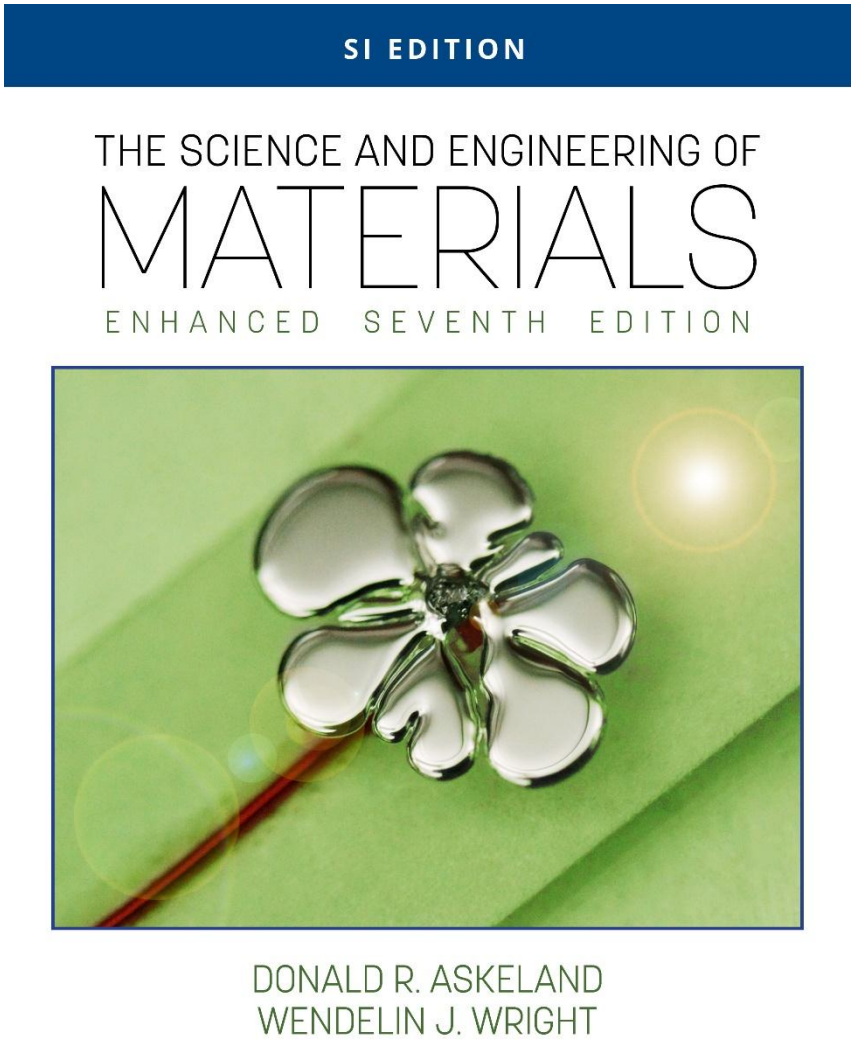

Chapter 1

Introduction to Materials Science and Engineering

Chapter Learning Objectives

- Describe the primary concepts that define materials science and engineering.
- Explain the role of materials science in the design process.
- Classify materials by properties.
- Classify materials by function.

Chapter Outline

Sections

- 1-1 What is Materials Science and Engineering?
- 1-2 Classification of Materials
- 1-3 Functional Classification of Materials
- 1-4 Classification of Materials Based on Structure
- 1-5 Environmental and Other Effects
- 1-6 Materials Design and Selection

1-1 What is Materials Science and Engineering?

- MSE is an interdisciplinary field concerned with inventing new materials/devices & improving existing materials by better understanding microstructure-composition-synthesis-processing relationships.

- Some relevant terms are:
  - Composition: Chemical make-up of a material
  - Structure: Arrangement of atoms seen at different levels of detail
  - Synthesis: How materials are made
  - Processing: How materials are shaped into useful components

1-1 What is Materials Science and Engineering?

- The structure of materials has a profound effect on their properties.
- The microstructure is the structure at the microscopic scale.
- The materials science and engineering tetrahedron is a method of analysis used to consider a situation from the MSE perspective.

1-1 What is Materials Science and Engineering?

