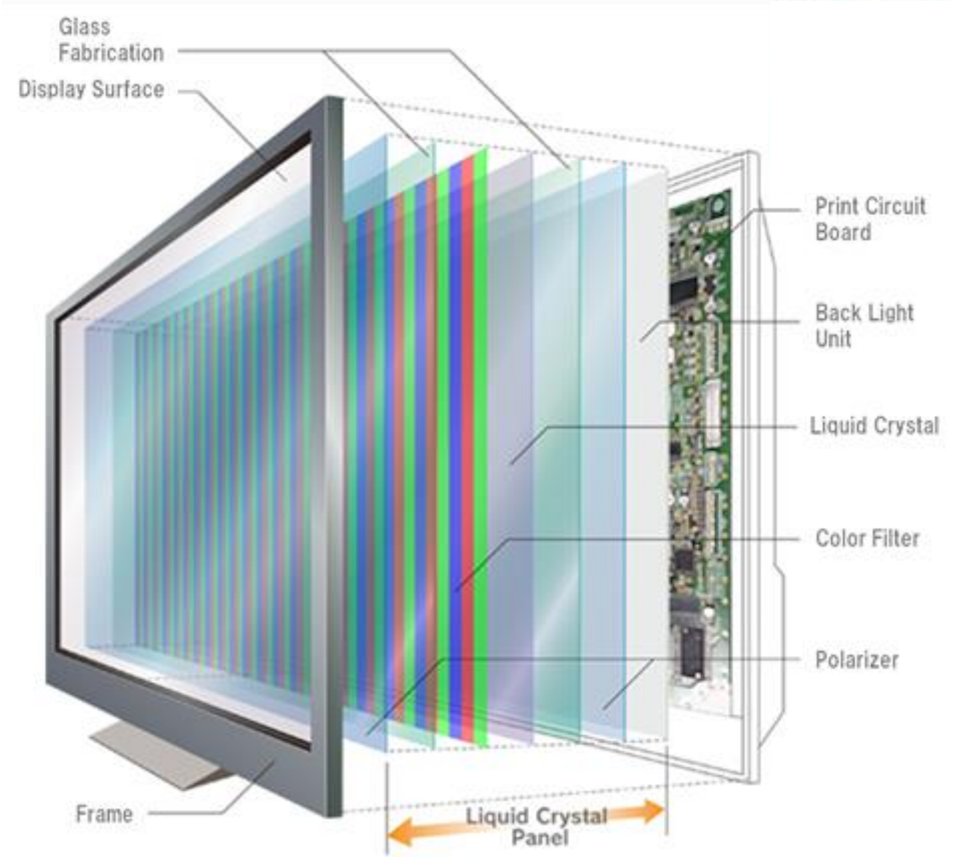
- Silica is used widely for making optical fibers installed around the world.
- Optical materials are used for making semiconductor detectors and lasers used in fiber optic communications.
- Alumina (Al_2O_3) and yttrium aluminum garnets (YAG) are used for making lasers.



1.5.Advanced Materials

Photonic or Optical Materials

- Amorphous silicon is used to make solar cells.
- Polymers are used to make liquid crystal displays (LCDs).



1.5.Advanced Materials

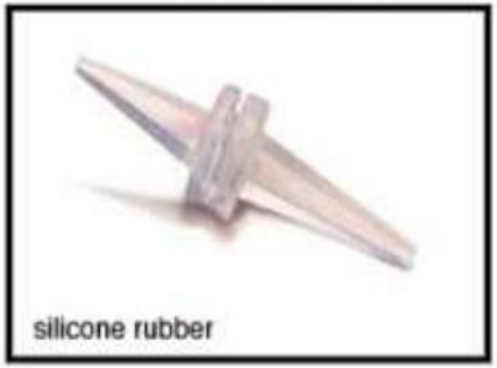
Biomaterials

- 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.

Finger joint



Breast implant

Heart valve

1.5.Advanced Materials

Smart Materials

- **Smart (or intelligent)** materials are a group of **new and state-of-the-art materials now being developed** that will have a significant **influence on many of our technologies.**

- The adjective smart implies that **these materials are able to sense changes in their environment and then respond to these changes in predetermined manners**—traits that are also found in living organisms.

- **Components** of a smart material (or system) **include some type of sensor (which detects an input signal) and an actuator (which 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.**

1.5.Advanced Materials

Smart Materials

- **Example:** one type of smart system is used in helicopters to reduce aerodynamic cockpit noise created by the rotating rotor blades.
- Piezoelectric sensors inserted into the blades monitor the blade stresses and the deformations, feedback signals from these sensors are fed into a computer-controlled adaptive device that generates noise-canceling antinoise.

