Engineering Materials Science
AME 2510
Chapter 1: Introduction

Dr. Feras Fraige

Contents

Introduction

- **Historical Perspective** Stone → Bronze → Iron → Advanced materials .
- **What is Materials Science and Engineering ?** Processing → Structure → Properties → Performance
- **Classification of Materials** Metals, Ceramics, Polymers, Semiconductors .
- **Advanced Materials** Electronic materials, superconductors, etc.
- **Modern Material's Needs, Material of Future** Biodegradable materials, Nanomaterials, "Smart" materials .

Syllabus

- **From atoms to microstructure: Inter-atomic bonding, structure of crystals, crystal defects, non-crystalline materials.**
- **Mass transfer and atomic mixing: Diffusion, kinetics of phase transformations.**
- **Mechanical properties, elastic and plastic deformation, dislocations and strengthening mechanisms, materials failure.**
- **Phase diagrams: Maps of equilibrium phases.**
- **Polymer structures, properties and applications of polymers.**
- **Electrical, thermal, magnetic, and optical properties of materials.**

Historical Perspective

- Beginning of the Material Science -People began to make tools from stone – Start of the Stone Age about two million years ago.
- Natural materials: stone, wood, clay, skins, etc.
- The Stone Age ended about 5000 years ago with introduction of Bronze in the Far East.
- Bronze is an **<u>alloy</u>** (a metal made up of more than one element), copper + < 25% of tin + other elements. Bronze: can be hammered or cast into a variety of shapes, can be made harder by alloying, corrode only slowly after a surface oxide film forms.

Historical Perspective

- The Iron Age began about 3000 years ago and continues today. Use of iron and steel, a stronger and cheaper material changed drastically daily life of a common person.
- Age of Advanced materials: throughout the Iron Age many new types of materials have been introduced (ceramic, semiconductors, polymers, composites…). Understanding of the **relationship among structure, properties, processing, and performance of materials**.
- Intelligent design of new materials.

Strength / Density of Materials

- A better understanding of structure-composition properties relations has lead to a remarkable progress in properties of materials.
- Example is the dramatic progress in the strength to density ratio of materials, that resulted in a wide variety of new products, from dental materials to tennis racquets.

