# THE DOCTORAL SCHOOL OF IPPT PAN

## COURSE OFFERED IN THE DOCTORAL SCHOOL OF IPPT PAN

| | | | | | | |
|---|---|---|---|---|---|---|
| Name of the course | Polish | **Wstęp do skaningowej mikroskopii elektronowej i technik pokrewnych.** | | | | |
| | English | **Introduction to scanning electron microscopy and related techniques.** | | | | |
| Type of the course | **Introductory Lecture** | | | | | |
| Course coordinator | **Dariusz Jarząbek** | | Course teacher | **Dariusz Jarząbek** | | |
| Implementing unit | **ZMM/LMD** | | Scientific discipline / disciplines | **Materials Science and Engineering, Mechanical Engineering, Biomedical Engineering** | | |
| Level of education | **Doctoral studies** | | Semester | **I, II, III or IV** | | |
| Language of the course | **English or Polish** | | | | | |
| Type of assessment | **Exam** | | Number of hours in a semester | **40** | ECTS credits | **4** |

| Type of classes | | Lecture | Auditory classes | Project classes | Laboratory | Seminar |
|---|---|---|---|---|---|---|
| Number of hours | in a week | **2** | | | **2** | |
| | in a semester | **30** | | | **10** | |

### 1. Prerequisites

a) Basic knowledge of physics at the engineering level, in particular:

- classical mechanics,
- fundamentals of electromagnetism,
- elementary concepts of quantum physics and atomic structure.

b) Knowledge of general and materials chemistry in the scope of the structure and properties of solids, including:

- basics of crystallography and structure of matter.

c) Ability to use engineering mathematics, especially in the field of:

- linear algebra,
- function analysis,
- fundamentals of differential and integral calculus.

d) Basic knowledge of materials science and materials engineering, including:

- types and properties of the main groups of materials (metals, ceramics, polymers),
- basic techniques of materials characterization.

e) General orientation in electronics and vacuum technology, facilitating the understanding of research equipment operation.

f) Ability to use scientific literature and read technical texts in English.

## 2. Course objectives

a) Introducing students to the theoretical foundations of scanning electron microscopy (SEM) – the mechanisms of electron signal generation and detection, the principles of electron optics, and the basics of vacuum and instrumentation electronics.

b) Presenting related techniques used in electron microscopy, such as: chemical composition analysis by EDS/WDS, backscattered electron (BSE) imaging, electron backscatter diffraction (EBSD), as well as ion and electron microscopy in FIB-SEM systems.

c) Developing the ability to interpret images and spectra obtained in SEM and to correlate them with the microstructure and properties of the studied materials.

d) Familiarizing students with the capabilities and limitations of SEM methods, as well as the principles of proper qualitative and quantitative analysis.

e) Acquiring practical knowledge of sample preparation for electron microscopy studies (conductive and non-conductive materials, sputter coating, cutting, mounting techniques).

f) Raising awareness of safety issues related to working with electron microscopes and high-vacuum systems.

g) Preparing students for the independent use of SEM in research and engineering practice, including the selection of appropriate techniques for specific research problems

## 3. Course content (separate for each type of classes)

### Lecture

**Introduction to Electron Microscopy**

- Fundamental differences between optical and electron microscopy.
- Operating principles of the electron column and vacuum systems.
- Electron sources, electron optics system, signal detectors.

**Scanning Electron Microscopy (SEM)**

- Principle of SEM operation.
- Types of signals: secondary electrons, backscattered electrons, X-ray radiation.
- Image contrast and its interpretation.
- Resolution and factors affecting image quality.

**Chemical Composition Analysis in SEM – X-ray Spectroscopy (EDS/WDS)**

- Mechanism of characteristic X-ray emission.
- Operating principles of EDS and WDS detectors.
- Element identification and quantitative analysis.
- Method limitations and accuracy.

**Electron Backscatter Diffraction (EBSD)**

- Principle of operation and Kikuchi pattern acquisition.
- Analysis capabilities: crystallographic orientation, texture, phase identification.
- Applications of EBSD in materials science.

**Focused Ion Beam Techniques (FIB, FIB-SEM)**

- Principle of FIB operation and types of ions.
- Use of FIB for sample preparation (e.g., for TEM).
- Applications of FIB in surface modification and 3D analysis.

**Introduction to Transmission Electron Microscopy (TEM)**

- Principle of TEM operation and differences compared to SEM.
- Information obtained in TEM: bright-field imaging, dark-field imaging, electron diffraction.
- High-resolution capabilities and crystallographic structure analysis.
- Sample preparation requirements – ultrathin foils (<100 nm).

**Complementary and Related Techniques**

- XRF – X-ray fluorescence as a method of chemical analysis.
- AFM – Atomic Force Microscopy as a tool for surface topography imaging.
- Comparison with SEM – scope of applications and limitations.

**Sample Preparation for Microscopy Studies**

- Conductive and non-conductive materials – sputter coating, conductive coatings.
- Cutting, mounting, and polishing of metallographic specimens.
- Specific sample preparation for EDS, EBSD, and FIB analyses.
- TEM sample preparation using FIB – milling, transfer, and final thinning process.

## Auditory Classes

**Organizational Introduction and Safety Rules for Working with the Electron Microscope**

- Introduction to health and safety regulations in electron microscopy laboratories.

**Sample Preparation for Observation**

- Discussion of preparation methods (sputter coating, mounting, electrical conductivity).
- Examination of pre-prepared samples.

**Basic Operation of the SEM**

- Procedures for sample insertion.
- Setting operating parameters (accelerating voltage, magnification, contrast, brightness, detection mode).

