Special provisions of the examination regulations for the Master's degree program in Materials Science at the Faculty of Natural Sciences at Paderborn University

dated 12.01.2024

Paderborn University has issued the following regulations on the basis of Section 2 (4) and Section 64 (1) of the North Rhine-Westphalia Higher Education Act (Hochschulgesetz - HG) of September 16, 2014 (GV.NRW. p. 547), last amended by Article 1 of the Act of July 12, 2019 (GV. NRW. p. 425, corrected p. 593):

Contents

§ 31
General and special provisions

These Special Provisions apply in conjunction with the General Provisions for the Examination Regulations for the Master's degree programs of the Faculty of Natural Sciences at Paderborn University as amended (General Provisions). For a proper structure of the study program, a study plan can be found in the appendix. Details on the modules can be found in the module descriptions in the appendix, which are part of these Special Provisions.

§ 32
Acquisition of skills and language regulations

(1) The course provides in-depth knowledge, skills and methods in materials science. The focus is particularly on the molecular understanding of matter and, based on this, students learn about the entire process chain from design using atomistic simulation through to macroscopic materials. A wide range of analysis and characterization techniques as well as synthesis methods are presented and applied by the students in two practical courses with a predominantly chemical or physical focus and in a lecture series.

Graduates are thus able to independently work on and critically evaluate issues in the field of materials science with a high level of scientific qualification. By setting a corresponding focus in the compulsory elective area, a profile can be formed in the areas of materials analysis and simulation, as well as sustainable materials and nanotechnology.

One of the strengths of this degree course is its highly interdisciplinary orientation thanks to the participation of the Faculties of Natural Sciences (Chemistry/Physics), Mechanical and Electrical Engineering, Computer Science and Mathematics. This enables an extensive range of courses and a wide range of compulsory elective modules. The content is thus taught from different perspectives, enabling students to communicate appropriately in interdisciplinary teams of scientists and engineers in their future careers. Basically, this is a science-based degree course that not only qualifies students for work in (research-based) industry, but also opens the door to an academic career with a subsequent doctorate.

Current topics such as sustainable materials, additive manufacturing methods or machine learning/artificial intelligence are also central components of this range of courses and can be explored in greater depth by choosing the appropriate course. The respective contents of the courses are described in detail in the module descriptions.

(2) The Master's degree program and Master's examination are held in English. All examinations are also conducted in this language.

§ 33
Academic degree

The academic degree "Master of Science" (M.Sc.) is awarded on successful completion of the Master's degree program.

§ 34
Start of studies

The course can only be started in the winter semester.

§ 35
Admission requirements

(1) In implementation of § 5 of the General Provisions, the degree program requires a degree that includes the competencies described below:
   a) Fundamentals of physics: Mastery of the fundamentals of mechanics, thermodynamics, electrodynamics, atomic physics, quantum mechanics and solid state physics, combined with the ability to create models and abstract mathematical formulations of physical facts.
   b) Practicals: Recognizing and extracting essential scientific correlations based on self-conducted experiments, logging and critical evaluation of the experimental results. Confident handling of basic chemical, physical or materials science experimental set-ups and measurement methods.
   c) Chemical fundamentals: mastery of the fundamentals of inorganic, organic and physical chemistry, material systematics, energetics, bonding theory, basic spectroscopic methods.
   d) Higher mathematics: Mastery of the basic mathematical concepts and methods required to understand and solve problems in the Master's degree program in Materials Science. This involves sound knowledge in the areas of linear algebra, analysis, Fourier series, differential equations, vector analysis.

(2) The Examination Board shall determine the prerequisites. If competencies or study components are missing, enrolment may be granted on condition that these are made up for through appropriate studies and proven by passing the associated examinations by the time of registration for the Master's thesis. The decision on this and on the type and scope of the studies and examinations is made by the Examination Board on the basis of the previous degree. The missing competencies or study components to be made up must not exceed 30 CP. The studies and examinations should be completed in the first semester of the Master's degree course.

(3) The Bachelor's degree must have been completed with an overall grade of at least 3.0 (or an equivalent foreign final grade).

(4) In addition to the requirements specified in § 5 of the General Provisions, the following additional admission requirements apply:

English language skills according to the Common European Framework of Reference for Languages with at least level B2.

English language skills can be proven in particular by Abitur certificates showing level B 2 or by Abitur certificates from NRW showing that English was completed as a continued foreign language at least at the end of qualification phase 1 of the upper secondary school with at least sufficient performance or 5 points (basic course or advanced course). Furthermore, English language proficiency can be proven, for example, by TOEFL (internet-based, 87 points), IELTS (5.5), Cambridge ESOL (FCE) or UNIcert II or an equivalent certificate. The certificate submitted must not be older than a maximum of two years from the start of the semester for which enrollment is requested. Proof of language proficiency is a prerequisite for enrollment.

(5) In the event that the applicant has definitively failed an examination required by the examination regulations in the previous degree program at a university within the scope of the Basic Law and the previous degree program has a significant content-related proximity to the Master's degree program

in Materials Science, enrollment will be denied under the conditions of § 5 paragraph 3 of the General Provisions.