Thermochromics material

D3o is a new innovation It is a soft malleable material most of the time, but when it comes into contact with force, it hardens on impact

1.5.Advanced Materials

Smart Materials

Carbon fiber body armor

1.5.Advanced Materials

<u>Nanomaterials</u>

- One **new material class that has fascinating properties and tremendous technological promis**e is the nanomaterials, which may be any one of the four basic types (**metals, ceramics, polymers, or composites**).
- However, unlike these other materials, they are <u>**not distinguished on the basis of their chemistry but rather their size**</u>. 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 nanometer (nm).**
- Prior to the advent of nanomaterials, the general procedure scientists used to understand the chemistry and physics of materials was to begin by studying **large and complex structures** and **then investigate the fundamental building** blocks of these structures that are smaller and simpler. This approach is sometimes termed <u>**top-down science**</u>.

1.5.Advanced Materials

Nanomaterials

- However, with 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 atomic-level** constituents, **one atom or molecule at a time (i.e., "materials by design").**

- **This ability to arrange atoms carefully provides opportunities to develop mechanical, electrical, magnetic, and other properties that are not otherwise possible.** We call this the **bottom-up approach**, and the study of the properties of these materials is termed **nanotechnology**.

- **Some of the physical and chemical characteristics exhibited by matter may experience dramatic changes as particle size approaches atomic dimensions**. **For example,** materials that are **opaque in the macroscopic domain may become transparent on the nanoscale**; **some solids become liquids**, **chemically stable materials become combustible**, and **electrical insulators become conductors.**

1.5.Advanced Materials

Nanomaterials

- Because of these **unique and unusual proper**ties, nanomaterials are finding niches in **electronic, biomedical, sporting, energy production, and other industrial applications.**

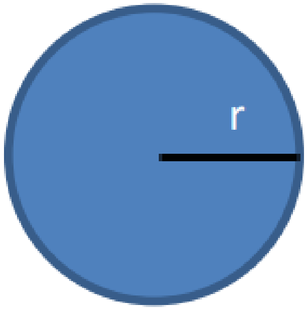
- Whenever a new material is developed, its **potential for harmful and toxicological interactions with humans and animals must be considered.**

- Although the **safety of nanomaterials is relatively unexplored**, there are concern that they may be **absorbed into the body through the skin**, **lungs**, and **digestive tract at relatively high rates**, and that some, **if present in sufficient concentrations, will pose health risks—such as damage to DNA or promotion of lung cancer.**

1.5.Advanced Materials

Nanomaterials

- Small nanoparticles have exceedingly **large surface area–to–volume ratios**, **which can lead to high chemical reactivities**.
- **Example:** let us consider a sphere of radius r.



The surface area of the sphere will be $4\pi r^2$

The volume of the sphere = $4/3\pi r^3$

Therefore the surface area to the volume ratio will be $4\pi r^2/(4/3\pi r^3) = 3/r$

- For r <<<<<< => ratio >>>>>

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1.6.Modern Materials' Needs

- **In spite of the tremendous progress that has been made in the discipline of materials science and engineering within the past few years, technological challenges remain, including the development of even more sophisticated and specialized materials**, as well as consideration of the **environmental impact** of materials production.

- **Nuclear energy** holds some promise, but it's necessary to find solutions to the problems that involve **materials, such as fuels, containment structures, and facilities for the disposal of radioactive waste.**

- **Significant quantities of energy are involved in transportation. Reducing the weight of transportation vehicles** (automobiles, aircraft, trains, etc.), as well as **increasing engine operating temperatures, will enhance fuel efficiency.**

- **New high-strength, low-density structural materials** remain to be developed, as well as **materials that have higher-temperature capabilities, for use in engine components.**

1.6.Modern Materials' Needs

- Furthermore, there is a recognized need to **find new and economical sources of energy** and to **use present resources more efficiently**. Materials will undoubtedly play a significant role in these developments. **For example, the direct conversion of solar power into electrical energy has been demonstrated**. **Solar cells** employ some rather c**omplex and expensive materials**. To ensure a viable technology, materials that are highly efficient in this conversion process **yet less costly must be developed**.

- **The hydrogen fuel cell is another very attractive and feasible energy-conversion technology that has the advantage of being nonpolluting**. It is just beginning to be implemented in **batteries for electronic devices** and holds promise **as a power plant for automobiles**. New materials still need to be developed for more efficient fuel cells and also for **better catalysts to be used in the production of hydrogen.**

- **Materials processing** and refinement methods need to be improved so that they produce **less environmental degradation**.

1.6.Modern Materials' Needs

- **Many materials** that we use are derived from **resources that are nonrenewable**, that is, not capable of being regenerated, **including most polymers, for which the prime raw material is oil, and some metals.**

- These nonrenewable resources are gradually becoming depleted, which necessitates **(1) the discovery of additional reserves**, **(2) the development of new materials having comparable properties with less adverse environmental impact**, and/or **(3) increased recycling efforts and the development of new recycling technologies.**

- **In front of environmental impact and ecological factors**, it is becoming increasingly important to consider the **"cradle-to-grave"** life cycle of materials relative to the overall manufacturing process.