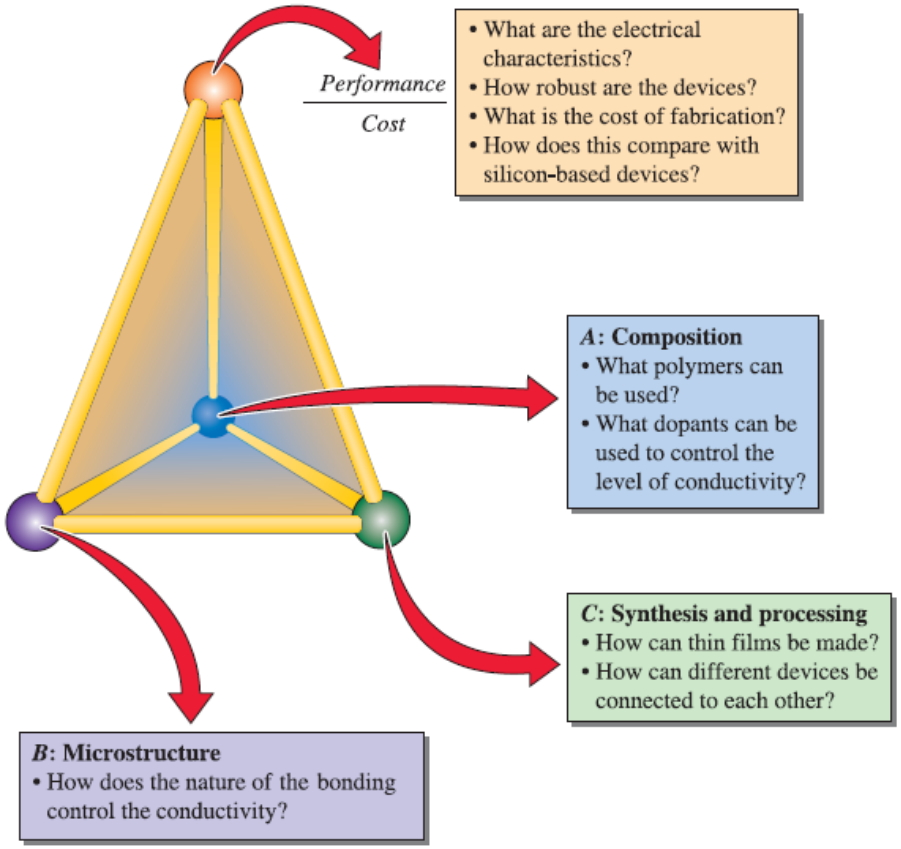

Figure 1-2 Application of the tetrahedron of materials science and engineering to semiconducting polymers for microelectronics.

1-2 Classification of Materials

- There are many ways to classify materials. One way is to describe the following 5 classes:
  - Metals & Alloys
  - Ceramics, Glasses & Glass-ceramics
  - Polymers (plastics)
  - Semiconductors
  - Composite materials
- Table 1-1 lists some materials, applications & properties of each of the above 5 categories.

1-2 Classification of Materials

	Examples of Applications	Properties
Metals and Alloys		
Copper	Electrical conductor wire	High electrical conductivity, good formability
Gray cast iron	Automobile engine blocks	Castable, machinable, vibration-damping
Alloy steels	Wrenches, automobile chassis	Significantly strengthened by heat treatment
Ceramics and Glasses		
SiO_2-Na_2O-CaO	Window glass	Optically transparent, thermally insulating
Al_2O_3, MgO, SiO_2	Refractories (i.e., heat-resistant lining of furnaces) for containing molten metal	Thermally insulating, withstand high temperatures, relatively inert to molten metal
Barium titanate	Capacitors for microelectronics	High ability to store charge
Silica	Optical fibers for information technology	Low optical losses
Polymers		
Polyethylene	Food packaging	Easily formed into thin, flexible, airtight film
Epoxy	Encapsulation of integrated circuits	Electrically insulating and moisture resistant
Phenolics	Adhesives for joining plies in plywood	Strong, moisture resistant

1-2 Classification of Materials

	Examples of Applications	Properties
Semiconductors		
Silicon	Transistors and integrated circuits	Unique electrical behavior
GaAs	Optoelectronic systems	Converts electrical signals to light, used in lasers, laser diodes, etc.
Composites		
Graphite-epoxy	Aircraft components	High strength-to-weight ratio
Tungsten carbide-cobalt (WC-Co)	Carbide cutting tools for machining	High hardness, yet good shock resistance
Titanium-clad steel	Reactor vessels	Low cost and high strength of steel with the corrosion resistance of titanium

1-2 Classification of Materials

- Materials in each group have properties. We are often interested in load-bearing, or mechanical properties of materials.