**Imaging of Samples Provided by Students or the Instructor – Practical Exercises**

- Selection of imaging parameters according to sample type.
- Observation of surface topography and material structure.
- Acquisition of SEM images.

**Basic Analysis of Additional Signals**

- Demonstration of chemical composition analysis using EDS.
- Optional presentation of EBSD fundamentals (recording and interpreting example Kikuchi patterns).

**Discussion of Results and Summary**

- Interpretation of images and spectra.
- Comparison of the capabilities and limitations of SEM and related techniques.

| 1. Learning outcomes | | | |
|---|---|---|---|
| Number of the learning outcome | Learning outcomes description | Reference to the learning outcomes according to the 8th level of PRK | Learning outcomes verification methods* |
| **Knowledge** | | | |
| 1. | The student knows the basic principles of scanning electron microscopy (SEM) and related techniques (EDS, EBSD, FIB, TEM – introduction, XRF, AFM). | PRK: P7_WG – has advanced knowledge in the field of the engineering discipline and related sciences. | exam |
| 2. | The student understands the mechanisms of signal generation and detection in SEM and their importance for the interpretation of images and spectra. | PRK: P7_WG – has knowledge of the methods, techniques, and tools used in materials research. | exam |
| 3. | The student knows the principles of sample preparation for SEM, EDS, EBSD, and TEM studies, as well as their impact on the obtained results. | PRK: P7_WK – is aware of the limitations of the applied research methods. | Report evaluation |
| **Skills** | | | |
| 1. | The student is able to operate the basic functions of SEM for sample imaging. | PRK: P7_UW – is able to properly apply research tools in practice. | Report evaluation |
| 2. | The student is able to adjust SEM operating parameters to the type of sample and the expected outcome. | PRK: P7_UW – is able to integrate knowledge and skills in solving engineering problems. | Report evaluation |
| 3. | The student is able to carry out basic qualitative analysis using the EDS method and make a preliminary interpretation of the obtained spectra. | PRK: P7_UW – is able to analyze and interpret experimental data. | Exam |
| 4. | The student is able to critically assess the capabilities and limitations of individual techniques (SEM, EDS, EBSD, FIB, TEM, AFM, XRF) and select an appropriate method for a research problem. | PRK: P7_UK – is able to formulate conclusions and arguments justifying the choice of a research method. | Exam |
| **Communication** | | | |

| | | | |
|---|---|---|---|
| 1. | The student is able to clearly present the results of observations and analyses obtained with SEM and related techniques. | PRK: P7_UK – is able to communicate with the academic and professional community in a specialist field. | Report evaluation |
| **Social competences** | | | |
| 1. | The student understands the importance of complying with safety regulations when working with high-vacuum equipment and electron/ion sources. | PRK: P7_KO – is able to perform professional duties responsibly, taking into account safety and ethics. | Report evaluation |
| 2. | The student is aware of the limitations of research methods and the necessity of critically interpreting the obtained results. | PRK: P7_KK – is ready to critically evaluate and apply their knowledge. | Exam |
| 3. | The student recognizes the importance of electron microscopy and related techniques in the development of science, engineering, and industrial diagnostics. | PRK: P7_KR – is ready to responsibly fulfill a professional role in research and industrial environments. | Exam |

*Allowed learning outcomes verification methods: exam; oral exam; written test; oral test; project evaluation; report evaluation; presentation evaluation; active participation during classes; homework; tests

## 2. Assessment criteria

**Final Exam (70% of the final grade)**

- Form: written
- Scope: lecture content (SEM, EDS, EBSD, FIB, TEM – introduction, XRF, AFM, sample preparation, capabilities and limitations of the methods)
- Assessed learning outcomes: theoretical knowledge, ability to interpret images and results, understanding of applications and limitations of the methods.

**Laboratory Report (30% of the final grade)**

- Form: individual written report
- Scope: description of laboratory exercises, presentation of imaging results and, if applicable, analyses (EDS/EBSD), interpretation and conclusions
- Assessed learning outcomes: practical skills, interpretation of results, correct use of terminology, ability to communicate in written form.

## 3. Literature

Primary references:

Scanning Electron Microscopy and X-Ray Microanalysis, Joseph I. Goldstein, Dale E. Newbury, Joseph R. Michael, Nicholas W.M. Ritchie, John Henry J. Scott, David C. Joy, DOI 10.1007/978-1-4939-6676-9, Springer New York, NY, 2017

Physical Principles of Electron Microscopy, An Introduction to TEM, SEM, and AEM, Ray F. Egerton, DOI 10.1007/978-1-4615-0215-9, Springer Science+Business Media, Inc. 2005

Secondary references:

Electron Backscatter Diffraction in Materials Science, Adam J. Schwartz, Mukul Kumar, Brent L. Adams, David P. Field, DOI 10.1007/978-0-387-88136-2, Springer New York, NY, 2009

Transmission Electron Microscopy, A Textbook for Materials Science, David B. Williams, C. Barry Carter, DOI 10.1007/978-0-387-76501-3, Springer New York, NY, 2017

| 4. PhD student's workload necessary to achieve the learning outcomes** | | |
|---|---|---|
| No. | Description | Number of hours |
| 1 | Hours of scheduled instruction given by the lecturer in the classroom | **40** |
| 2 | Hours of consultations with the lecturer, exams, tests, etc. | **10** |
| 3 | Amount of time devoted to the preparation for classes, preparation of presentations, reports, projects, homework | **20** |
| 4 | Amount of time devoted to the preparation for exams, test, assessments | **30** |
| | **Total number of hours** | **100** |
| | **ECTS credits** | **4** |

** 1 ECTS = 25–30 hours of the PhD students work (2 ECTS ≈ 60 hours; 4 ECTS ≈ 110 hours, etc.)