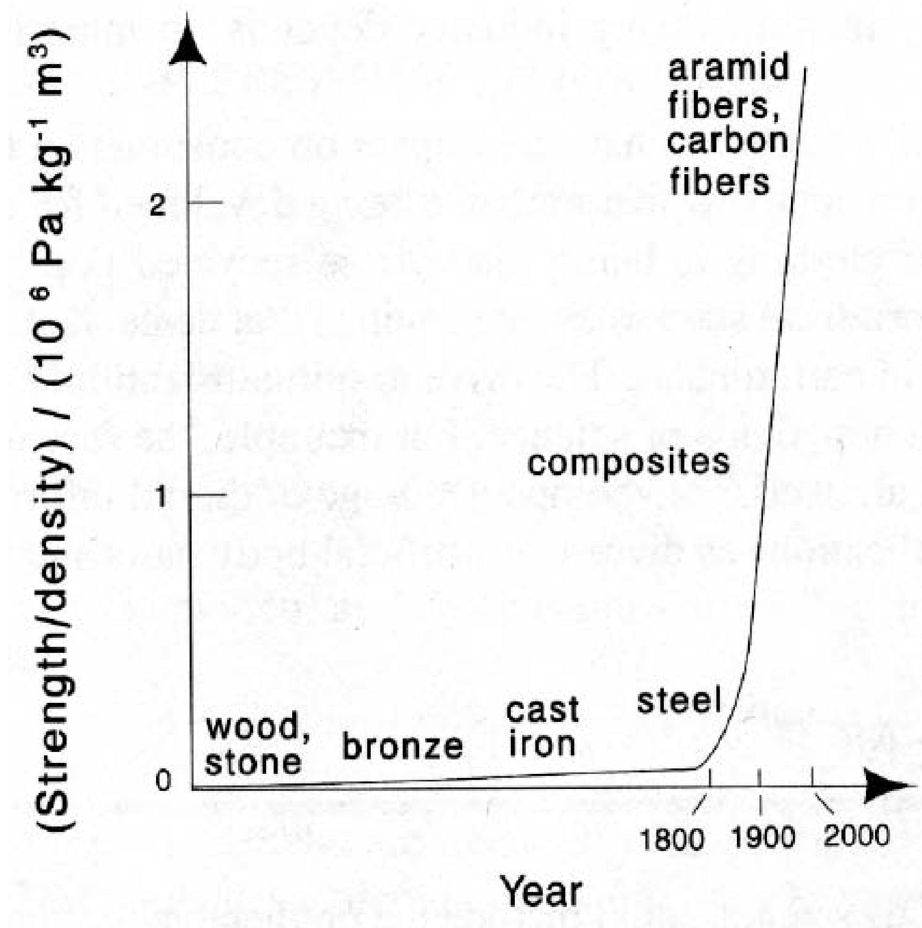
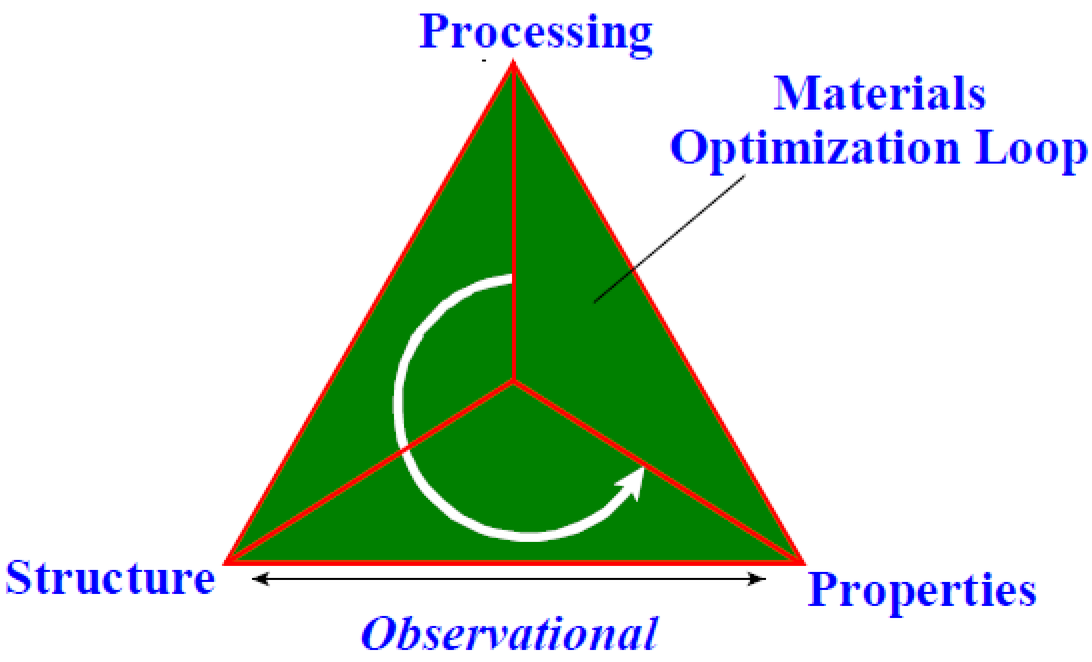


Figure from: M. A. White, Properties of Materials (Oxford University Press, 1999)

What is Materials Science and Engineering ?

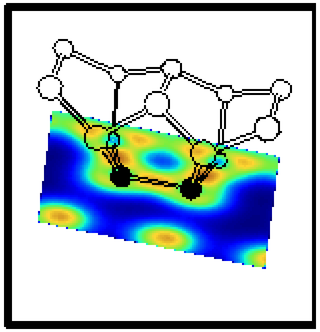
- Material science is the investigation of the relationship among processing, structure, properties, and performance of materials.