§ 36
Structure, course content, modules

(1) The following modules must be completed in the Master's degree program in Materials Science:

Compulsory modules:

Module 1: General Concepts in Materials Science (10 LP)
Module 2: Atomistic Materials Modeling (6 LP)
Module 3: Nanomaterials (5 LP)
Module 4: Materials Analysis (5 LP)
Module 5: Laboratory Course on Materials Physics and Analysis (6 CP)
Module 6: Laboratory Course on Materials Chemistry and Analysis (5 LP)
Module 7: Sustainable Materials and Processes (6 CP)
Module 8: Project based Course (8 LP)
Module 9: Master Thesis (30 LP)

Compulsory elective modules:

[Compulsory elective area 1: Materials Analysis]
Module 10: Advanced Electron Microscopy (6 LP)
Module 11: Ion Beam Analysis of Materials (6 LP)
Module 12: Time resolved Spectroscopy (5 LP)
Module 13: Surface and Interface Analysis (5 LP)

[Compulsory elective area 2: Theoretical and Computational Materials Science]
Module 14: Atomistic Dynamics and Artificial Intelligence in Materials Science (6 CP)
Module 15: Computational Spectroscopy (6 LP)
Module 16: Simulation of Materials at the Meso- and Macroscale (6 CP)
Module 17: Spintronics (6 LP)

[Compulsory elective area 3: Advanced Materials and Biomaterials]
Module 18: Particles and Composites (5 LP)
Module 19: Additive Manufacturing (5 CP)
Module 20: Sustainable Electrochemistry (6 CP)
Module 21: Biomaterials (5 LP)

[Compulsory elective area 4: Nanomaterials and Nanotechnology]
Module 22: Functional Materials (6 LP)
Module 23: Photonic Nanostructures (6 CP)
Module 24: Micro Electromechanical Systems (6 LP)
Module 25: Semiconductor Epitaxy (6 LP)
Module 26: Semiconductor Technology (6 CP)
Module 27: Solid-State Materials Chemistry (6 CP)

(2) In the compulsory elective area, there are four thematic focuses, the content of which can be found in the overview above. At least one module must be chosen from three of these four areas. A total of three modules with 5 CP and four modules with 6 CP must be taken in the compulsory elective area. In addition, students are responsible for setting their own focus.

(3) If the majority of students select modules from the compulsory elective areas 1 and 2 or 3 and 4, a corresponding profile is shown on the Master's certificate with the additional designation "Materials Analysis and Simulation" or "Sustainable Materials and Nanotechnology".

§ 37
Participation requirements, admission

(1) Participation requirements for a module in accordance with Section 7 (2) of the General Provisions are governed by the module descriptions.

(2) Admission to the Master's thesis can only be granted to students who are enrolled in the Master's degree course in Materials Science at Paderborn University at the time of applying for admission or who have been admitted as a secondary student in accordance with § 52 HG and have acquired all CPs of the curriculum with the exception of up to 12 CPs that do not relate to internships. These requirements must also be met during the examinations.

(3) Further requirements for participation in examinations in accordance with Section 12 (2) of the General Provisions are set out in the module descriptions.

§ 38 Examiners

The group of examiners can be expanded within the scope of Section 65 HG.

§ 39
Achievements in the modules

(1) In the modules, work must be completed in accordance with the module descriptions.

(2) Examinations are held in the form of written examinations, oral examinations or in other forms in accordance with § 15 of the General Provisions. The following other forms are envisaged in particular:

1. Project report:

   Here, students should present and critically discuss the main results of their project studies in an appropriate manner. The external form and content of the report should be based on a publication in a specialist journal so that students become familiar with the publication of research data in international journals during their studies.

2. Seminar report:

   The students each prepare a report, including the critical evaluation and technically appropriate discussion of original data from practical experiments; structured in analogy to a scientific publication. The examination consists of the evaluation of the quality of these reports against the background of the knowledge acquired in the associated seminar.

3. Experiment as a whole: The experiment consists of several partial performances:
   - An ungraded test before the experiment, in which the preparation of the experiment in theory and practice, as well as the knowledge of the necessary safety regulations is checked the sensible execution of the experiment including the recording of measurement data

- a short, ungraded discussion after the experiment about the results and any problems encountered during implementation
- a graded report that briefly highlights the theoretical background and the execution of the experiment and should focus on the evaluation of the data and its critical discussion. A practical course consists of several individual experiments, all of which must be completed. The overall grade for the practical course is calculated from the average of all grades.

4. Lecture: Here, students are asked to prepare a current research topic for an interdisciplinary audience on the basis of (specified) publications and present it in a scientifically appropriate and exemplary manner.

Further details can be found in the module descriptions.

(3) The duration of a written examination is 60 to 180 minutes.

The duration of an oral examination is approx. 30 to 45 minutes.

The duration of a presentation is 15 to 45 minutes.

The scope of a project report is 30 to 50 pages.

A seminar report should be 2 to 3 pages long.

The scope of an internship report is 5 to 10 pages, whereby the focus should be on the evaluation and discussion of the results.

Further details can be found in the module descriptions.

(4) If the module descriptions contain framework specifications regarding the form, duration or scope of examinations, the Examination Board shall determine, in consultation with the examiner, how the examination is to be performed. This will be announced by the respective lecturer and in the Campus Management System of Paderborn University or in another suitable manner within the first three weeks of the lecture period at the latest.

(5) The following in particular may be considered as coursework:

- Lecture on an exemplary topic (max. 30 minutes)
- Protocol on practical experiments (approx. 4,000 words)

The module descriptions provide further details. If the module descriptions contain framework specifications, the respective lecturer will specify how the coursework is to be completed. This will be announced by the respective lecturer in the first three weeks of the lecture period at the latest and in the Campus Management System of Paderborn University or in another suitable manner.

