Material scientists and engineers now have a rapidly evolving ability to tailor materials from the atomic scale upwards to obtain desired properties. A new age in materials, known as the "Tailored (or Designed) Materials Age", has been used to describe the revolutionary changes in materials science and engineering (MSE), as well as their impact on society. For example, advanced composites have been developed to combine the properties of high stiffness, strength, toughness and low density to meet special structural requirements. Surface treatments, including the development of various coatings and surface modification techniques, provide a combination of extreme hardness, wear, corrosion and high temperature oxidation resistance on the top surface, combined with a tough, shock-absorbing body. Artificial layered structures offer limitless possibilities for creating new electronic and semiconductor devices which can be produced using many methods, including molecular beam epitaxy (MBE), chemical vapour deposition (CVD), vacuum evaporation, sputter deposition, ion beam deposition, and solid-phase epitaxy. We now face exciting and dramatic changes in the materials world, giving our industries and society endless developmental opportunities.

1.2. Classification and Properties of Materials

1.2.1. *Classification of Materials*

Engineering materials are classified using different methods. The traditional method is to classify then according to their *nature*:

(i) Metals and alloys are inorganic materials composed of one or more metallic elements. They may also contain a small number of nonmetallic elements. Metals usually have a crystalline structure and are good thermal and electrical conductors. Many metals are strong and ductile at room temperature and maintain good strength at high and low temperatures.

(ii) Ceramics are inorganic materials consisting of both metallic and nonmetallic elements bonded together chemically. Ceramics can be crystalline, non-crystalline, or a mixture of both. Generally, they have high melting points and high chemical stabilities. They also have high hardness and high temperature strength, but tend to be brittle. Ceramics are usually poor electrical conductors.

(iii) Polymers are organic materials which consist of long molecular chains or networks containing carbon. Most polymers are non-crystalline, but some consist of mixtures of both crystalline and non-crystalline regions. They typically have low densities and are mechanically flexible. Their mechanical properties may vary considerably. Most polymers are poor electric conductors due to the nature of the atomic bonding.

(iv) Composites are mixtures of two or more types of materials. Usually, they consist of a matrix phase and a reinforcing phase. They are designed to ensure a combination of the best properties of each of the component materials.

There is also an increasing trend to classify engineering materials into two further categories: *structural materials* and *functional materials*. Structural materials, as the name indicates, are materials used to build structures, bodies and components. For instance, in a car the body, frame, wheels, seats, inside lining, engine and various mechanical transmission parts are all constructed from structural materials. The most important consideration for this type of application are the mechanical properties.

The functional materials, on the other hand, are used for special purposes in equipment such as conductors, insulators or the storage of electricity, the generation or conduction of light, the conversion of optical, mechanical or thermal signals into electrical voltages, or the provision of a strong magnetic field. The electronic devices in the control systems of a car, for instance, are built with semiconductors, an important type of functional material.

1.2.2. *Properties of Materials*

The properties of engineering materials can be classified into two main groups: physical and chemical. Dependent on the application, the physical properties of materials can be further grouped into two categories, which correspond either to structural or functional materials.

(i) Mechanical properties include Young's modulus, tensile and shear strengths, hardness, toughness, ductility, deformation and fracture behaviours, fatigue and creep strengths, wear resistance, etc.

(ii) Physical properties include electrical and electronic properties, magnetic properties, optical and thermal properties, etc.

The chemical properties of engineering materials generally include corrosion, oxidation, catalysis properties and chemical stabilities.

This text does not concentrate on the mechanical properties of materials, but on the physical properties, such as electrical and electronic properties, magnetic properties, and optical and thermal properties. It must be remembered that mechanical properties are always important in the applications of functional materials. This text emphasises the performance and applications of functional materials in modern industries.

1.2.3. *Four Elements of Materials Science and Engineering*

Materials science is primarily concerned with the study of the basic knowledge of materials: the relationships between the composition/structure, properties and processing of materials. Materials engineering is mainly concerned with the use of this fundamental knowledge to design and to produce materials with properties that will meet the requirements of society. As subjects of study, materials science and materials engineering are very often closely related. The subject "materials science and engineering" combines both a basic knowledge and application, and forms a bridge between the basic sciences (physics, chemistry and mathematics) and the various engineering disciplines, including electrical, mechanical, chemical, civil and aerospace engineering.

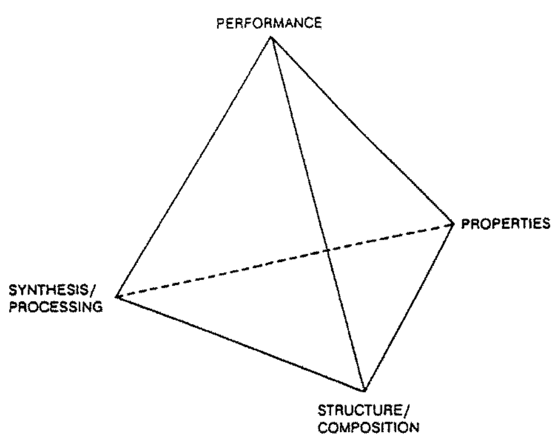

Fig. 1.1. Four elements of materials science and engineering.

There are four essential elements in materials science and engineering: (i) processing/synthesis; (ii) structure/composition; (iii) properties; and (iv) performance/application (Fig. 1.1). There is a growing realisation among scientists and engineers that in order to develop new materials and provide materials efficiently for society, all four elements need to be considered. This gives materials science and engineering its interdisciplinary nature. Nowadays, it is common (and indeed preferred in many cases) for people with different backgrounds (materials, physics, chemistry, metallurgy, ceramics, electronics, etc.) to work together to solve materials problems and to make important contributions to this field.

1.3. Materials and Electrical/Electronic Engineering

Functional materials play a very important role in almost all industries. They are often the critical component of equipment or instrumentation determining the overall performance and efficiency of the whole system. The topic of functional materials has experienced rapid growth in the last thirty years as it is among the most active discipline in modern science and engineering. New developments in functional materials, such as semiconductors, superconductors and optical fibres, are revolutionising modern society. Without these materials, modern devices, computers, automatic machines, telecommunications systems, aircraft, etc., could not exist. For example, in the automobile industry, a standard 1994 model car consisted of electronics worth more than US$800. This is more than the value of steel used in its body, frame, engine and transmission system, which cost approximately US$675.

The electronics industry is one of the most dynamic industries in the global economy. The worldwide electronic materials market, valued at US$2.5 billion, was responsible for an equipment market valued at more than US$400 billion in 1985. The electronics industry is also a leader in the use of new materials. Highly engineered materials are vital to the continued progress of the electronics industry. Strong interrelationships between device design, materials science and engineering, and process chemistry determine the performance of a device. Semiconductors are the basic materials in the electronics industry; most current devices are based on a single crystal silicon. A high-quality, single-crystal, defect-free silicon with a diameter of 150 mm is grown from the melt using a highly automated