Structure

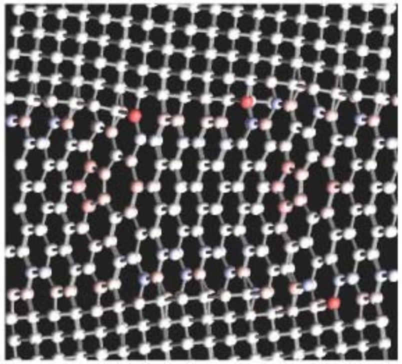
- **Subatomic level (Chapter 2)**

Electronic structure of individual atoms that defines interaction among atoms (interatomic bonding).



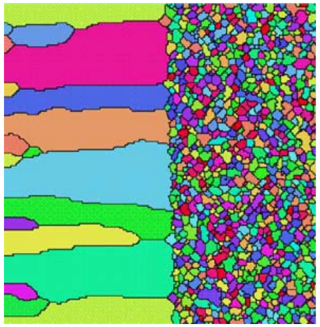
- **Atomic level (Chapters 2 & 3)**

Arrangement of atoms in materials (for the same atoms can have different properties, e.g. two forms of carbon: graphite and diamond)



- **Microscopic structure (Ch. 4)**

Arrangement of small grains of material that can be identified by microscopy.



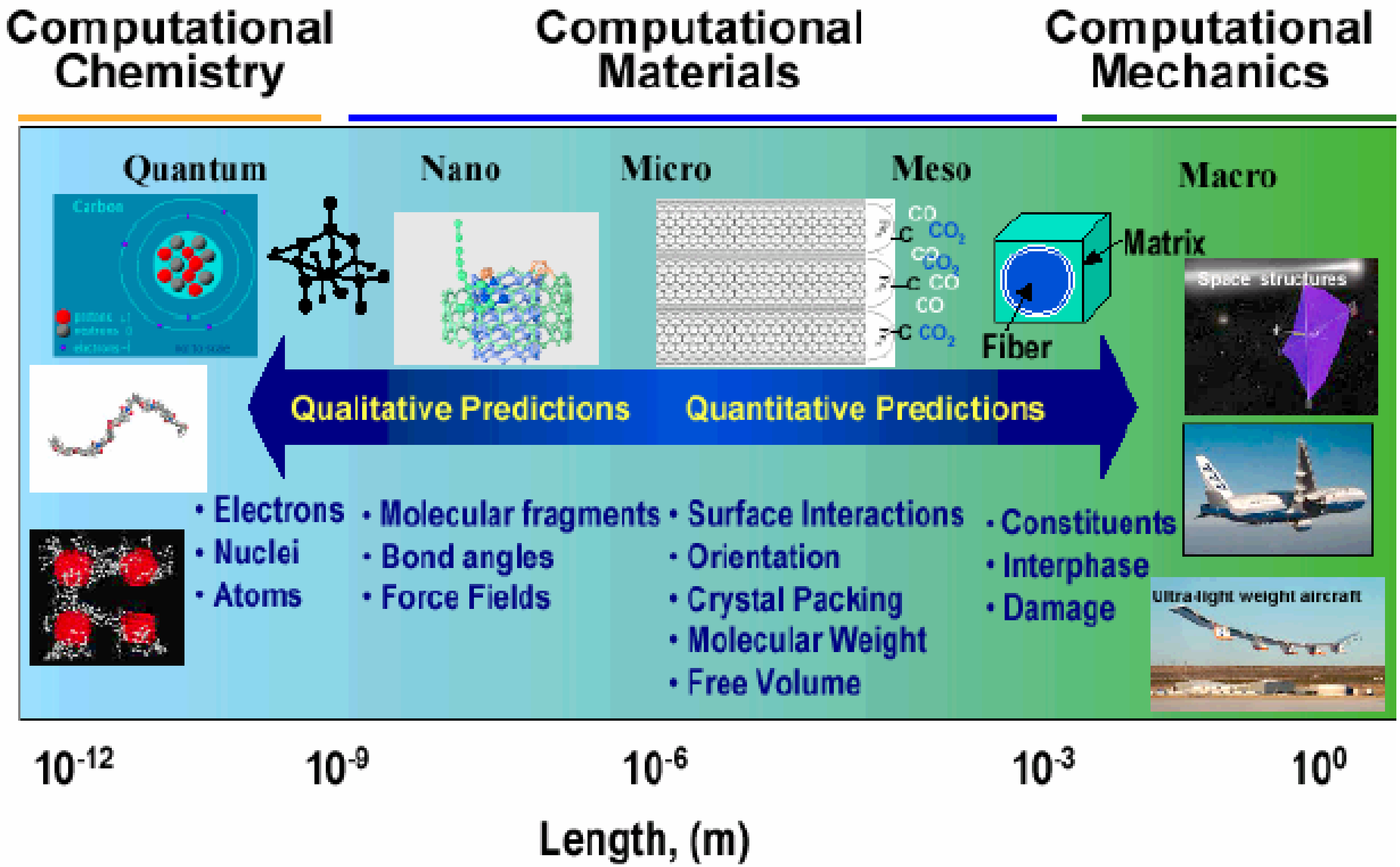
- **Macroscopic structure**

Structural elements that may be viewed with the naked eye.

Length-scales

- **Angstrom = 1Å = 1/10,000,000,000 meter = 10^{-10} m**
- **Nanometer = 10 nm = 1/1,000,000,000 meter = 10^{-9} m**
- **Micrometer = 1μm = 1/1,000,000 meter = 10^{-6} m**
- **Millimeter = 1mm = 1/1,000 meter = 10^{-3} m**
- Interatomic distance ~ a few Å
- A human hair is ~ 50 μm
- Elongated bumps that make up the data track on a CD are
- ~ 0.5 μm wide, minimum 0.83 μm long, and 125 nm high

NASA Langley Research Center
Hampton, Virginia
