Chapter 1. Introduction

The development of novel materials and processes requires a deep knowledge of physical foundations of materials as a tool for systematic tailoring of material properties.

Course objectives are to be introduced to the "**Science**" part of "Materials Science and Engineering". We will be concerned about:

- the structure of the materials (metals, polymers, ceramics, and composites) at the atomic and microstructural levels;
- the relationships between structure and properties for materials;
- fundamental principles and laws responsible for behavior or property of material.

The key properties to consider are:

- <u>Mechanical</u> – response to *force*, strength, resilience, Young's modulus;
- <u>Electrical</u> – response to *electrical field*, conductivity, dielectric constant;
- <u>Thermal</u> – response to *temperature and temperature gradient*, heat capacity, thermal conductivity;
- <u>Magnetic</u> – response to a *magnetic field*, magnetization;
- <u>Optical</u> – interaction with *light*, reflectivity, transmittance, index of refraction;
- <u>Deteriorative</u> – response to *chemical environment*

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What determines the properties of the solid material? First, the *elemental composition* is important. Yet, if you take graphite and diamond, both materials consist of carbon, and it becomes important *how are the atoms arranged at the atomic level.* Or, in another words, what the nature of chemical bonding in the solid and what is the crystal structure of the solid material. Crystal structures of graphite and diamond are distinctly different (Figure 1.1). Next we have to look at a bigger scale: how well is the crystal structures ordered; how many defects are in the solid; how are the "grain" ("crystallites") arranged at a larger scale? All these questions will be relevant we correlate ***composition, structure and properties*** of the solid materials.

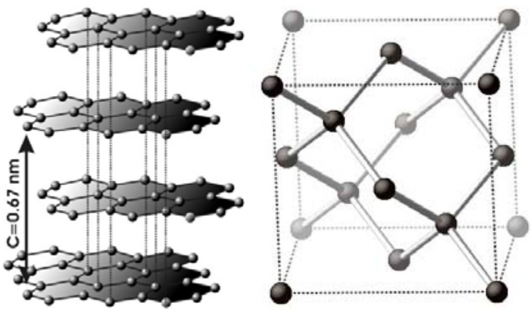

Figure 1.1 Crystal structures of graphite and diamond.

How are materials classified? We can divide the solids by the type of the bond that hold them together into *ionic* (i.e. rock salt, ceramics), *covalent* (diamond), and *metallic* (steel). Some solids (ice, wax, PVC) has *secondary* bonds that are typically weaker. A material might also use more than one bond type.

Another possible classification would be considering combination of bonding, structure and function. Several special groups can be separated among the solid materials (Table 1).

Table 1. Classification of the solids materials

	Metals	Ceramics	Polymers
Bonding	metallic	covalent usually oxides (Al_2O_3), nitrides (SiN), carbides (SiC)	long organic (inorganic) chains
Structure	well defined	crystalline, noncrystalline, mixture	"crystalline", amorphous, mixture
Properties	strong, good electrical and thermal conductors	insulators, withstand high temperature, electric fields, often brittle	conductors and insulators, low and high density, flexible and rigid

Other special cases include: composites (mixture of at least two materials, i.e. fiber glass, concrete, polymer composites), special functional materials (i.e. shape memory alloys, piezoelectric, microelectromechanical systems (MEMS), biomaterials, etc.). There is special class of materials – nanomaterials - emerged recently with the *characteristic length scale* (particle size, grain size) below 10-50nm.

In biomimetic materials the structural design was duplicated from nature.

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- Materials → Molecules → Atoms, Atoms = protons (p) + neutrons (n) + electrons (e). Protons and neutrons are made of quarks.

Quantitative measurements need units: *metric* or *S.I.* (Systeme International) or *mks* (meter-kilogram-second) units will be a preferred

meter	(m)	for length
cubic meter	(m^3)	for volume
kilogram	(kg)	for mass
Kelvin	(K)	for temperature
second	(s)	for time
mole	(mol)	for amount of substance