课程大纲
COURSE SYLLABUS

1.	**课程代码/名称** **Course Code/Title**	微观组织表征与分析/ MEE5210 **Microstructure characterization and analysis**
2.	**课程性质** **Compulsory/Elective**	专业选修课 Elective
3.	**课程学分/学时** **Course Credit/Hours**	3/48
4.	**授课语言** **Teaching Language**	中英双语 Chinese-English Bilingual
5.	**授课教师** **Instructor(s)**	王帅 Shuai Wang
6.	**是否面向本科生开放** **Open to undergraduates or not**	是 yes
7.	**先修要求** **Pre-requisites**	（如面向本科生开放，请注明区分内容。 If the course is open to undergraduates, please indicate the difference.） 研究生先修：无 本科生先修：PHY105B 大学物理（下）B General Physics II B；CH101B 化学原理 B General Chemistry B

8. 教学目标
Course Objectives

（如面向本科生开放，请注明区分内容。 If the course is open to undergraduates, please indicate the difference.）

“Seeing is believing”,表征与分析手段已经成为多数学科研究中不可缺少的重要组成部分。使用电子显微学对微观组织进行观察是表征与分析的重要一环。固体中的微观组织结构，如空位、位错、表面与界面、裂纹等，其性质往往决定了固体本身的性能。随着材料科学、纳米技术、薄膜技术及精密加工等学科方向的发展，微观组织与性能的关系越来越受到关注，例如：通过控制点缺陷可以改变二维材料的性质，通过改变位错的分布和运动状态可以强化材料，采用表面加工改性可以提升和改善薄膜能耐，以及改善粉末冶金和增材制造的产品性能，通过晶界工程学可以获得超高强度结构材料，通过表面镀膜使基体抗裂纹、抗腐蚀、抗辐射等。加强微观组织电子显微学表征理论和相关技术应用的教育是促进交叉学科发展、进行教育改革、科技发展和经济建设的客观要求。

该课程主要目的是向机械工程、材料科学与工程、应用物理、化学、航空航天工程、微电子科学与工程的本科生和研究生。介绍与固体中微观组织相关的的基础理论、表征及分析技术，并提高运用理论解决工程应用问题的能力。通过重点掌握扫描电镜显微学、透射电镜显微学、原子力显微学等表征手段的基本原理，增强学生对微观组织结构的电子显微学研究方法的认识，提升在相关科研和工作领域的分析能力。