Computational Materials - Nanotechnology Modeling and Simulation



Types of Materials

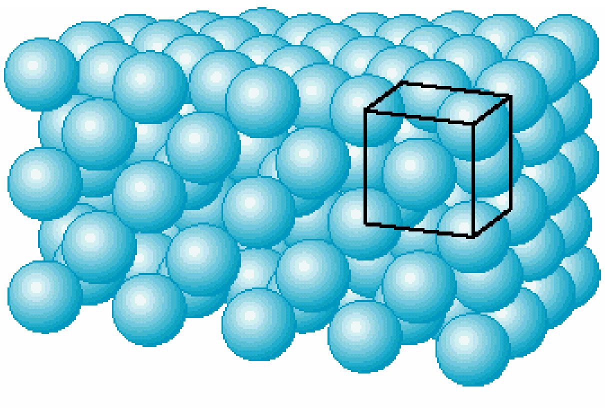
- Materials Classification according to the way the atoms are bound together (Chapter 2).
- **Metals: valence electrons are detached from atoms, and** spread in an 'electron sea' that "glues" the ions together. Strong, ductile, conduct electricity and heat well, are shiny if polished.
- **Semiconductors: the bonding is covalent (electrons are** shared between atoms). Their electrical properties depend strongly on minute proportions of contaminants. Examples: Si, Ge, GaAs.
- **Ceramics: atoms behave like either positive or negative** ions, and are bound by Coulomb forces. They are usually combinations of metals or semiconductors with oxygen, nitrogen or carbon (oxides, nitrides, and carbides). Hard, brittle, insulators. Examples: glass, porcelain.
- **Polymers: are bound by covalent forces and also by weak** van der Waals forces, and usually based on C and H. They decompose at moderate temperatures (100 – 400 C), and are lightweight. Examples: plastics rubber.

