普通高等教育“十三五”规划教材

材料科学导论（双语）

Introduction to Materials Science(Bilingualism)

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前 言

随着人类文明的进步和科学技术的发展，材料已成为国民经济的三大支柱产业之一。为了适应材料科学与技术的发展，培养学生及时跟踪国际材料科学与技术发展前沿的能力，使学生成为材料科学领域的创新型复合人才，因而国内许多高校面向材料类本科生开设了双语专业课程。

目前，材料类双语专业课程《材料概论（双语）》或《材料科学与工程导论（双语）》教材尽管也有出版，但存在如下的主要问题：(1) 系统性不强，即知识点不全，不利于学生系统和全面的掌握相关知识；(2) 部分教材有少许课后练习题，但是没有参考答案，这样不利于学生课后对学习效果的检测和评价；(3) 更有甚者是半中文半英文，这样更不利于学生学习利用纯正的英语表述专业知识。这样难以满足培养应用型人才教学的要求。

编者基于上述三个问题得到如下基本认识：一是现代材料类高素质创新型人才标准——国际化、工程化和复合化的要求；二是基础应用性材料科学知识体系：科学性、系统性和简易性的特色；三是各类不同层次高校学生的教学要求。本教材针对低年级材料类大学生的实际条件和需求，在满足国际化专业人才语言交流能力的基本前提下，特别强调了专业基础知识体系的科学化、系统化和简易化，从而新编了《材料科学导论（双语）》和《材料工程导论（双语）》系列教材，以满足新时代各类特别是技术应用型材料科学与工程学科专业教学的需要。

本套教材具有如下特点：

1．将材料学知识英语化

用英语语言思维构筑学生的国际化视野和专业语言交流能力。

2．对知识性体系简易化

在保持教学内容的科学性、系统性的前提下，做到学生理解和掌握的简易性（通俗性），即突出“真、全、简”三个字。

3．优化教学流程和效果

(1) 任务驱动教学

每章主要包括主要知识点的介绍、专业词汇的注解和课后练习题（附参考答案），充分体现了教学内容的实用性，有助于提高学生牢固掌握本章知识点的实践能力。

(2) 教材定位准确

本套教材针对材料类学生学习专业基础课后开设的课程，有助于学生应用英语去

描述自己本专业的材料学知识。

(3) 内容结构合理

本套教材内容由浅入深,循序渐进,符合读者认识事物的规律性。同时,也便于教学的组织、实施和考核,有利于教学效果的巩固和教学质量的提高。

《材料科学导论(双语)》教材是由宿迁学院材料工程系傅小明副教授、江苏大学外国语学院蒋萍老师担任主编,并编写绪论(第1章)、第一篇材料相变基础的第2、3和4章、第三篇材料性能基础的第8章,以及全书的统稿;杨在志老师编写第二篇材料结构基础的第5章和第三篇材料性能基础的第9章;李金涛老师编写第二篇材料结构基础的第6和7章;孙虎老师编写第三篇材料性能基础的第10章。江苏大学外国语学院蒋萍老师编写全书专业术语和专业词汇的注解,以及全书习题及其参考答案。

本书在编写过程中得到了兰州理工大学博士生导师马勤教授悉心的指导,在此特表感谢。

由于编者水平有限,经验不足,书中难免有不足之处,恳请专家、学者和广大读者批评指正。

编 者

2017 年 04 月

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Part Ⅱ Foundation of Material Structures

Chapter 1 Introduction

1.1 Historical Perspective

Materials are probably more deep-seated① in our culture than most of us realize. Transportation, housing, clothing, communication, recreation and food production-virtually every segment of our everyday lives is influenced to one degree or another by materials. 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 (*i.e.*, Stone Age, Bronze Age).

The earliest humans had access to only a very limited number of materials, those than occur naturally: stone, wood, lay, 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 materials could be altered by heat treatment and by the addition of other substances. At the point, materials utilization was totally a selection process, that is, deciding from a given, rather limited set of materials the one that was best suited for an application by virtue of its characteristics. It was not until relatively recent times that scientists came to understand the relationships between the structural elements of materials and their properties. This knowledge acquired in the past 60 years or so, has empowered them to fashion, to a large degree, the characteristics of materials. Thus, tens of thousands of different materials have evolved with rather specialized characteristics that meet the needs of our modern and complex society; these include metals, plastics, glasses and fibers.