- Some relevant terms to mechanical properties are:
  - Stress: Load or force per unit area
  - Strain: Elongation or change in dimension divided by the original dimension

- Strain is caused by stress. If strain goes away after stress is removed, it is elastic. Otherwise it is called plastic strain.

1-3 Functional Classification of Materials

- We can also classify materials according to their major function.

- Some categories and their applications are:
  - Aerospace: Fuselage & wings of aircrafts
  - Biomedical: Artificial organs, stents, prosthetics
  - Electronic: Integrated circuits for computer chips
  - Energy/Environmental: Nuclear fuel, fuel cells
  - Magnetic: Hard drives, transformer cores
  - Photonic/Optical: Optic fibers, LCD displays
  - Smart Materials: Sensors, photochromic glasses
  - Structural: Buildings, bridges, etc.

1-3 Functional Classification of Materials

1-4 Classification of Materials Based on Structure

- Materials can be classified based on their structure, seen at various scales. Some classifications are:
  - Crystalline: atoms arranged in a periodic fashion
  - Amorphous: atom arrangement lacks long-range order
  - Single crystals: crystalline materials consisting of a single crystal
  - Polycrystalline: crystalline materials consisting of multiple crystals or grains

1-5 Environmental and Other Effects

- The structure-property relationships in materials fabricated into components are often influenced by the surroundings in which use takes place.

- Some common environmental conditions to watch out and design for are:
  - Temperature: High temperatures can cause metals/alloys to suddenly lose their strength.
  - Corrosion: The material may form oxides (e.g., rust)
  - Fatigue: Repeated loading/unloading may cause micro-cracks in the material which grow over time.
  - Strain Rate: How quickly a material is stretched may dictate whether it snaps or elongates

1-6 Materials Design and Selection

- A number of factors must be considered when designing/selecting a material for an application. Some basic engineering considerations are:
  - The material must possess requisite mechanical & physical properties.
  - It must be capable of being processed or manufactured into the desired shape.
  - It must be economical for the application.
  - It must be environmentally friendly.

- Often, multiple materials can be used in a situation, and engineers must consider various trade-offs to determine the optimal choice.

Summary

- MSE is an interdisciplinary field concerned with inventing new materials/devices & improving existing materials by better understanding microstructure-composition-synthesis-processing relationships.

- Engineered materials are ones designed/fabricated by using MSE principles.

- Engineered material properties depend on composition, structure, synthesis & processing. Performance/cost ratio is an important index.

Summary

- Material structure refers to atom/ion arrangement.
- Material properties vary strongly with structure, even if the composition is the same.
- Materials classes are metals & alloys, ceramics, glasses & glass-ceramics, polymers, composites, semiconductors.
- Metals/alloys have good strength, ductility, formability, electrical & thermal conductivities.

Summary

- Metal/alloy applications include automotives, buildings, bridges, aerospace, etc.

- Ceramics are inorganic crystalline materials. They are strong, good electrical/thermal insulators, resistant to high temperatures and corrosion, mechanically brittle.

- Modern ceramics are used in microelectronic and photonic technologies.

Summary

- Glasses are amorphous, inorganic solids typically derived from molten liquids. Tempering increases glass strength.

- Glass-ceramics are formed by annealing glasses to nucleate small crystals to improve resistance to fracture and thermal shock.

- Polymers have low strength, good corrosion resistance, good electrical/thermal insulation, favorable strength to weight ratio, low suitability for high temperature use.

Summary

- Polymers may be either ductile or brittle, depending on structure, temperature, and strain rate.
- Semiconductors have unique electrical/optical properties essential for manufacturing electronic and communication devices.
- Composites are made of 2 or more different materials, to provide unique combinations of physical & mechanical properties not found in single materials.

Summary

- Functional classification of materials includes aerospace, biomedical, electronic, energy & environmental, magnetic, optical (photonic), and structural materials.

- Materials can also be classified as amorphous or crystalline (single crystal or polycrystalline).

- Material properties may depend on temperature, level/type of applied stress, strain rate, oxidation/corrosion, and other environmental factors.

Summary

- Selecting materials possessing needed properties which can be economically and safely manufactured into products is a complex process, requiring knowledge of structure-property-processing-composition relationships.