(6) Attendance requirements are regulated in the module descriptions.

§ 40
Master's thesis

(1) The Master's thesis should be between 50 and 100 pages in length. The processing time for the Master's thesis is 20 weeks. If the duration is less than 16 weeks, this must be justified in writing by the supervisor.

(2) An oral defense in accordance with § 19 of the General Provisions is required. The oral defense lasts 30-45 minutes. In the oral defense of the Master's thesis, the candidate shall present and explain the thematic focus and results of the thesis (approx. 20 minutes). This is followed by a discussion. The Master's thesis and oral defense have a weighting of 4:1 when calculating the grade for the final module.

§ 41
Overall grade

The overall grade is calculated in accordance with § 21 of the General Provisions.

§ 42
Additional benefits

Students can complete additional work in accordance with § 20 of the General Provisions in modules of the degree program that do not have a participant limit.

§ 43
Repetition of examinations

A failed final module examination or partial module examination can be repeated three times.

§ Section 44
Transitional provisions

(1) These Special Provisions apply to all students who are enrolled for the first time in the Materials Science Master's degree program in the Faculty of Natural Sciences at Paderborn University from the winter semester 2024/2025.

(2) Students who were enrolled on the Master's degree course in Materials Science at Paderborn University before the winter semester 2024/2025 shall take their Master's examination, including repeat examinations, for the last time in the winter semester 2026/2027 in accordance with the examination regulations for the Master's degree course in Materials Science at the Faculty of Natural Sciences at Paderborn University in the version dated 16 June 2017 (AM.Uni.Pb. 45.17), last amended by the statutes dated 23 March 2018 (AM.Uni.Pb. 05.18). The Master's examination, including repeat examinations, is then taken in accordance with these special provisions. Upon application to the Examination Board, it is possible to change to these special provisions beforehand. The application is irrevocable.

§ Section 45
Entry into force, expiry and publication

(1) The Special Provisions enter into force on 01.10.2024. At the same time, the examination regulations for the Master's degree course in Materials Science at the Faculty of Natural Sciences at Paderborn University in the version dated March 23, 2018 (AM.Uni.Pb. 05.18) shall cease to apply. § Section 44 remains unaffected.

(2) The Special Provisions are published in the Official Notices of Paderborn University (AM.Uni.Pb.).

(3) In accordance with Section 12 (5) HG, a violation of procedural or formal provisions of the Higher Education Act or of the university's regulatory or other autonomous law can no longer be asserted against these regulations after one year has elapsed since the publication of these regulations, unless

   1. the order has not been duly published,

2. the Executive Committee has previously objected to the decision of the body adopting the regulations,
3. the formal or procedural defect has been notified to the university in advance, stating the violated legal provision and the fact giving rise to the defect, or
4. no reference was made to the legal consequences of the exclusion of complaints when the order was made public.

Appendix 1:
Study plan

Semester	Module	LP	Workload (h)
1.	General Concepts of Materials Science	10	300
	Atomistic Materials Modeling	6	180
	Nanomaterials	5	150
	Materials Analysis	5	150
	Variant A: one module from the compulsory elective area with 5 LP	5	150
	Option B: one module from the compulsory elective area with 6 CP	6	180
Total		**31 or 32**	**930 or 960**
2.	Laboratory course on Materials Physics and Analysis	6	180
	Variant A: three modules from the compulsory elective area with 6 CP and one module with 5 CP	23	690
	Option B: two modules from the compulsory elective area with 6 CP and two modules with 5 CP	22	660
Total		**29 and 28 respectively**	**870 or 840**
3.	Laboratory course on Materials Chemistry and Analysis	5	150
	Project based course	8	240
	Sustainable Materials and Processes	6	180
	Variant A and B: one module from the compulsory elective area with 5 CP and one module from the compulsory elective area with 6 CP	11	330
Total		**30**	**900**
4.	Master Thesis	30	900
Total		**30**	**900**

Appendix 2: Module descriptions

General Concepts in Materials Science							
General Concepts in Materials Science							
Module number: 1	**Workload (h):** 300	**LP:** 10	**Semester of study:** 1.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
Ia	Advanced Concepts in Materials Science and Engineering	V	45	75	P	approx. 120
Ib	Advanced Concepts in Materials Science and Engineering	Ü	15	30	P	up to 30
IIa	Quantum Mechanics in Materials Science	V	30	60	P	approx. 120
IIb	Quantum Mechanics in Materials Science	Ü	15	30	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none; basic knowledge of the structure and crystal structure of solid substances, basics of thermodynamics are recommended

4 Contents I:

- Real structure of solids and crystal defects
- Diffusion in solids
- Elastic and plastic deformation of solid materials
- Displacements and consolidation mechanisms
- Ageing and fatigue of materials
- Failure mechanisms and prediction
- Binary and ternary phase diagrams
- Phase transitions
- Properties of metallic, polymeric and ceramic materials
- Structure-property relationships of composites
- Fundamentals of tribology

Contents II:

- Atoms as the smallest chemical unit (law of multiple proportions)
- The Franck-Hertz experiment
- The photoelectric effect
- The structure of an atom

