A COURSE SYLLABUS – DOCTORAL SCHOOL
regarding the qualification cycle from 2025/2026 to 2028/2029

GENERAL INFORMATION ABOUT COURSE	
Course title	***RESEARCH METHODOLOGY***
Name of the unit running the course	Doctoral School of the University of Rzeszów
Type of course *(obligatory, optional)*	compulsory
Year and semester of studies	First year/First and second semester
Discipline	**Physical Sciences**
Language of Course	Polish language
Name of Course coordinator	Dr Józef Cebulski, Professor at the University of Rzeszów
Name of Course lecturer	Dr Józef Cebulski, Professor at the University of Rzeszów
Prerequisites	Knowledge, skills and social competences achieved at level 7 of the Polish Qualifications Framework, in particular in the field of solid state physics, semiconductor physics and the basics of experimental methods. Ability to use scientific literature in English.

BRIEF DESCRIPTION OF COURSE
(100-200 words)

The course 'Research Methodology' aims to prepare doctoral students to independently plan, conduct and critically analyse scientific research in the field of physical sciences, with particular emphasis on research into HgCdTe and HgMnTe semiconductor structures obtained by molecular beam epitaxy (MBE). The course covers issues related to the methodology of the research process, the formulation of research problems and hypotheses, the selection of appropriate methods for the production of materials and methods for their structural, morphological, compositional and physical characterisation.

As part of the course, doctoral students develop skills in critical analysis of scientific literature, designing experimental procedures, interpreting measurement results (including HRXRD, SEM, ToF-SIMS, magnetic and transport measurements) and assessing the impact of technological process parameters on the properties of the materials under study. The course also prepares students to prepare research reports, scientific publications and conduct research in accordance with the principles of scientific integrity and research ethics.

COURSE LEARNING OUTCOMES AND METHODS OF EVALUATING LEARNING OUTCOMES

Learning outcome	The description of the learning outcome defined for the course	Relation to the degree programme outcomes (symbol)	Learning Format (Lectures, classes,…)	Method of assessment of learning outcomes (e.g. test, oral exam, written exam, project,…)
Knowledge (no.)	knows and understands, has knowledge			
P8S_WG3	Knows and understands advanced specialist terminology and methodological concepts used in experimental research in the field of II–VI semiconductor physics, in particular HgCdTe and HgMnTe structures.	**P8S_WG**	Conversatory	Oral examination,
P8S_WG4	Has a solid knowledge of methods for planning and conducting scientific research involving epitaxial growth using the MBE method and methods for	**P8S_WG**	Conversatory	Oral examination

	structural and physical characterisation of semiconductor materials.			
P8S_WK3	Knows the principles of transferring scientific research results to technological applications, taking into account intellectual property protection and potential applications in infrared detection and spintronics.	**P8S_WK**	Conversatory	Oral examination
Skills (no.)	can			
P8S_UW1	Can formulate a research problem, objective and hypothesis concerning HgMnTe/HgCdTe structures and design a research procedure leading to their verification.	**P8S_UW**	Conversatory	project, discussion
P8S_UK1	Can select and apply appropriate experimental methods to analyse the crystal quality, chemical composition and physical properties of the structures under study, and compare and interpret the results obtained in an international research environment.	**P8S_UK**	Conversatory	written assignments, project
P8S_UO1	Is able to plan and carry out a research project, as well as prepare reports, research reports and present research results in various scientific environments, including international ones, while maintaining the principles of reliability and correct scientific documentation.	**P8S_UO**	Conversatory	written assignments, project
Social competence (no.)	is ready to			
P8S_KR1	Is ready to conduct scientific research in a responsible manner, in accordance with the principles of research ethics, laboratory safety and intellectual property protection.	**P8S_KR**	Conversatory	project, discussion
P8S_KR1	Is ready to cooperate with research teams and to actively participate in the national and international scientific community.	**P8S_KR**	Conversatory	project, discussion

Semester (no.)	Lectures	seminar	Conversatory / Lab classes	Internships	others	ECTS
I	-	-	-	-	30	3
II	-	-	-	-	30	3
total:	-	-	-	-	60	6

METHODS OF INSTRUCTION

- *SEMINAR WITH MULTIMEDIA PRESENTATION*,
- *RESEARCH PROJECT*,
- *ANALYSIS AND INTERPRETATION OF SCIENTIFIC LITERATURE*,
- *PROBLEM-BASED DISCUSSION*,
- *CONDUCTING EXPERIMENTAL RESEARCH*.

