**课程简介和教学大纲**

**课程代码： 课程名称：功能材料基础**

**学分： 2 周学时 4.0-0.0**

**面向对象：大三、大四本科生、研究生**

**预修课程要求：**大学物理、物理化学、高等数学

**一、课程介绍**

**（一）中文简介**

本课程的授课对象为材料学专业的高年级本科生和研究生。学习本课程有助于学生理解固体材料的神秘特性并开发出有用的新型功能材料。本课程涉及的科技同样有助于表征及理解软物质（如高分子）的物理及化学现象。教学内容包括：（1）了解材料的各种结构、热、机械、光、电、磁特性；（2）从微观及原子尺度理解以上现象的本质；（3）了解发现上述性能的方法；（4）思考如何发现新现象及对现象做出新解释；（5）培养从物理的角度发展材料科技的意识。

**（二）英文简介**

This course is a degree program for senior undergraduate and graduate students of Zhejiang University, who study on materials science. It is a subject to help the understanding of the mysterious nature of all the solid materials, and then to find new functional materials in order to enrich our society. The science and technology employed in solid-state physics are also useful to examine and understand the physical/chemical phenomena of soft materials such as polymers. This course includes five points. The attendee (1)knows the various structural, thermal, mechanical, electric, magnetic, optical properties and phenomena which solid state materials exhibit, (2) understands the reasons why such properties appear in solids, from microscopic picture of atomic scale (of electron and nucleus), (3) learns methods how scientists discovered such properties previously, (4) considers a way to discover new properties and to establish new explanation for the observed experimental results, and (5) tries to construct ideas to expand the future science and technology on solid materials under the physicist’s mind.

**二、教学目标**

**（一）学习目标**

This course isa science of understanding macroscopic (thermal, mechanical, electric, magnetic, optical, etc.) properties of various solid materials through a microscopic picture of nano-to-femto scale in not only particle size but also time interval. For this purpose we have to learn various specialized experimental and theoretical methods. Through the exchange of knowledge between the speaker and the attendees during this course, the attendees are expected to be familiar to the principles in those experimental techniques (e.g., crystal growth, semiconductor device fabrication, measurements of X-ray diffraction, optical absorption and emission spectra, conductivity, etc.) and theoretical analysis methods (e.g., electro-magnetism, quantum mechanics, statistic dynamics, non-linear optics, etc.) which are necessary for deep understanding. In addition, the attendeesare expected to construct ideas for new technology on polymers.

**（二）可测量结果**

（1）掌握现代固体理论的主要概念及发展历史；

（2）从微观及原子尺度理解材料表现出的结构、热、机械、光、电、磁等特性；

（3）从原创科学家的角度了解和材料学相关的基本物理表征手段；

（4）树立从物理的角度发展材料新科技的意识。

注：以上结果可以通过课堂讨论、课程作业以及笔试等环节测量。

**三、课程要求**

**（一）授课方式与要求**

**授课方式：**a.教师讲授（讲授核心内容、总结、课堂提问、答疑、组织讨论等）；b.课后作业及预习；c.每次课均有质疑和答疑环节，鼓励学生质疑现有理论体系；d.期末考试

**课程要求：**熟悉材料物理学的基本知识及专业词汇、提高专业英语的阅读、写作及听说能力，培养材料学专业的学生对物理的兴趣。

**（二）考试评分与建议**

期末考试占50％，课堂发言占30％，课后作业占20％。

**四、教学安排**（每次课2学时）

第一次：Learning of physics on solid materials学习固体材料的物理（绪论）

主要内容：

When we look at a tiny rock salt on dining table carefully, many questions appear to us. Why does the salt take a cubic shape? Whynot hexagonal as quartz? Why is it transparent, different from the powdered salt? When salt is burned, orange color is observed. Why? Salt is expressed by chemical formula NaCl. Why not expressed as Na2Cl like H2O or NaCl2 like CO2? How do Na and Cl in NaCl crystal combine with each other? Why each does not want to separate from other? NaCl is not magnet and electric conductor, different from iron and copper metals. Why not? Is it possible to change NaCl to magnetic and electrically conductive material? We have such many questions for NaCl. Questions also appear for mysterious properties of other crystals, e.g., semiconductors, metals, and superconductors. From these questions, we notice importance of study on physics about solidmaterials. In the 1st lessonof this course, we discuss on (1) what are “solid materials”, (2) what is “physics”, and (3) why we have to study physics on solid materials. Finally we discuss the usefulness of learning solid state physics for the studyofpolymer science and technology.

思考题：1.What allows the existence of NaCl crystal on the earth?2. What is polymer?

第二次：Crystal structure and itsanalysis methods晶体结构及其测定方法

Material is a multi-functioned assembly of atoms or molecules. Crystal is a typical phase state of materials. Material with periodic structure and array of atoms or molecules is called single crystal. Not all structuresare equal. We have cubic, hexagonal and trigonal structures, etc. We learn what kinds of structures appear in our earth, and how the structures were found experimentally. Discussion is given on the principle of X-ray diffraction method, which is currently used for analysis of structure.