	• Energy distribution in the black body radiator • Effect as a mechanical variable • Effect of the harmonic oscillator • Planck's quantum of action • The Bohr atomic model • Wave-particle dualism • The Schrödinger equation • Operators • Eigenfunctions and eigenvalues • Physical interpretation of the wave amplitude • Three-dimensional waves • The particle in the box • Further examples from atomic and molecular physics • How atoms and molecules radiate • The Heisenberg uncertainty principle
5	**Learning outcomes / competences:** **I:** In the lecture, students acquire knowledge of essential and advanced concepts of materials science on the basis of basic physical and chemical concepts. The lecture enables beginners from natural science subjects to familiarize themselves with the fundamentals of materials science not covered there and deepens the scientific background for students with a degree in materials science. **II:** Taking into account the historical development of quantum mechanics from classical mechanics, students are familiarized with the fundamentals of quantum mechanics. The introduction focuses on the mathematical and physical fundamentals required for an introduction to quantum mechanics. Building on this, a few examples from molecular physics and the interaction of electromagnetic waves with atomistic particles are used to demonstrate initial applications of quantum mechanics. This enables students to carry out in-depth studies in quantum mechanics at any time. In the respective exercises, students apply the content learned in the lectures to simple problems and present their solutions, e.g. by presenting them on the blackboard. In this way, they practise linguistically and logically correct argumentation and the ability to present scientific facts appropriately.
6	**Examination performance:** [x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
Ia-IIb	Written exam or Oral examination	120-180 min. 30-45 min.	100 %

7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:**

	The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Mirko Schaper / N. N. (Lecturers of Physical Chemistry)
13	**Other notes:** none
14	**Recommended reading:** **I:** W. D. Callister, D. G. Rethwisch; Materials Science and Engineering, Wiley **II:** P. W. Atkins, Physical Chemistry, Wiley

Atomistic Materials Modeling							
Atomistic Materials Modeling							
Module number: 2	**Workload (h):** 180	**LP:** 6	**Semester of study:** 1.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Atomistic Materials Modeling	V	30	60	P	approx. 120
b	Atomistic Materials Modeling	Ü	30	60	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

- Elements of the quantum theory of molecules and solids
- Basics of electronic structural calculations
- Density functional theory
- Basic rates and pseudopotentials
- Calculation of structural and vibrational properties and thermodynamic quantities of molecules and solids

5 Learning outcomes / competencies:

Ability to independently simulate atomic-scale materials using standard methods of theoretical materials physics:

The students

- understand the basic methods of atomistic material simulation and their areas of application and limitations, they know the relevant nomenclature,
- are able to identify suitable methods for the structural elucidation of molecules, solids and nanostructures,
- are proficient in common program packages for atomistic structure elucidation such as Gaussian and Quantum Espresso, including the determination of useful numerical parameters and basis sets,
- have the ability to discuss and evaluate the calculated results in comparison with data from the original literature.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Written exam or Oral examination	120-180 min. 30-45 min.	100 %

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

	none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Physics
12	**Module coordinator:** Prof. Dr. Wolf Gero Schmidt / Prof. Dr. Arno Schindlmayr
13	**Other notes:** none
14	**Recommended reading:** K. Ohno, K. Esfarjani, Y. Kawazoe: *Computational Materials Science: From Ab Initio to Monte Carlo Methods*, 2nd edition, Springer, Berlin/Heidelberg, 2018, DOI:10.1007/978-3-662-56542-1 J. G. Lee: *Computational Materials Science: An Introduction*, 2nd edition, CRC Press, Boca Raton, 2016, DOI:10.1201/9781315368429

Nanomaterials

Nanomaterials

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
3	150	5	1.	WS	1	en	P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Physics and Technology of Nanomaterials	V	30	60	P	approx. 120
b	Physics and Technology of Nanomaterials	Ü	30	30	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none; basic knowledge of the structure and crystal structure of solid substances, basics of thermodynamics, basics of quantum mechanics are recommended

4 Contents:

- Thermodynamic and crystallographic fundamentals of nanomaterials
- Production of thin films from the liquid phase and vacuum, vacuum physics
- Structuring and modification of thin films using thermal, wet-chemical, ion beam and plasma-based processes
- Lateral structuring of thin layers and surfaces using conventional and advanced lithography processes
- Production, processing and application of 1-, 2- and 3-dimensional nano-objects (nanowires and nanotubes, graphene and van der Waals materials, nanoclusters, core-shell structures)

5 Learning outcomes / competences:

Learning outcomes

Knowledge of basic methods for the production of modern nanomaterials, their atomistic structure and the resulting physicochemical properties and applications. Understanding and mathematical formulation of the physical facts and models.

Competencies:

Analyze questions on the topic of nanomaterials, identify problems, establish a connection to the lecture, create technological concepts, formulate problems mathematically, discuss results and classify them in a material-physical context.

Ability to think conceptually, analytically and logically and the ability to apply the acquired knowledge in different areas of materials physics and to transfer it to new classes of materials.

Presentation skills by presenting solutions to problems as part of the exercise. Teamwork skills by working on problems in small groups.

6	**Examination performance:** [x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP) <table><tr><th>to</th><th>Form of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a) and b)</td><td>Written exam or Oral examination</td><td>120 - 180 min. 30-45 min.</td><td>100 %</td></tr></table>
7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Physics
12	**Module coordinator:** Prof. Dr. Jörg Lindner / Prof. Dr. Dirk Reuter
13	**Other notes:** none
14	**Recommended reading:** B. Bhushan (ed.): Springer Handbook of Nanotechnology Materials Research Society Bulletin, Selected Issues; Cambridge University Press

Materials Analysis							
Materials Analysis							
Module number: 4	**Workload (h):** 150	**LP:** 5	**Semester of study:** 1.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Advanced Analytical Techniques	V	30	60	P	approx. 120
b	Advanced Analytical Techniques	Ü	15	45	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

The lecture is held as a lecture series. Contents are microscopic, spectroscopic, electrochemical methods for the characterization of materials. Examples include scanning electron microscopy, X-ray diffraction, X-ray absorption, Rutherford backscattering spectroscopy, nuclear magnetic resonance spectroscopy, mass spectroscopy, light scattering, neutron techniques, calorimetric measurement methods, infrared and Raman spectroscopy, ellipsometry, electron spectroscopy.