Properties

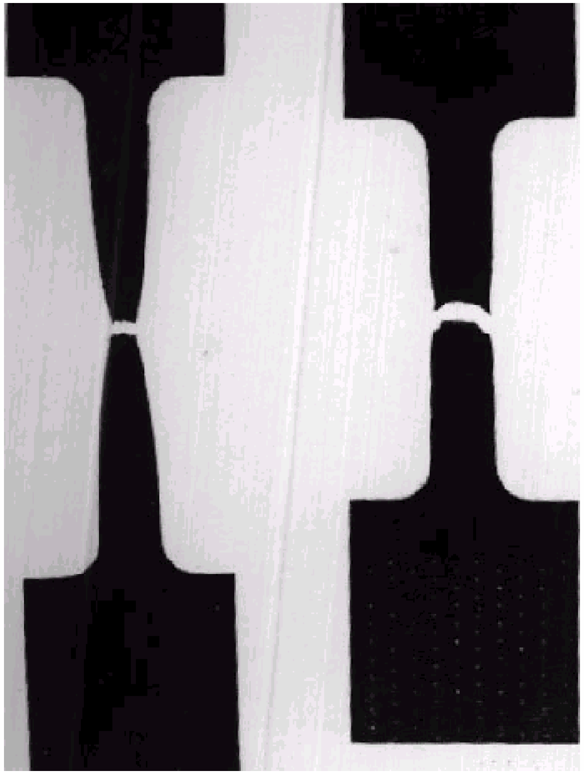
- Properties are the way the material responds to the environment and external forces.
- Mechanical properties – response to mechanical forces, strength, etc.
- Electrical and magnetic properties - response electrical and magnetic fields, conductivity, etc.
- Thermal properties are related to transmission of heat and heat capacity.
- Optical properties include to absorption, transmission and
- scattering of light.
- Chemical stability in contact with the environment - corrosion resistance.

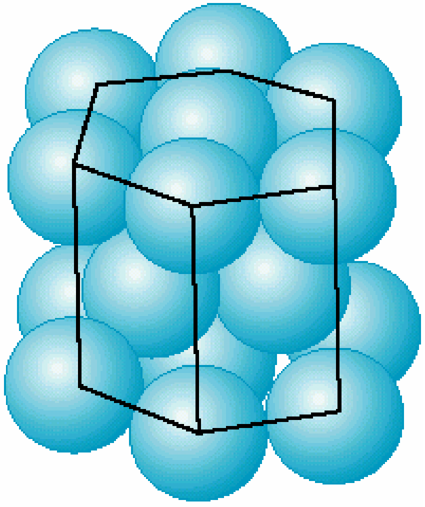
Material Selection

- Different materials exhibit different **crystal structures** (Chapter 3) and resultant **properties**