COURSE CONTENT

Semester I – Methodology of scientific research design in thin film physics

1. Methodology of scientific research in semiconductor materials physics
Specificity of scientific research in solid state physics with particular emphasis on thin films and semiconductor heterostructures; the role of experimental research in understanding the properties of reduced-dimensionality materials.
2. Research problem and scientific hypothesis in thin film research
Formulation of research problems related to the growth, structure and properties of semiconductor thin films; construction of hypotheses concerning the relationship between manufacturing process parameters and the quality and physical properties of HgCdTe and HgMnTe films.
3. Analysis and synthesis of scientific literature on thin films
Critical analysis of scientific papers on thin semiconductor film growth technology and their structural and electronic properties; identification of current research directions on HgCdTe materials.
4. Designing a research process for thin semiconductor layers
Planning scientific research involving the production of thin layers and heterostructures; selection of a research strategy enabling control of the composition, homogeneity and crystalline quality of the layers.
5. Thin film testing methods – general overview
Classes of methods used in structural, morphological and compositional testing of thin semiconductor films; the importance of multi-method testing in the analysis of HgCdTe/HgMnTe systems.
6. Data analysis and interpretation of results in layer studies
Principles of experimental data processing for thin layers; interpretation of results in the context of structural and electronic models of II–VI semiconductors.
7. **Development of methodological assumptions for research on thin films**
Editing of a methodological report covering the research problem, hypothesis and research plan concerning HgCdTe/HgMnTe thin films; presentation and discussion of assumptions.

Semester II – Methodology for conducting and interpreting research on HgCdTe thin films

1. Conducting scientific research on thin semiconductor films
Principles of conducting experimental research on the growth and properties of thin films; documenting the course of research and evaluating its repeatability.
2. Assessment of the quality of thin films and heterostructures
Criteria for assessing the crystalline quality, compositional homogeneity and defectiveness of HgCdTe thin films; the importance of structural quality for the physical properties of the material.
3. Interpretation of structural and physical test results
Analysis of thin film test results in the context of structure-property relationships; comparison of results with literature data for HgCdTe/HgMnTe systems.
4. Verification of research hypotheses in layer studies
Assessment of the degree of confirmation of hypotheses concerning the influence of growth parameters on the properties of thin layers; identification of methodological limitations.
5. Synthesis of results and scientific conclusions
Combining thin film research results into a coherent scientific picture; formulating conclusions and indicating further directions for research.
6. Presentation and dissemination of research results
Standards for compiling thin film research results in the form of reports and scientific publications; communication of results within the scientific community.
7. Ethics of scientific research in materials science
Principles of scientific integrity in research on semiconductor thin films; researcher responsibility and intellectual property protection.

COURSE ASSESSMENT CRITERIA

The course is taught in semesters I and II. After semester I, the course ends with a ZO1 grade, and after semester II, it ends with an E2 examination. Classes are conducted in direct contact between the doctoral student and the supervisor.

Discussion of 3 selected questions from the 10 below/ in the first and second semesters, respectively.

SEMESTER I – final questions (research design methodology)

1. What is the specificity of scientific research in thin-film semiconductor physics compared to bulk material research?
2. What role does a research hypothesis play in planning research on HgCdTe/HgMnTe thin films and what conditions must it meet to be scientifically valid?
3. How does an analysis of the current state of knowledge allow for the identification of a research problem in thin semiconductor film research?
4. What are the basic criteria for selecting a research strategy in studies on the growth and properties of HgCdTe thin films?
5. Why are repeatability and reproducibility key elements of scientific research methodology in materials physics?
6. What is the significance of designing research with controlled variables in the thin film manufacturing process?
7. Discuss the role of multiple tests in the analysis of the quality of thin semiconductor layers.
8. What are the main sources of uncertainty in thin film research and how should they be taken into account at the research planning stage?
9. How can the results of structural thin film research be linked to their potential physical properties?
10. How should the methodological documentation for scientific research on HgCdTe/HgMnTe thin films be structured?

SEMESTER II – exam questions (methodology of conducting and interpreting research)

1. What are the basic principles of conducting reliable experimental research in the field of thin semiconductor layers?
2. What does the evaluation of the research process involve and when is it necessary to modify the original methodological assumptions?
3. How is the quality of thin semiconductor layers assessed in terms of their structure and homogeneity?
4. Explain the concept of structure-property relationships in relation to thin HgCdTe layers.
5. What criteria determine the confirmation or falsification of a research hypothesis in materials research?
6. What is the critical interpretation of the results of experimental research on thin semiconductor layers?
7. What is the significance of comparing the results of one's own research with data from the literature in the process of scientific reasoning?
8. How should the results of partial studies be synthesised into a coherent scientific picture?
9. What are the basic principles for presenting thin film research results in scientific reports and publications?
10. Discuss the importance of research ethics and researcher responsibility in the context of thin semiconductor film research.