5 Learning outcomes / competences:

Students acquire a sound basic knowledge and an overview of modern methods for the characterization of solids, solid surfaces and material interfaces. The students know the potentials and limits of the applicability of the methods.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Written exam or Oral examination	120 min. 30-45 min.	100%

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

none

9 Requirements for the awarding of credit points:

Credit points are awarded if the final module examination is passed.

10 Weighting for overall grade:

	The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Guido Grundmeier / Prof. Dr. Jörg Lindner
13	**Other notes:** none
14	**Recommended reading:** The lecturers provide the students with the relevant literature or literature references for the respective topic in good time before the lecture.

Laboratory Course on Materials Physics and Analysis

Laboratory Course on Materials Physics and Analysis

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
5	180	6	2.	SS	1	en	P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
I	Materials Physics and Analysis	P	45	105	P	up to 7
II	Scientific Practice and Data Management	S	15	15	P	up to 30

2 Elective options within the module:

I: The students select three experiments from a list of experiments that is currently presented on the Internet. The experiments originate from the scientific fields of work of the working groups involved in the degree program.

3 Participation requirements:

none

4 Contents:

I: Basic analytical methods of materials science are taught and applied to current issues. Examples of this are

- Texture analysis and stress-strain measurement in the scanning electron microscope
- X-ray diffraction on powders and thin films
- Surface wetting and interfacial energies
- Computer-aided determination of electron densities
- Ellipsometry on thin layers

II: Philosophy of science and scientific method (hypothesis, falsification, laws of nature, empiricism); statistics of research data (repeatability, reproducibility, significance, precision and accuracy); handling of research data (data storage, Big Data, regulations, archiving); professional ethics in materials science (citation, authorship, copyright, open science and data, scientific misconduct, confidentiality and neutrality); handling of literature; critical evaluation of scientific texts (definition of objective rules for critical evaluation of scientific writing, practical examples, etc.)

5 Learning outcomes / competences:

I: Knowledge of the fundamentals and application of selected methods for the characterization of advanced functional and structural materials. Application of modern data acquisition methods and computer techniques.

Students learn and deepen their ability to plan structured experiments to characterize a material with regard to macroscopic properties and to systematically implement them in a real laboratory environment, evaluate and document the results. By critically handling their own measurement data and comparing it with known and published measurement results, students acquire the competence to classify the measurement results of others in terms of their reliability and significance. By recording the results, students acquire written presentation skills in preparation for writing scientific papers later on. Students also improve their teamwork skills by working on problems in small groups.

II: Using concrete data and examples from the research areas covered in the Materials Science Master, students learn how to work with scientific data and how to properly collect and communicate scientific results according to the

<table>
<tr><td></td><td>guidelines for good scientific behavior. The skills learned here should lead to the development of critical thinking and a deep understanding, which implies the application of the scientific method.</td></tr>
<tr><td>6</td><td>Examination performance:
[ ] Final module examination (MAP) [ ] Module examination (MP) [x] Module part examinations (MTP)
<table>
<tr><th>to</th><th>Form of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>I</td><td>Entirety of the tests</td><td>3</td><td>83%</td></tr>
<tr><td>II</td><td>Written exam or
Seminar report</td><td>approx. 90 min.
2-3 pages</td><td>17%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Academic achievement / qualified participation:
none</td></tr>
<tr><td>8</td><td>Requirements for participation in examinations:
I: Attendance on the test days is mandatory.</td></tr>
<tr><td>9</td><td>Requirements for the awarding of credit points:
Credit points are awarded if the final module examination is passed.</td></tr>
<tr><td>10</td><td>Weighting for overall grade:
The module is weighted with the number of credit points (factor: 1).</td></tr>
<tr><td>11</td><td>Use of the module in other degree programs:
none</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr. Jörg Lindner / Prof. Dr. Guido Grundmeier / PD Dr. Teresa de los Arcos</td></tr>
<tr><td>13</td><td>Other notes:
none</td></tr>
<tr><td>14</td><td>Recommended reading:
Re I)
The exact literature for each course will be announced directly by the respective tutors. Examples of literature on relevant topics are as follows:
XRD:
Harrington, Santiso - Back-to-Basics tutorial - X-ray diffraction of thin films- Journal of Electroceramics 47, 141-163 (2021)
Ellipsometry:
HG Tompkins and WA McGahan. Spectroscopic eliipsometry and reflectometry. John Wiley and Sons (1999)
Supercapacitors:
Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications, B.E. Conway, 1999. ISBN: 978-1-4757-3058-6.
Advances in Supercapacitor and Supercapattery: Innovations in Energy Storage Devices, M. Khalid, ISBN: 9780128198971
Re II)
Wiltsche, "Introduction to the Philosophy of Science", UTB Verlag, 2021;</td></tr>
</table>

	DFG Code "Guidelines for Safeguarding Good Scientific Practice"; Kovac, "The ethical chemist: Professionalism and ethics in science", Oxford University Press, 2018; Hepburn & Andersen, "Scientific method", 2015; Meier & Zünd, "Statistical methods in analytical chemistry". John Wiley & Sons, 2005.