(a) Aluminum



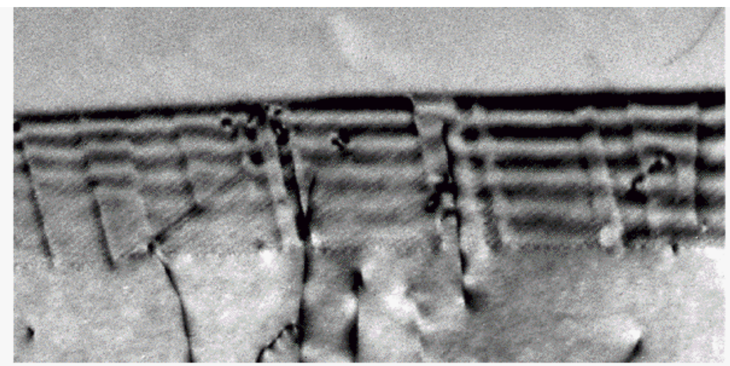


(b) Magnesium

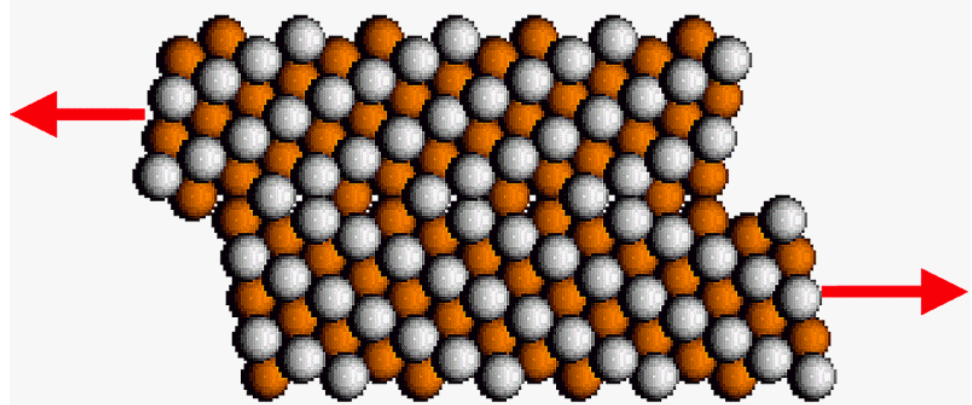
Material Selection

- Different materials exhibit different **microstructures** (Chapter 4) and resultant **properties**
- Superplastic deformation

involves low-stress sliding along grain boundaries, a complex process of which material scientists have limited knowledge and that is a subject of current investigations.