The development of many technologies that make our existence so comfortable has been intimately associated with the accessibility of suitable materials. An advancement in the understanding of a material type is often the forerunner to the stepwise progression of a technology. For example, automobiles would not have been possible without the availability of inexpensive steel or some other comparable substitute. In our contemporary era, sophisticated electronic devices rely on components that are made from what are called semiconducting materials.

1.2 Materials

The materials making up the surrounding world consist of discrete particles, having a submicroscopic size. Their behavior is determined by atomic theories. The states of organization of materials range from the complete disorder of atoms or molecules of a gas under weak pressure to the almost complete order of atoms in a monocrystal.

In this introductory work materials are defined as solids used by man to produce items which constitute the support for his living environment.

Indeed, no object exists without materials. All sectors of human activity depend on materials, from the manufacture of an integrated circuit to the construction of a hydroelectric dam. They appear in our bodies to strengthen or replace our damaged biomaterials. Materials are also as indispensable to our society as food, energy and information. Their essential role is too often forgotten.

The definition employed in this introductory work is limited to solid materials. It excludes liquids and gases, as well as solid combustibles.

1.3 Classification of Materials

Solid materials have been conveniently grouped into three basic classifications: metals, ceramics and polymers. This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another, although there are some intermediates. What may be considered to be a fourth group—the composites-consists of combinations of two or more different materials. Another classification is advanced materials-those used in high-technology applications (*viz*, semiconductors, biomaterials, smart materials and nanoengineered materials). A brief explanation of the material types and representative characteristics is offered next.

1.3.1 Metals

Metallic materials are normally combinations of metallic elements. They have large numbers of nonlocalized electrons, that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. Metals are extremely good conductors of electricity and are not transparent to visible light; a polished metal surface has a lustrous appearance. Furthermore, metals arquite strong, yet deformable, which accounts for their extensive use in structural applications.

1.3.2 Ceramics

Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides and carbides. The wide range of materials that falls within this classification includes ceramics that are composed of clay minerals, cement and glass. These materials are typically insulative to the passage of electricity and heat, and are more resistant to high temperatures and harsh environments than metals and polymers. With regard to mechanical behavior, ceramics are hard but very brittle.

1.3.3 Polymers

Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen and other nonmetallic elements; furthermore, they have very large molecular structures. These materials typically have low densities and may be extremely flexible.

1.3.4 Composites

A number of composite materials have been engineered that consist of more than one material type. Fiberglass is a familiar example, in which glass fibers are embedded within a polymeric material. A composite id designed to display a combination of the best characteristics of each of the component material. Fiberglass acquires strength from the glass and flexibility from the polymer. Many of the recent material developments have involved composite materials.

1.3.5 Advanced Materials

Materials that are utilized in high-technology (or high-tech) applications are sometimes termed advanced materials. By high technology we mean a device or product that operates or functions using relatively intricate and sophisticated principles; examples include electronic equipment (camcorders, CD/DVD players, *etc.*), computers, fiber-optic systems, spacecraft, aircraft and military rocketry. These advanced materials are typically traditional materials whose properties have been enhanced, and also newly developed, high-performance materials. They may be of all material types (*e. g.*, metals, ceramics, polymers), and are normally expensive. Advanced materials include semiconductors, biomaterials, and what we may term "materials of the future" (that is, smart materials and nanoengineered materials).

1.3.5.1 Semiconductors

Semiconductors have electrical properties that are intermediate between the electrical conductors and insulators. Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms, which concentrations may be controlled over very small spatial regions. The semiconductors have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries (not to mention our lives) over the past two decades.

1.3.5.2 Biomaterials

Biomaterials are employed in components implanted into the human body for replacement of diseased or damaged body parts. These materials must not produce toxic substances and must be compatible with body tissues (*i. e.*, must not cause adverse biological reactions). All of the above materials-metals, ceramics, polymers, composites and semiconductors may be used as biomaterials. For example, some of the biomaterials that are utilized in artificial hip replacements.

