ENGINEERING MATERIALS

Lecture No. 1

Crystalline and non Crystalline Materials

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ENGINEERING MATERIALS

Please take a few moments and reflect on what your life would be like without all of the materials that exist in our modern world. Believe it or not, without these materials we wouldn't have automobiles, cell phones, the internet, airplanes, nice homes and their furnishings, stylish clothes, refrigerators, televisions, computers . . . (and the list goes on). Virtually every segment of our everyday lives is influenced to one degree or another by materials. Without them our existence would be much like that of our Stone Age ancestors

WHY STUDY MATERIALS SCIENCE AND ENGINEERING?

Why do engineers and scientists study materials? Simply, because things engineers design are made of materials. Many an applied scientist or engineer (e.g., mechanical, civil, chemical, electrical), is at one time or another exposed to a design problem involving materials— for example, a transmission gear, the superstructure for a building, an oil refinery component, or an integrated circuit chip. Of course, materials scientists and engineers are specialists who are totally involved in the investigation and design of materials.

HISTORICAL PERSPECTIVE

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).

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.

Structural elements may be classified on the basis of size and in this regard there are several levels:

• Subatomic structure—involves electrons within the individual atoms, their energies and interactions with the nuclei.

• Atomic structure—relates to the organization of atoms to yield molecules or crystals.

• Nanostructure—deals with aggregates of atoms that form particles (nanoparticles) that have nanoscale dimensions (less that about 100 nm).

• Microstructure—those structural elements that are subject to direct observation using some type of microscope (structural features having dimensions between 100 nm
and several millimeters).

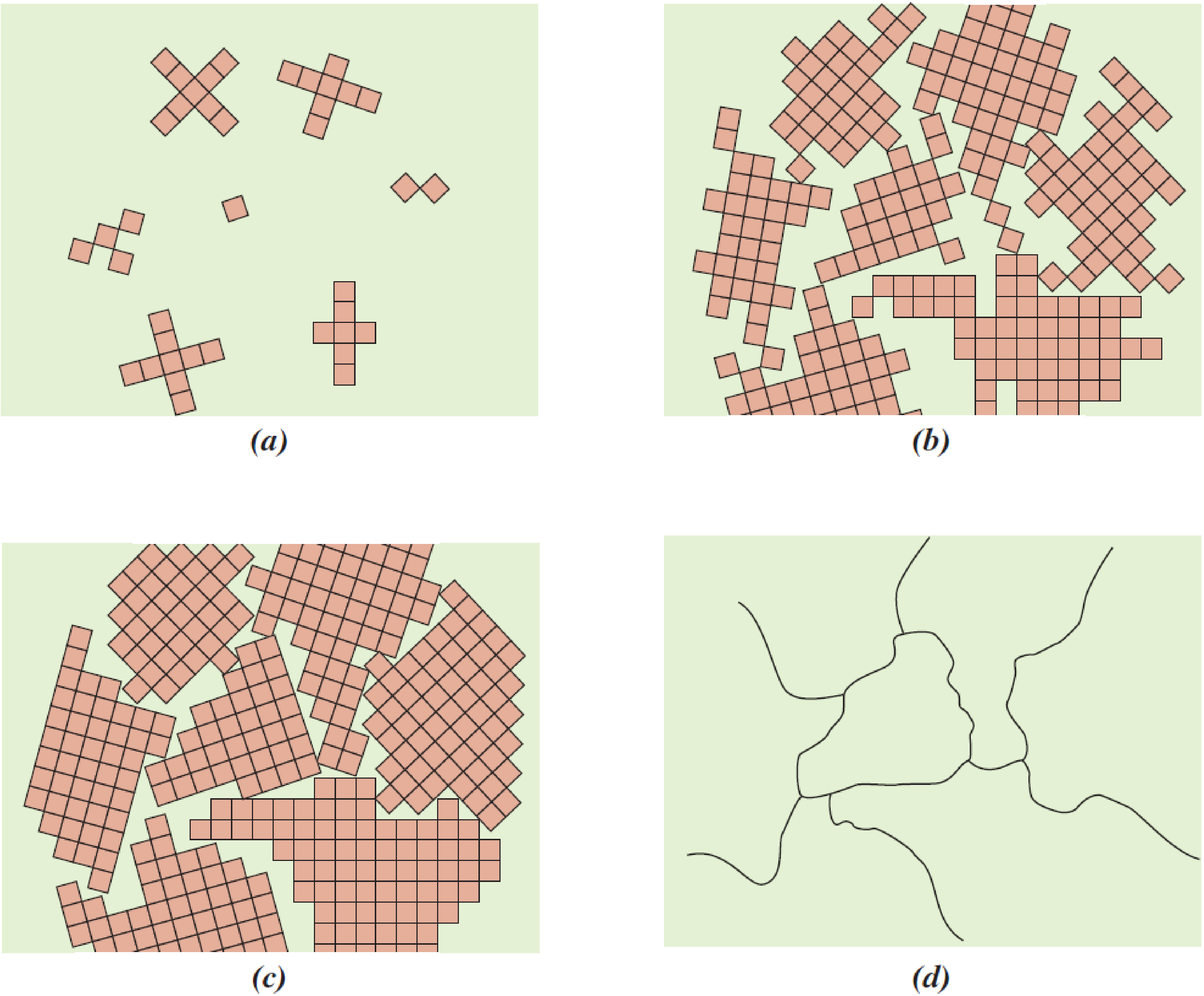
• Macrostructure—structural elements that may be viewed with the naked eye (with scale range between several millimeters and on the order of a meter).