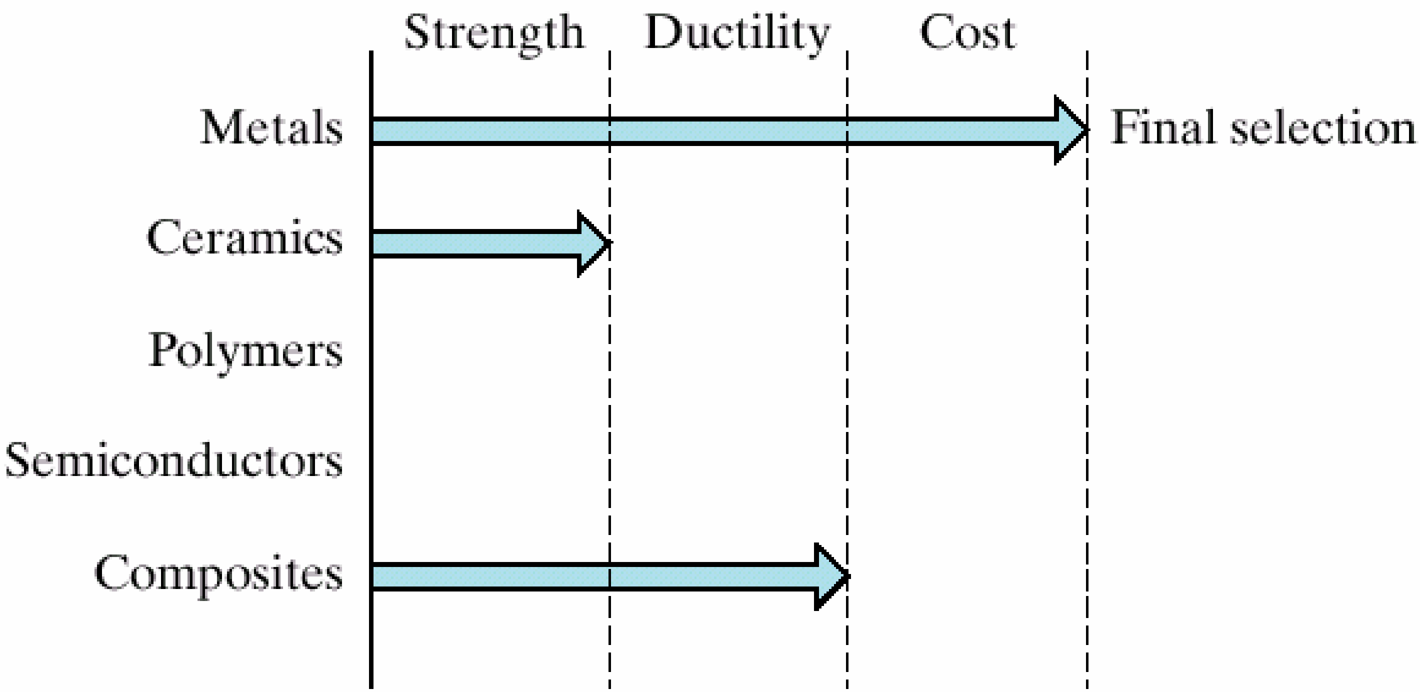


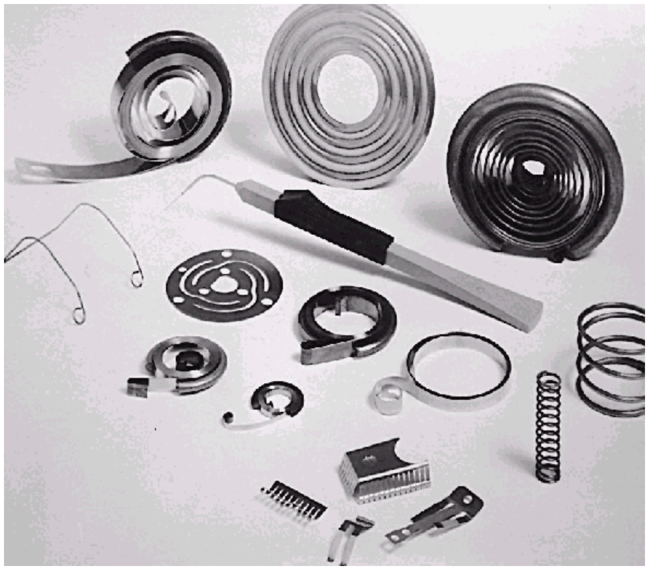
Extrinsic grain boundary dislocations in Al



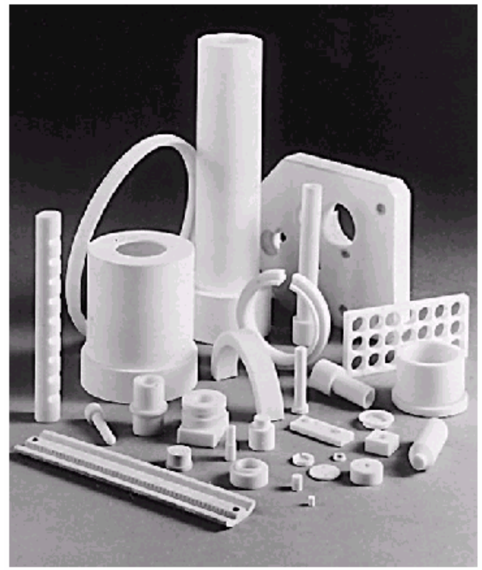
Sliding of defect free Σ11 {131} grain boundary