1.3.5.3 Smart Materials

Smart (or intelligent) materials are a group of new and state-of-the-art materials now being developed that will have a significant influence on many of our technology. The adjective "smart" implies that these materials are able to sense changes in their environments and then respond to these changes in predetermined manners-traits that are also found in living organisms. In addition, this "smart" concept is being extended to rather sophisticated systems that consist of both smart and traditional materials.

Components of a smart material (or system) include some type of sensor (that detects an input signal), and an actuator (that performs a responsive and adaptive function). Actuators may be called upon to change shape, position, natural frequency or mechanical characteristics in response to changes in temperature, electric fields, and/or magnetic fields. Four types of materials are commonly used for actuators: shape memory alloys, piezoelectric ceramics, magnetostrictive materials and electroheological/magnetorheological fluids. Shape memory alloys are metals that, after having been deformed, revert back to their original shapes when temperature is changed. Piezoelectric ceramics expand and contract in response to an applied electric field (or voltage); conversely, they also generate an electric field when their dimensions are altered. The behavior of magnetostrictive materials is analogous to that of the piezoelectrics, except that they are responsive to magnetic fields. Also, electrorheological and magnetorheological fluids are that experience dramatic changes in viscosity upon the application of electric and magnetic fields, respectively.

Materials/devices employed as sensors include optical fibers, piezoelectricmaterials (including some polymers) and microelectromechanical devices.

For example, one type of smart system is used in helicopters to reduce aerodynamic cockpit noise that is created by the rotating rotor blades. Piezoelectric sensors inserted into the blades monitor blade stresses and deformations; feedback signals from these sensors are fed into a computer-controlled adaptive device, which generates noise-canceling[③] antinoise.

1.3.5.4 Nanoengineered Materials

Until very recent times the general procedure utilized by scientists to understand the chemistry and physics of materials has been to begin by studying large and complex structures, and then to investigate the fundamental building blocks of these structures that are smaller and simpler. Thisapproach is sometimes termed "top-down[④]" science. However, with the advent of scanning probe microscopes, which permit observation of individual atoms and molecules, it has become possible to manipulate and move atoms and molecules to form new structures, thus, design new materials that are built from simple atomic-level constituents (*i.e.*, "materials by design"). This ability to carefully arrange atoms provides opportunities to develop mechanical, electrical, magnetic and other properties that are not otherwise possible. We call this the "bottom-up⑤" approach, and the study of the properties of these materials is termed "nanotechnology". The "nano" prefix denotes that the dimensions of these structural entities are on the order of a nanometer (10^{-9} m) as a rule, less than 100 nanometers (equivalent to approximately 500 atom diameters). One example of a material of this type is the carbon nanotube. In the future we will undoubtedly find that increasingly more of our technological advances will utilize these nanoengineered materials.

1.4 Structural Characteristic of Materials

Solids exist in nature in two principal forms: crystalline and amorphous, which differ substantially in their properties.

Crystalline bodies remain solid, *i.e.* retain their shape, up to a definite temperature (melting point) at which they change from the solid to liquid state (Figure 1.1). During cooling, the inverse process of solidification takes place, again at the definite solidifying temperature, or point. In both cases, the temperature remains constant until the material is completely melted or respectively solidified.

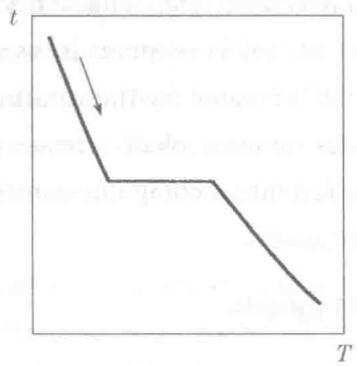

Figure 1.1 Cooling curve of a crystalline substance

Amorphous bodies, which heated, are graduallysoftened in a wide temperature range and become viscous and only then change to the liquid state. In cooling, the process takes place in the opposite direction.

The crystalline state of a solid is more stable than amorphous state.

Amorphous bodies differ from liquid in having a lower mobility of particles. An amorphous state can be fixed in many organic and inorganic substances by rapid cooling from the liquid state. On repeated heating long holding at 20～25 ℃ or, in some cases, deformation of an amorphous body, the instability of the amorphous