Laboratory Course on Materials Chemistry and Analysis							
Laboratory Course on Materials Chemistry and Analysis							
Module number: 6	**Workload (h):** 150	**LP:** 5	**Semester of study:** 3.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
	Materials Chemistry and Analysis	P	45	105	P	up to 7

2 Elective options within the module:

The students select three experiments from a list of experiments that is currently displayed on the Internet. The experiments originate from the scientific fields of work of the working groups involved in the degree program.

3 Participation requirements:

none

4 Contents:

Basic methods of preparative materials chemistry and materials chemistry analysis are taught and applied to current issues. Examples of this are

- Spectroscopy of material surfaces and interfaces
- Atomic force microscopy-based methods
- Molecular adsorption on surfaces of porous solids
- Synthesis of nanoparticles
- Sol-gel process
- Synthesis and analysis of polymer hybrid materials
- Additive manufacturing of polymer materials
- Solid state NMR

5 Learning outcomes / competences:

Knowledge of the fundamentals and application of selected methods for the characterization of advanced functional and structural materials. Application of modern data acquisition methods and computer techniques.

Students learn and deepen their ability to plan structured experiments for the synthesis and characterization of a material with a focus on materials chemistry and to systematically implement them in a real laboratory environment, evaluate and document the results. By critically dealing with their own measurement data and comparing it with known and published measurement results, students acquire the competence to classify the measurement results of others with regard to their reliability and significance. By recording the results, students acquire written presentation skills in preparation for writing scientific papers later on. Students also improve their teamwork skills by working on problems in small groups.

6 Examination performance:

[ ] Final module examination (MAP) [x] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
	Entirety of the tests	3	100%

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

Attendance on the test days is mandatory.

9 Requirements for the awarding of credit points:

Credit points are awarded if the final module examination is passed.

10 Weighting for overall grade:

The module is weighted with the number of credit points (factor: 1).

11 Use of the module in other degree programs:

none

12 Module coordinator:

Prof. Dr. Guido Grundmeier / Prof. Dr. Jörg Lindner / PD Dr. Teresa de los Arcos

13 Other notes:

none

14 Recommended reading:

The exact literature for each experiment will be announced directly by the respective tutors. Exemplary literature on relevant topics is the following:

AFM:

Greg Haugstad. "Atomic Force Microscopy: Understanding Basic Modes and Advanced Applications". 2012 John Wiley & Sons, Inc

FTIR:

W. Suetaka. "Surface Infrared and Raman Spectroscopy". 2014 Springer

Basics of NMR:

James Keeler, Understanding NMR Spectroscopy, Wiley 2004.

Application of solid-state NMR:

T. Polenova et al, Magic Angle Spinning NMR Spectroscopy: A Versatile Technique for Structural and Dynamic Analysis of Solid-Phase Systems, Anal. Chem. 2015, 87, 5458.

Polymers & nanoparticles:

J. P. Rao, K. E. Geckeler, Progr. Polym. Sci. 2011, 36, 887-913

C. S. Chern, Progr. Polym. Sci. 2006, 31, 443-486

S. C. Thickett, R. G. Gilbert, Polymer 2007, 48, 6965-6991

D. Kuckling, A. Doering, F. Krahl, and K.-F. Arndt: Stimuli-Responsive Polymer Systems. In: K. Matyjaszewski and M. Möller (eds.) Polymer Science: A Comprehensive Reference 2012, 8, 377-413. Amsterdam: Elsevier BV.

Q.-S. Zhang, L.-S. Zha, J.-H. Ma, B.-R. Liang, J. Appl. Polym. Sci. 2007, 103, 2962-2967

Batteries:

	Beard, Kirby W. Linden's handbook of batteries. McGraw-Hill Education, 2019. Winter, Martin, and Ralph J. Brodd. "What are batteries, fuel cells, and supercapacitors?". Chemical reviews 104.10 (2004): 4245-4270. **Other:** Lazarides et al Making Hydrogen from Water Using a Homogeneous System Without Noble Metals. J. AM. CHEM. SOC. 2009, 131, 9192-9194 10.1021/ja903044n

Sustainable Materials and Processes

Sustainable Materials and Processes

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
7	180	6	3.	WS	1	en	P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
I	Synthesis of Sustainable Materials and Green Processes	V	30	45	P	approx. 120
IIa	Applied Electrochemistry	V	30	45	P	approx. 120
IIb	Applied Electrochemistry	Ü	15	15	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

II: Basic knowledge of electrochemical thermodynamics and kinetics is recommended

4 Contents:

I: Lecture series: Concepts and examples of sustainable synthesis routes for materials and coatings: Alloy production, polymer synthesis, composites, sol-gel chemistry, thin film deposition (e.g. electrodeposition, CVD, PVD and PECVD processes), vacuum process technology, renewable resources, basic concepts of "Green Chemistry" and "Life Cycle Assessment", sustainable processing of materials.

II: Electron transfer processes, semiconductor electrochemistry, advanced electrochemical analytics, fundamentals of electrocatalysis and electrochemical synthesis, electrochemical surface technologies and nanotechnologies, aqueous corrosion, electrochemical water purification and recovery of metals.