思考题：Crystal with pentagon structure is not found. Why?

第三次：Chemical bond化学键

Stable assembly is formed by strong bond among the constituents (elements such as atoms). At least five types of bonds have been found, i.e., ionic bond, covalent bond, metallic bond, hydrogen bond, and Van der Waals bond. For example, NaCl salt takes ionic bond, while carbon atoms in diamondtakecovalent bond. They are quite different from each other. Explanation is made on the difference of these bonds, their mechanism, and the reasons why different bond types are formed depending on the elements.

思考题：Why graphene (assembly of carbon) takes a hexagonal structure?

第四次：Lattice vibration and solid state thermal properties晶格振动和固体热性质

Heat is needed for material to increase its temperature. The specific heat or heat capacity is observed to depend largely on temperature after scientist can decrease temperature down to nearly zero K (Kelvin, in absolute temperature). From its temperature dependence from nearly 0 K to room temperature, scientists including Einstein and Debye knew that all the elements (their nuclei) in crystal are vibrating, i.e., lattice vibration. In the 4thlesson, we learn the models by Einstein and Debye for the lattice vibration, and we enjoy the nearly perfect explanation by Debye for the observed temperature dependence of the specific heat.

第五次：Electronic properties of solid固体的电性质

One of the verifications for the presence of electrons in solid materials is due to electric conductivity which is observed for metal under application of electric field. Ohm’s law is well known in the conducting materials. This law reveals not only chargemoving in an electric field but also the presence of lattice vibration. The conductivity of metal is understood by free electron model in the first approximation. From this model, we learn the behavior of electrons in solid materials.

思考题：How wasthe electron in atom discovered?

第六次：Energy band能带理论

Electron in solid materials is important because it determines various properties (thermal, electrical, magnetic, optical properties, etc.) of materials. Two kinds of electrons are present. One is valence electrons, which contribute to bonding, the other is conduction electrons which mainly contribute to electric and thermal conductivity and optical phenomena. In the periodic array of nuclei in the constituent elements of solids, both electrons form energy band, which represents electron’s wavevector dependence of energy. From the energy band, we can understand the difference among electric insulator, conductor, and semiconductor easily. In this lesson the explanation is given on how the energy band is formed, by taking into account of the periodicity of lattice.

第七次：Electric conductivity导电性

Solid materials show not only the electric conductivity that follows the Ohm’s law but also the conductors that do not obey Ohm’s law. The typical one is superconductor, which is predominantly observed at low temperature below 77 K. Conducting polymers and organic semiconductors also exhibit curious conductivity by changing applied voltage. These phenomena are presented for several materials, and their mechanism and electron behavior are explained.

思考题：Electron moving under electric field leads to conductivity. How much velocity does electron have?

第八次：Magnetic properties of solid固体的磁性

Magnet of iron metal attracts another iron metal and iron-compound. After attraction, the iron-compound becomes magnet, i.e., magnetized. The magnetism is cooperative phenomena about neighboring atoms or ions. Several magnetic phases were found, e.g., paramagnetism, ferromagnetism and anti-ferromagnetism. In this lesson, explanation is made on (1) what generates magnetism? (2) whatis the difference betweenferromagnetism and anti-ferromagnetism? (3) magnetic phase changes by the change on temperature (magnetic phase transition), and (4) the application of magnet totechnologiesincluding the microwave at kitchen.

思考题：The earth is known as magnet. Why is the earth possible to be magnet?

第九次：Dielectric properties of solid 固体的介电特性

When an electric field is applied to a dielectric crystal such as an ionic crystal without conductivity, interesting phenomena occur in the ionic crystal by the interaction of the electrons and nuclei therein. For example, polarization is generated by moving the valence electron around its nucleus and by shiftingthe nucleus in a limited lattice space (generation of spontaneous electric dipole moment), depending on the frequency of the applied field. As a result ferroelectricity due to the lattice shift appears macroscopically as a structural phase transition, while absorption and emission due to the electron moving appear microscopically. These phenomena are understood by applying the Maxwell equations to the dielectric materials. Then the observed frequency dependence of the polarizability can be explained. Piezoelectricity is an effect in which applying stress to a material leads to a macroscopic electric polarization. Piezoelectric materials have many applications, e.g., microphone, cigarette lighters, or actuators (loudspeakers). Piezocrystal-based actuators are especially important for nanotechnology (like tip in a scanning tunneling microscope) because they permit precise positioning. A classical analysis for the typical experimental results on the ferroelectricity and piezoelectricity is presented.

思考题：What happens for the atoms and molecules that have no light absorption? Is there no effect for the atoms and molecules even light comes to them?

第十次：Semiconductor crystals半导体晶体

Semiconductors are classified by their electrical resistivity at room temperature, with values higher than conductors like metal but much lower than isolators like NaCl. The electrical resistivityis strongly dependent on temperature. At low temperature near 0 K a pure (intrinsic) and non-doped semiconductorswill be an insulator. In the 10thlesson, the fundamental characteristics of semiconductor, including electron population under the Fermi-Dirac distribution, are presented.