SINGLE CRYSTALS

For a crystalline solid, when the periodic and repeated arrangement of atoms is perfect or extends throughout the entirety of the specimen without interruption, the result is a **single crystal.** All unit cells interlock in the same way and have the same orientation. Single crystals exist in nature, but they can also be produced artificially. They are ordinarily difficult to grow because the environment must be carefully controlled. If the extremities of a single crystal are permitted to grow without any external constraint, the crystal assumes a regular geometric shape having flat faces, as with some of the gemstones; the shape is indicative of the crystal structure. An iron pyrite single crystal is shown in Figure 1 Within the past few years, single crystals have become extremely important in many modern technologies, in particular electronic microcircuits, which employ single crystals of silicon and other semiconductors.

POLYCRYSTALLINE MATERIALS

Most crystalline solids are composed of a collection of many small crystals or **grains;** such materials are termed **polycrystalline.** Various stages in the solidification of a polycrystalline specimen are represented schematically in Figure 2. Initially, small crystals or nuclei form at various positions. These have random crystallographic orientations, as indicated by the square grids. The small grains grow by the successive addition from the surrounding liquid of atoms to the structure of each. The extremities of adjacent grains impinge on one another as the solidification process approaches completion. As indicated in Figure 2, the crystallographic orientation varies from grain to grain. Also, there exists some atomic mismatch within the region where two grains meet; this area, called a **grain boundary.**