5 Learning outcomes / competences:

I: Students have broad knowledge in the field of synthesis and processing of sustainable materials. They have an advanced understanding of the assessment of sustainability concepts in materials development.

II: Students have in-depth knowledge in the field of complex electrochemical processes at solid-state interfaces. They have an advanced understanding of integral and local electrochemical analysis at interfaces as well as the application of sustainable electrochemical processes in material synthesis, nanotechnology, surface technology and material recovery.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
Ia to IIb	Written exam or oral examination	120 min. 30-45 min.	100%

7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination or the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Guido Grundmeier / Junior Prof. Dr. Hans-Georg Steinrück
13	**Other notes:** none
14	**Recommended reading:** **I:** Current review articles on the changing topics are provided by the lecturers before the respective lecture. **II:** C. H. Hamann, W. Vielstich: *Elektrochemie, Wiley-VCH*; W. Schmickler, E. Santos: *Interfacial Electrochemistry*, Springer K. Oldham, J. Myland, A. Bond: *Electrochemical Science and Technology: Fundamentals and Applications*, Wiley.

Project based course							
Project based course							
Module number: 8	**Workload (h):** 240	**LP:** 8	**Semester of study:** 3.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
I	Current Topics of Materials Science	S	30	60	P	approx. 120
II	Project based course	P	75	75	P	up to 8

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

Collaboration on current research projects in the participating subject areas. The participating professors are responsible for both the topic and the supervision. Students should practise scientific work by independently familiarizing themselves with the topic of a narrowly defined question through literature research and familiarizing themselves with the necessary experimental methods largely independently.

5 Learning outcomes / competences:

I: Students present a current research topic in an oral presentation. This should include the current state of research and a possible approach to solving the problem. In doing so, they acquire the competence to interest an interdisciplinary audience in an issue.

II: Students work on a small project task using scientific methods. They acquire the ability to work in an interdisciplinary manner by participating in an interdisciplinary project.

By preparing a report, students acquire the ability to critically analyze measurement data and test results and to present scientific facts in writing. By working in small groups, they learn to work in a team.

6 Examination performance:

[ ] Final module examination (MAP) [ ] Module examination (MP) [x] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
I	Lecture	30-45 min	37,5 %
II	Project report	Maximum length 50 pages	62,5 %

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

	none
9	**Requirements for the awarding of credit points:** Credit points are awarded when the module examinations have been passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Guido Grundmeier / Prof. Dr. Jörg Lindner
13	**Other notes:** none
14	**Recommended reading:** Individual recommendations according to the chosen subject area (mainly articles from peer reviewed journals).

Master Thesis							
Master Thesis							
Module number: 9	**Workload (h):** 900	**LP:** 30	**Semester of study:** 4.	**Rotation:** SS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** P

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
I	Master thesis	P	300	420	P	1
II	Oral defense	S	30	150	P	1

2 Elective options within the module:

none

3 Participation requirements:

Completion of all modules with the exception of up to 12 missing credit points, insofar as these do not relate to internships.

4 Contents:

As a rule, the topic can be freely selected from the projects offered by the participating subject areas.

5 Learning outcomes / competences:

By completing the Master's thesis, students demonstrate that they are able to work scientifically on a limited problem from a field of chemistry under supervision and summarize this in writing. They expand their methodological skills through practical work and independent literature research. They expand their foreign language skills by working with English-language specialist literature. By working on their own project, they develop independence, planning skills and creativity. Their ability to work in a team is promoted through integration into a working group.

6 Examination performance:

[ ] Final module examination (MAP) [ ] Module examination (MP) [x] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
I	Master thesis	50-100 pages	80%
II	Oral defense	30-45 min.	20%

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

none

9 Requirements for the awarding of credit points:

Credit points are awarded when the Master's thesis and the oral defense have been passed.

10 Weighting for overall grade:

	The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Guido Grundmeier / Prof. Dr. Jörg Lindner
13	**Other notes:** none
14	**Recommended reading:** Individual recommendations according to the chosen subject area.

Advanced Electron Microscopy							
Advanced Electron Microscopy							
Module number: 10	**Workload (h):** 180	**LP:** 6	**Semester of study:** 1. o. 3.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1	**Module structure:**

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Microscopy and spectroscopy with electrons	V	30	60	P	approx. 120
b	Microscopy and spectroscopy with electrons	Ü	30	60	P	up to 30

2	**Elective options within the module:** none
3	**Participation requirements:** none; good knowledge of the real structure of crystalline solids and quantum mechanics is recommended

4 Contents:

The lecture covers the basics of transmission electron microscopy in its entirety and explains its application for the characterization of materials on the nanometer and subnanometer scale.

- Electron-optical components and beam paths in (scanning) transmission electron microscopes (S)TEM
- Electron microscopic preparation methods
- Imaging methods and contrast types
- Electron diffraction
- Electron-solid-state interaction
- Kinematic and dynamic theory of electron diffraction
- Conventional electron microscopy and lattice defects
- Contrast transmission and high resolution
- Energy dispersive X-ray spectroscopy EDX
- Electron energy loss spectroscopy EELS in TEM and STEM
- Spectroscopy of inter- and intraband transitions and plasmons
- Energy-filtered transmission electron microscopy EFTEM

5 Learning outcomes / competences:

a: Mastery of the basic concepts of conventional, high-resolution and analytical transmission electron microscopy, from the fundamentals of electron-solid interaction and electron diffraction to the resulting contrast mechanisms and their application to characterize the real structure, chemical composition and electronic excitations of solids.

b: Consolidation of the lecture material using selected, relevant topics as well as practical exercises and classification in an overall physical context.