通过学习，本科生应可以：

1.熟知米勒指数和基本晶体学。认识缺陷分析中的基础热力学原理，认识能量与原子排列几何的关系。

2.熟知固体中缺陷的种类及其重要性，熟知点缺陷和位错的分类。

3.熟悉重要的分析微观组织、原子结构、三维形貌、化学成分的表征手段的基本原理。

4.认识电子与固体相互作用机制，认识不同种类射线在显微学分析上的功用。

5.认识扫描电镜、聚焦离子束、透射电镜观察显像和基本分析原理，认识分析电子显微学的优越性和局限性，认识在电镜测试中衬度、分辨率、景深等的含义。

6.通过课堂练习，了解高质量学术期刊图片的要求、编辑和排版方法。

通过学习，研究生应可以：

1.熟练掌握米勒指数和基本晶体学。掌握缺陷分析中的基础热力学原理，掌握能量与原子排列几何的关系。

2.熟知固体中缺陷的种类及其重要性，熟知点缺陷和位错的分类。理解固体界面的取向错配角、点缺陷、原子的共格与非共格关系对固体性能的影响。

3.熟知重要的分析微观组织、原子结构、三维形貌、化学成分的表征手段的基本原理。

4.理解电子与固体相互作用机制，认识不同种类射线在显微学分析上的功用，了解 abbe 衍射极限和布拉格定理。

5.理解扫描电镜、聚焦离子束、透射电镜观察显像和基本分析原理，熟知分析电子显微学的优越性和局限性，认识在电镜测试中衬度、分辨率、景深等的含义。

6.通过文献学习和实际操作，认识获得具有可出版质量的电镜图片必须具备的要素。通过课堂练习，熟知高质量学术期刊图片的要求、编辑和排版方法。

Seeing is believing, characterization and analysis are essential components for researches in many areas. Investigation of microstructure by using electron microscopy is one of the most important and challenging part for characterization. As the advances of materials science, nano-tech, thin films, and precision machining, lots of attentions have been drawn to the observation and manipulation of microstructure. For instance, the manipulation of point defects can modify the properties of two-dimensional materials, the mechanical properties of materials are controlled by the distribution and evolution of dislocations, the modification of interfaces structure can change the property of films and increase the product quality of additive manufactured materials, grain boundary engineering has been used to strengthen metals, deposition of films can increase the resistance to fracture, corrosion and irradiation. The ability for characterization and analysis of microstructure is critical for students planned to work in area of design of structural materials, thin films, semiconductor, micro- and nano- devices, precision machining, and additive manufacturing.

The objective of this course is to acquaint both undergraduate and graduate students in Mechanical Engineering, Materials Science and Engineering, Applied Physics, Chemistry, Aerospace Engineering, and Microelectronics Science and Engineering with fundamental theory, application and analysis methods of microstructure, and enhance the student's ability of understanding and using the theory of microstructure formation and evolution to solve engineering problem. By acquainting student with the basic theory and characterization methods in scanning electron microscopy, focused ion beam, transmission electron microscopy, and electron back-scattering diffraction pattern analysis, improve their understanding of microstructure in different scales, and promote their researching and working ability in the related field.

After the course, the undergraduate students should be able to:

1. Know Miller index and basics of Crystallography. Understand the basic thermodynamics used in analysis of microstructure, and the connection between energy and atomic arrangement.

2. Know different kinds of defects in solid and their importance in science and engineering.

3. Know the fundamental methods for characterizing microstructure, atomic configuration, roughness, 3D tomography, and composition distribution of surface and interface, and understand their basic principles.

4. Know the interaction between electrons and solids. Know the usage of different type of signals.

5. Describe the theory of imaging and investigation methods in scanning electron microscope, focused ion beam and transmission electron microscope. Know the cons and pros of scanning electron microscope and transmission electron microscope. Know the meaning of contrast, resolution, depth of field in microscope.

6. According to practice in class, know the general requirement, editing method and typical typeset.

After the course, the graduate students should be able to:

1. Master Miller index and basics of Crystallography. Master the basic thermodynamics used in analysis of microstructure, and the connection between energy and atomic arrangement.

2. Describe different kinds of defects in solid and their importance in science and engineering. Know different types of interface, and give the physical meaning of the misorientation, point defects, and coherent/incoherent relation in interface.

3. Know the fundamental methods for characterizing microstructure, atomic configuration, roughness, 3D

tomography, and composition distribution of surface and interface, and understand their basic principles.

4. Understand the interaction between electrons and solids. Known the usage of different type of signals. Know the concept and principle of Abbe diffraction limits and Bragg equation.

5. Describe the theory of imaging and investigation methods in scanning electron microscope, focused ion beam and transmission electron microscope. Know the cons and pros of scanning electron microscope and transmission electron microscope. Understand the meaning of contrast, resolution, depth of field in microscope.

6. Make high quality images for publication. According to practice in class, understand the general requirement, editing method and typical typeset.

9. 教学方法
Teaching Methods

课堂讲授，广泛使用多媒体，引入实例，利用 Python Jupyter notebook 互动辅助教学，课程项目报告（书面+口头）
1. Classroom teaching. 2. Applying multimedia widely. 3. Case and reference study. 4. Using Python Jupyter notebook to interact with students. 5. Class project (writing report +oral presentation)、
对本科生和研究生采用相同方法，不同评估标准（课后作业和课程报告难度不同）。

10. 教学内容
Course Contents
（如面向本科生开放，请注明区分内容。 If the course is open to undergraduates, please indicate the difference.）
对本科生和研究生采用相同内容，要求掌握程度不同（课后作业和课程报告难度不同）。