Material selection: Properties/performance and cost

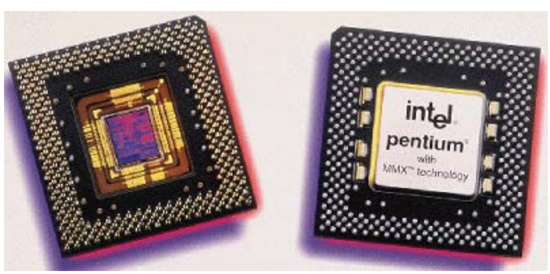




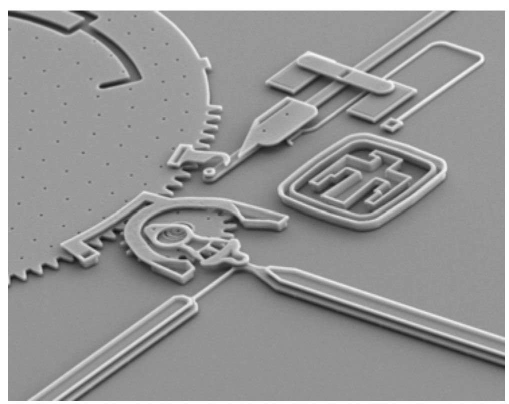
metals



ceramics

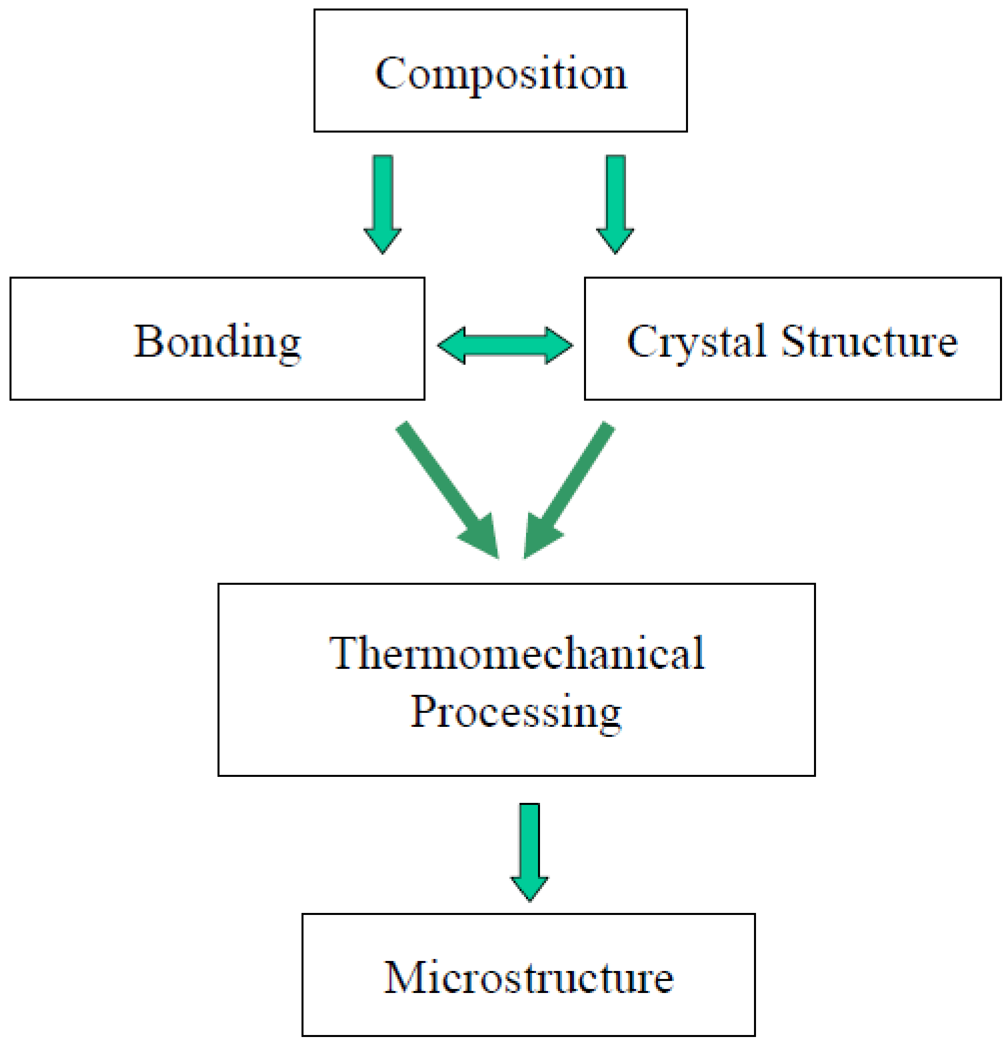


semiconductors



polymers

Composition, Bonding, Crystal Structure and Microstructure DEFINE Materials Properties



Future of materials science

- Design of materials having specific desired characteristics directly from our knowledge of atomic structure.
- **Miniaturization: “Nanostructured" materials, with** microstructure that has length scales between 1 and 100 nanometers with unusual properties. Electronic components, materials for quantum computing.
- **Smart materials: airplane wings that adjust to the air** flow conditions, buildings that stabilize themselves in earthquakes…
- **Environment-friendly materials: biodegradable or** photodegradable plastics, advances in nuclear waste processing, etc.
- **Learning from Nature: shells and biological hard tissue** can be as strong as the most advanced laboratory-produced ceramics, mollusces produce biocompatible adhesives that we do not know how to reproduce…
- Materials for lightweight batteries with high storage densities, for turbine blades that can operate at 2500°C, room-temperature superconductors? chemical sensors (artificial nose) of extremely high sensitivity, cotton shirts that never require ironing…