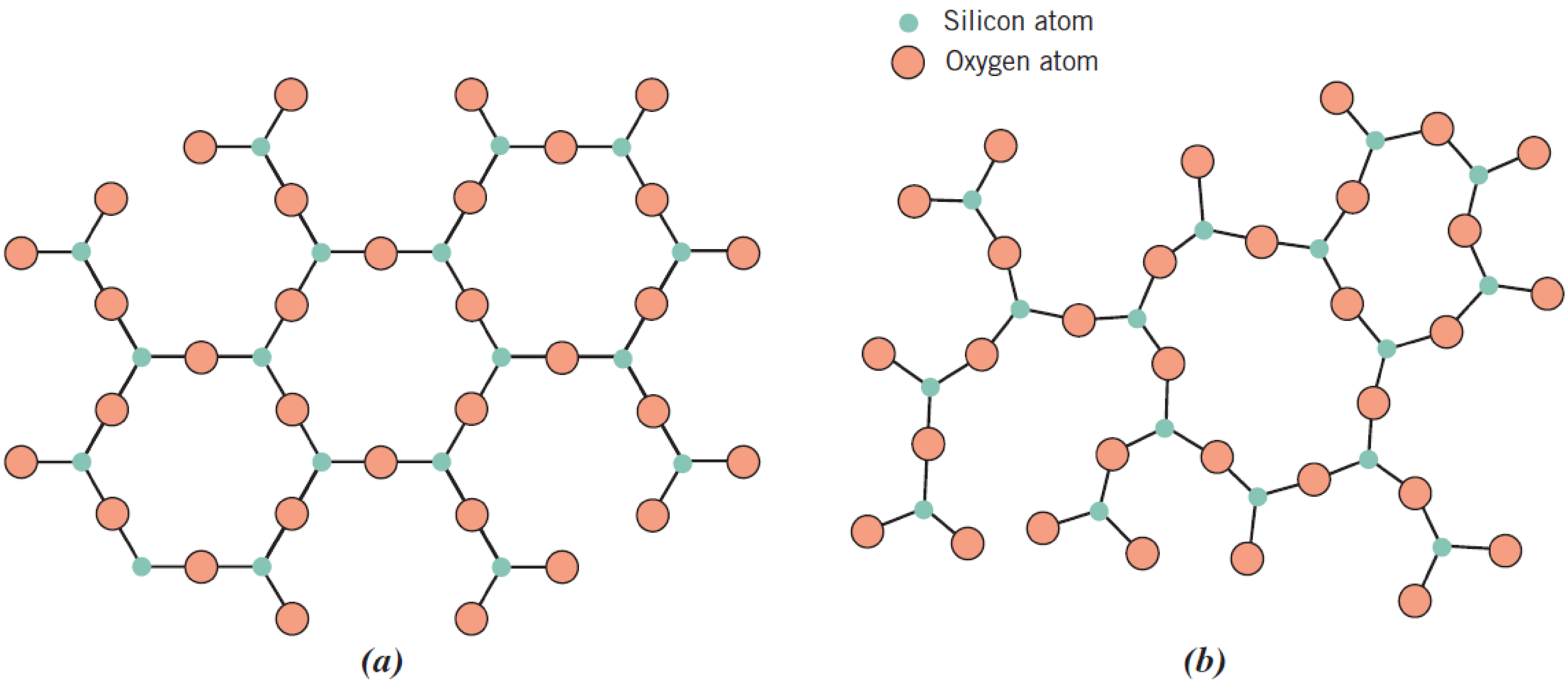
(a) (b) (c) (d)

Non-crystalline

It has been mentioned that **noncrystalline** solids lack a systematic and regular arrangement of atoms over relatively large atomic distances. Sometimes such materials are also called **amorphous** or supercooled liquids, inasmuch as their atomic structure resembles that of a liquid. An amorphous condition may be illustrated by comparison of the crystalline and noncrystalline structures of the ceramic compound silicon dioxide (SiO_2), which may exist in both states. Figures 3.24*a* and 3.24*b* present two-dimensional schematic diagrams for both structures of SiO_2. Even though each silicon ion bonds to three oxygen ions (and a fourth oxygen ion above the plane) for both states, beyond this, the structure is much more disordered and irregular for the noncrystalline structure. Whether a crystalline or an amorphous solid forms depends on the ease with which a random atomic structure in the liquid can transform to an ordered state during solidification.