Section 1	概论 (2 Credit hours) Introductions - Historical sketch - Definition and importance Applications
Section 2	完美晶体：晶体学基础 (4 Credit hours) Perfect crystal: Basics of crystallography - Name the atomic configurations - Bravais lattice in 2-D and 3-D - Miller indices - Reciprocal space - Important crystal structures Atomic packing
Section 3	完美晶体中的不完美：缺陷 (2 Credit hours) Imperfections in perfect solids: Defects - 0-D defects: Point defects - 1-D defects: Dislocations-linear defects 2-D and 3-D defects
Section 4	位错(4 Credit hours) Dislocation - Basics theory of elasticity - History of dislocation theory - Character of dislocation - Dislocation stress field - How to move a dislocation Dislocation interactions
Section 5	界面(4 Credit hours) Interfaces - Definitions and classification - Surface and surfactant - Coincidence site lattice

	- Interfacial energy - Separation of grain boundary Grain boundary engineering
Section 6	表征分析：目的和基础理论 (2 Credit hours) Characterization: objective and basics - Objective for surface and interface observation - Optical microscopy and Abbe limitation - Resolution, contrast, depth of field Distortion in optics
Section 7	电子与物质的相互作用(2 Credit hours) Interactions between electrons and solid - Elastic scattering - Inelastic scattering Irradiation damage
Section 8	电子衍射理论基础(2 Credit hours) Electron diffraction - Bragg Equation - Reciprocal space and Ewald sphere - Structural factor - Diffraction pattern and orientations Kikuchi pattern
Section 9	扫描电子显微镜和能谱 (4 Credit hours) scanning electron microscope and energy spectrum - Schematic Diagram for scanning electron microscope - Instruments for electron microscope - How to see electrons - Different detectors and their functions - Electron channeling effect EDS: chemical composition analysis in electron microscope
Section 10	课堂专题演讲 (4 Credit hours) Class presentation and discussion
Section 11	聚焦离子束 (4 Credit hours) Characterization: Focused ion beam - Schematic Diagram for focused ion beam - Difference between electrons and ions - Instruments for focused ion beam - Ion channeling effect - Damage induced by ion beam How to make TEM sample by using focused ion beam machining
Section 12	透射电子显微学 (4 Credit hours) Transmission electron microscopy - Schematic Diagram for transmission electron microscope - Bright field and dark field image - How to see dislocations - Scanning transmission electron microscopy Atomic image and dislocation image in STEM
Section 13	背散射电子衍射分析(4 Credit hours) Electron back scattering diffraction (EBSD) pattern - Stereographic projection - From Wulff net to standard projection - Representation of orientation - Pole figure and inverse pole figure

		- Kikuchi band and EBSD - EBSD: How it works Interpretation of EBSD data
	Section 14	其他表征分析技术 (2 Credit hours) Other characterization and analysis approaches - XRD - STM - SIMS - AFM - ATP
	Section 15	提升显微照片的质量(2 Credit hours) Improve quality of images - Softwires you should know - Requirement of journals - Concept of pixels - Modify the size of images - Change contrast and brightness - Fonts and typeset Output of images
	Section 16	缺陷的模拟计算方法 (2 Credit hours) Calculation methods of defects - Introduction to molecular dynamics and optimization of atomic structure - Introduction to the first principle calculation and its application on surface and interface research Hybrid methods: QMMM
	Note	Lectures slots could be swapped around

11. 课程考核
Course Assessment

（①考核形式 Form of examination；②.分数构成 grading policy；③如面向本科生开放，请注明区分内容。If the course is open to undergraduates, please indicate the difference.）

评估形式 Type of Assessment	**占考试总成绩百分比 % of final score（研究生）**	**占考试总成绩百分比 % of final score（本科生）**
出勤 Attendance	5	5
课堂表现 Class Performance	10	10
小测验 Quiz	0	0
平时作业 Assignments	25	15
课堂专题演讲 Class Presentation	30	30
课程报告 Project report	30	40

12. 教材及其它参考资料
Textbook and Supplementary Readings

教材：
“电子显微分析”，章晓中，（清华大学出版社，2006 年）
其他参考：

“金属学原理”，余永宁，（冶金工业出版社，2013 年）
“Transmission Electron Microscopy-- A Textbook for Materials Science” David B. Williams, C. Barry Carter. (Springer, 2008)
“Electron Microscopy of Thin Crystals” Peter Bernhard Hirsch. Edition 2, R. E. Krieger Publishing Company, 1977.