The comprehensive examination takes place at the end of the second semester and is an oral examination consisting of an additional 4 questions from the above (not including the 6 questions that the doctoral student answered, i.e. 3 questions after each semester in the first semester and 3 questions after each semester in the second semester). The doctoral student draws 3 questions, and the supervisor chooses one.

TOTAL PhD STUDENT WORKLOAD REQUIRED TO ACHIEVE THE INTENDED LEARNING OUTCOMES – NUMBER OF HOURS AND ECTS CREDITS

Activity	Number of hours
Scheduled course contact hours	**2 x 30 hrs. – 60 hrs.**
Other contact hours involving the teacher (consultation hours, examinations)	**4**

Non-contact hours – student`s own work (preparation for classes or examinations, project, etc.)	**116 hrs.**
Total number of hours	**180 hrs.**
Total number of ECTS credits	**6**

INSTRUCTIONAL MATERIALS

Compulsory literature:	1. **Henini, M.** (Ed.). (2018). *Molecular Beam Epitaxy: From Research to Mass Production* (2nd ed.). Oxford: Elsevier.ISBN: 978-0-12-812136-8. *(Podstawowa monografia dotycząca metodologii i praktyki wzrostu cienkich warstw metodą MBE).* 2. **Yu, P. Y., & Cardona, M.** (2010). *Fundamentals of Semiconductors: Physics and Materials Properties* (4th ed.). Berlin–Heidelberg: Springer.ISBN: 978-3-642-00709-5. *(Fundamenty fizyki półprzewodników, niezbędne do interpretacji własności cienkich warstw).* 3. **Rogalski, A.** (2010). *Infrared Detectors* (2nd ed.).Boca Raton: CRC Press. ISBN: 978-1-4200-7671-4. *(Kluczowe źródło dotyczące materiałów HgCdTe i ich zastosowań).* 4. **Herman, M. A., & Sitter, H.** (1996). *Molecular Beam Epitaxy: Fundamentals and Current Status*. Berlin–Heidelberg: Springer. ISBN: 978-3-642-80062-7. *(Klasyczna pozycja opisująca metodologię badań i wytwarzania cienkich warstw epitaksjalnych).*
Complementary literature:	1. **Harrison, P., & Valavanis, A.** (2016). *Quantum Wells, Wires and Dots: Theoretical and Computational Physics of Semiconductor Nanostructures* (4th ed.). Chichester: Wiley. ISBN: 978-1-118-92336-8. *(Teoretyczne podstawy struktur o obniżonej wymiarowości).* 2. **Sze, S. M., & Ng, K. K.** (2007). *Physics of Semiconductor Devices* (3rd ed.). Hoboken, NJ: Wiley. ISBN: 978-0-471-14323-9. *(Kontekst urządzeniowy i aplikacyjny cienkich warstw półprzewodnikowych).* 3. **Adachi, S.** (2009). *Properties of Semiconductor Alloys: Group-IV, III–V and II–VI Semiconductors*. Chichester: Wiley. ISBN: 978-0-470-74114-6. *(Właściwości materiałowe stopów półprzewodnikowych, w tym II–VI).* 4. **Becker, C. R.** (2014). Growth and properties of HgTe quantum wells – A topic review. *Physica Status Solidi (b), 251*(6), 1125–1132. https://doi.org/10.1002/pssb.201350121 *(Przegląd właściwości cienkich warstw HgTe).* 5. **Qin, G., Kong, J. C., Yang, J., Ren, Y., Li, Y. H., et al.** (2023). HgCdTe Films Grown by MBE on CZT(211)B Substrates. *Journal of Electronic Materials, 52*, 2441–2448. https://doi.org/10.1007/s11664-022-10193-w *(Współczesny przykład badań eksperymentalnych nad cienkimi warstwami HgCdTe).*

*(1 ECTS CREDIT CORRESPONDS TO 25 - 30 HOURS OF THE TOTAL WORKLOAD OF A DOCTORAL STUDENT, NEEDED TO ACHIEVE THE ESTABLISHED EFFECTS).

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Date and signature of the Course lecturer

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Approved by the Head of the Department or an authorised person