Non-crystalline

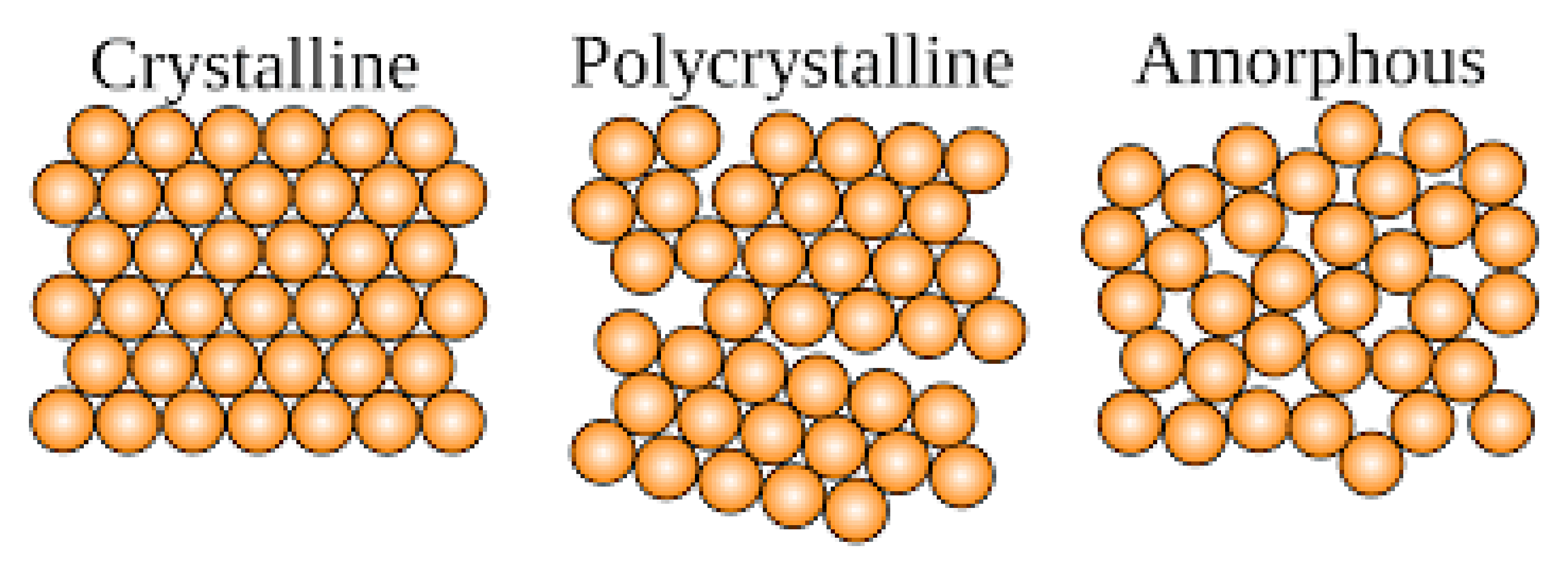
Amorphous materials, therefore, are characterized by atomic or molecular structures that are relatively complex and become ordered only with some difficulty. Furthermore, rapidly cooling through the freezing temperature favors the formation of a noncrystalline solid, because little time is allowed for the ordering process. Metals normally form crystalline solids, but some ceramic materials are crystalline, whereas others—the inorganic glasses—are amorphous. Polymers may be completely noncrystalline or semicrystalline consisting of varying degrees of crystallinity.


Silicon atom
Oxygen atom
(a)
(b)

Virtually all important properties of solid materials may be grouped into six different categories: These are noted as follows:

- Mechanical properties—relate deformation to an applied load or force; examples include elastic modulus (stiffness), strength, and resistance to fracture.
- Electrical properties—the stimulus is an applied electric field; typical properties include electrical conductivity and dielectric constant.
- Thermal properties—are related to changes in temperature or temperature gradients across a material; examples of thermal behavior include thermal expansion and heat capacity.
- Magnetic properties—the responses of a material to the application of a magnetic field; common magnetic properties include magnetic susceptibility and magnetization.
- Optical properties—the stimulus is electromagnetic or light radiation; index of refraction and reflectivity are representative optical properties.

Deteriorative characteristics—relate to the chemical reactivity of materials; for example, corrosion resistance of metals.



Thank you for listening