Study Programme: PhD academic studies in Physics

Course Unit Title: Microstructure of Functional Materials

Course Unit Code: FD24MFM

Lecturer: dr Kristina Čajko

Type and Level of Studies: PhD Physical Sciences

Course Status (compulsory/elective): Elective

Semester (winter/summer): summer

Language of instruction: English

Mode of course unit delivery (face-to-face/distance learning): Face-to-face

Number of ECTS Allocated: 15

Prerequisites: -

Course Aims:

Acquiring modern theoretical and practical knowledge about the microstructure of functional materials. Correlation of material microstructure and electrical/dielectrical characterization of materials. Ability of student to independently use computer methods for the analysis of the obtained results of electrical measurements and correlation with the properties of the microstructure of the material.

Learning Outcomes

After completing and learning the course content, the student should have developed:

General abilities:

- Knowledge of the basic concepts of the microstructure of functional materials, as well as the basic concepts in the characterization of electrical/dielectrical properties by impedance spectroscopy.
- Ability to independently use academic and expert literature in this field.

Course specific abilities:

Student's ability to analyse experimentally obtained data using commercially available different software tools to characterize the microstructure of materials.

Syllabus:

Theory

Microstructure of functional materials (polycrystals, nanostructured, disordered systems). Impedance spectroscopy. Nyquist diagrams and electric circuit models for correlation of the microstructure of the investigated materials with the impedance response. Analysis and fitting the impedance spectra with appropriate models of equivalent electrical circuits for determining electrical parameters of materials (resistance and capacitance of grains and grain boundaries, activation energy of the relaxation process). Electrical characteristics of functional materials (bulk, nanostructured ceramics, thin films, nanoparticles) in a wide temperature and frequency range. Conductivity in direct and alternating regime. Dielectric characteristics of materials. Relaxation processes and their correlation with the impedance response of the material. Debye model. Scanning electron microscopy (SEM). Transmission electron microscopy (TEM). Atomic force microscopy (AFM). Influence of grains and grain boundaries. Analysis of the surface of the material using commercially available software tools for processing images obtained through SEM, TEM, AFM, etc. Analysis of different morphological forms/particles on the surface of the material. Determination of average dimensions, surface and distribution of morphological forms on the surface of the sample.

Practice

Preparation and presentation of the seminar work that follow and supplement the course program.

Recommended literature

1. E. Barsoukov, J. R. Macdonald editors, *Impedance Spectroscopy Theory, Experiment and Applications*, 3rd Edition, John Wiley & Sons, 2018.
2. W. D. Callister, Jr., D. G. Rethwisch, editors, *Materials Science and Engineering: An Introduction*, 10th Edition, John Wiley & Sons, Inc., 2018.
3. P. Hofman, *Solid State Physics: An Introduction, 3rd Edition*, Wiley-VCH, New York, 2022.
4. A. J. Moulson, J. M. Herbert, *Electroceramics: Materials, Properties, Applications*, John Wiley & Sons, 2003.
5. P. W. Hawkes, J. C. H. Spence editors, *Springer Handbook of Microscopy*, Springer, 2019.
6. R.F. Egerton, *Physical Principles of Electron Microscopy, An Introduction to TEM, SEM, and AEM*, 2nd Edition, Springer, 2016.

Weekly Contact Hours	Lectures: 5	Practical work: 5

Teaching Methods

Lectures (5 hours per week during the semester), study research work (5 hours per week during the semester, includes the preparation and presentation of the seminar work).

Knowledge Assessment (maximum of 100 points)

Oral exam: 70 points, preparation and presentation of the seminar work: 30 points

The methods of knowledge assessment may differ: (written exam, oral exam, project presentation, seminars, etc…