第十一次：Semiconductor and its applications半导体的应用

Semiconductor, particularly silicon, germanium, and gallium arsenide, has many applications to our society with high-technology. Devices based on semiconductors include transistors, switches, diodes (e.g., light-emitting diode, photovoltaic cells, photo-detectors) and thermistors. They may be used as single circuit elements or as the components of integrated circuits. We discuss these applications as well as the mechanism in the 11th lesson.

第十二次：Interaction of light with materials光和材料的相互作用

Charge particles can interact with both the electric and magnetic fields. The former is by the Coulomb force, while the latter is by the Lorentz force. Usually the effects by these forces have been studied under the static fields, i.e., time-independent fields. However, these forces are also generated by time-dependent fields. Thereforeboth of the Coulomb and Lorentz forces give influence to the charged particles under light and time-dependent electro-magnetic field. This indicates that the materials consisted of atoms and molecules have strong interaction with light. This leads to light absorption, emission, inelastic-scattering by materials, i.e., presenting the optical properties of the materials. This mechanism is understood by classical electro-magnetic theory in the 1st order approximation or by the quantum mechanics theory more precisely. The latter theory gives transition probability between two electronic states and the selection rule in the transitions. This makes the analysis of the observed absorption and emission spectra easy, helping the understanding of the optical properties of materials. For the positive charge, same mechanism is true. This leads to the light absorption and emission by interaction of the nucleus (lattice) with light, helping analysis of the spectra due to lattice vibration. The details of these mechanisms are given in this 12th lesson.

第十三次：Optical properties of solid固体的光学性质

Optical properties of materials appear as light absorption, light emission, light scattering, light refraction, photo-chemical reaction (the change of material structure), and so on. Light is usually attributed to wave with wavelength in visible range (400-800 nm). Exactly speaking, light is defined as electro-magnetic wave with a wavelength. The wavelength covers a wide range from nearly zero to infinity, from gamma ray with short wavelength to radio-wave with much longer wavelength than visible light. Depending on the wavelength, different optical properties are observed. Regarding the light emission under the photo-excitation into the material, two kinds of luminescence can be generated. One is fluorescence and the other is phosphorescence. The former has short emission decay time (nearly nano-sec order), while the latter has longer decay time over micro-sec.It is important to consider “Which luminescence is observed from the material?”, because it determines the electronic states responsible for the relaxation process after photo-excitation. Detection methods for optical properties and the related analysis methods are explained in the 13th lesson.

思考题：There are two kinds of electrons in crystals. One is located inside crystal, while the other is located near the surface of crystal. What different optical properties can be expected between these two electrons?

第十四次：Optical properties of inorganic solids无机材料的光学性质

Various solid materials exhibit various optical properties. This seems to give an impression of difficulty in the analysis of the observed optical properties, because we feel to prepare different analysis methods for different materials. However, universal analysis method is available. For example, the absorption and emission spectra of rare-earth compounds and transition-metal complexes can be analyzed by the same way. There are 14 elements from La3+ to Lu3+ in the rare-earth group, where they have (4f)n (n=1-14) outer electrons active to the illuminated UV-infrared light. The inner 4f-4f transitions are responsible for the observed absorption and emission spectra. Thecomplexes with different rare-earth ions can beidentified by the analysis ofthe transition. The same as the transition-metal complexes with (3d)n (n=1-10). In the 14th lesson, such an analysis is demonstrated.

第十五次：Optical properties of organic materials有机材料的光学性质

Like inorganic light emitting diodes (LEDs), organic LEDs (OLEDs) have been intensely studied recently. OLEDs use all organic compounds in the devices except the electrodes. Different from the inorganic LEDs, OLEDstake the advantages of two-dimensional emitting, low-fabrication cost, flexible, and easy color tuning. These devices are used for lighting due to full color emission and for display that willreplacecurrent liquid crystal display in near future. The emission mechanism of OLEDs is different from that ofinorganic LEDs,in spite of the same electron-hole recombination process. On the other hand, carbon nano-tube (CNT) is studied owing to their excellent electrical and optical properties. Graphene and fullerene, which belong to the same group of CNT, also shows interesting properties, e.g., zero-mass electron in graphene. Several applications are under consideration now. In the 15th lesson, introductory explanation regarding the new devices based on organic solid materials is given.

思考题：OLEDsarenow used in lighting and display. What kinds of other applications are conceivable?

第十六次 Research using solid materials in Zhejiang University浙江大学的材料科学研究

Many excellent papers regarding solid materialshave been published bythe Department of Polymer Science and Technology, Zhejiang University. From several papers, we learn what is made for solid materials including polymer and organic complexes in our Department.

思考题：Choose one paper on solid material, and introduce its functions.

**五、参考教材及相关资料**

(1) *Solid State Physics : Revised Edition 1st Edition*, Neil W. Ashcroft, N. David Mermin, Dan Wei, Harcourt College Publishers, **2016**.

(2) 《固体物理（第2版）》，韦丹，清华大学出版社，2007年10月。

**六、课程教学网站：**

将通过校内网络提供必要的课件和文字材料链接