Specific key competencies:

- Ability to think conceptually, analytically and logically and the ability to apply the acquired knowledge in different areas of materials science

	• Presentation skills by presenting solutions to problems as part of the exercise • Ability to work in a team by working on problems in small groups
6	**Examination performance:** [x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)
7	**Academic achievement / qualified participation:** none
8	**Prerequisites for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Physics
12	**Module coordinator:** Prof. Dr. Jörg Lindner
13	**Other notes:** none
14	**Recommended reading:** D. B. Williams, C. B. Carter, *Transmission Electron Microscopy*, A Textbook for Materials Science. Springer Publisher

Examination table for item 6:

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Written exam or Oral examination	90 min. or 30-45 min.	100%

Ion Beam Analysis of Materials

Ion Beam Analysis of Materials

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
11	180	6	1. or 3.	WS	1	en	WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Ion Beam Analysis of Materials	V	15	30	P	approx. 120
b	Ion Beam Analysis of Materials	P	30	60	P	up to 8
c	Ion Beam Analysis of Materials	S	15	30	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

a: The lecture explains the basics of ion-solid-state interaction and its application for material analysis and modification, in particular:

- Ion sources, ion optics, accelerator principles
- Interaction of ionizing radiation with biological organisms and radiation protection
- Solid-state thin-film analysis using Rutherford backscattering spectroscopy (RBS)
- Trace element analysis using nuclear reaction analysis (NRA)
- Element detection using particle-induced X-rays (PIXE)
- Ion-solid-state interaction, ion ranges, defect formation
- Doping of semiconductors by means of ion implantation
- Application of particle accelerators in astrophysics, geophysics, nuclear physics and medical physics
- Nanostructuring with ion beams

b: Production and analysis of samples using the particle accelerators available at RUBION as part of projects related to the lecture material.

c: Presentation of the experimental results and their theoretical background

5 Learning outcomes / competences:

The block course, organized in cooperation with the Ruhr University Bochum at the RUBION accelerator laboratory, introduces the basics of nuclear solid state physics and applications of accelerator physics.

a: Mastery of the basic concepts of the specialty.

b: Introduction to independent action, experimentation, as well as recognizing and extracting essential correlations from their own experimental experiences. Students learn about beam time operation at a large-scale research facility.

c: The students gain experience in web-based collaboration in inter-university teams by each team preparing and presenting a written evaluation and documentation as well as a final presentation on a sub-project.

6	**Examination performance:** [ ] Final module examination (MAP) [ ] Module examination (MP) [x] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
b)	Project report	approx. 30 pages	50%
c)	Lecture	approx. 30 min.	50%

7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded when the module examinations have been passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Physics
12	**Module coordinator:** Prof. Dr. Jörg Lindner
13	**Other notes:** none
14	**Recommended reading:** M. Nastasi, J. W. Mayer, Y. Wang *Ion Beam Analysis: Fundamentals and Applications*, CRC Press

Time resolved Spectroscopy

Time resolved Spectroscopy

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
12	150	5	1. or 3.	WS	1	en	WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
I	Time resolved Spectroscopy	V	30	60	P	approx. 120
II	Applications on Synchrotron Techniques in Time resolved Spectroscopy	S	30	30	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none; basic knowledge of quantum mechanics and spectroscopy is recommended

4 Contents:

I: Theoretical principles of various spectroscopic methods that allow high time resolution in the investigation of materials and processes at interfaces. Selected applications in the field of materials chemistry and process technology.

II: Various X-ray scattering methods and X-ray spectroscopy methods. One- to two-day excursion to the PETRA III synchrotron in Hamburg.

5 Learning outcomes / competences:

I: Students have knowledge of the theoretical principles and applications of methods for investigating dynamic processes in materials or chemical compounds and at material interfaces on the basis of spectroscopic methods.

II: Students have knowledge of how a synchrotron and synchrotron X-ray methods work. They can apply them to questions in materials science and assess which problems are suitable for certain measurement methods.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
I) and II)	Written exam or oral examination	120 min. or 30-45 min.	100%

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

	none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** N. N. (Lecturers of Physical Chemistry), Jun.-Prof. Dr. Hans-Georg Steinrück
13	**Other notes:** none
14	**Recommended reading:** **I:** T. Weinacht, Brett J. Pearson, Time-Resolved Spectroscopy: An Experimental Perspective, CRC press 2019 Current review articles on this topic will be provided by the lecturers before the respective lecture. **II:** D. McMorrow, J. Als-Nielsen, *Elements of modern X-ray physics*. John Wiley & Sons 2011 P. Willmott, *An introduction to synchrotron radiation: techniques and applications*. John Wiley & Sons 2019 W. H. De Jeu, *Basic X-ray scattering for soft matter,* Oxford University Press 2016 B. K. Agarwal, *X-ray spectroscopy: an introduction*, Vol. 15. Springer 2013 G. Bunker, Introduction to XAFS: A practical guide to X-ray absorption fine structure spectroscopy, Cambridge University Press 2010 F. de Groot, A. Kotani, Core level spectroscopy of solids, CRC Press, Taylor & Francis Group 2008

Surface and Interface Analysis							
Surface and Interface Analysis							
Module number: 13	**Workload (h):** 150	**LP:** 5	**Semester of study:** 2.	**Rotation:** SS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Surface and Interface Spectroscopic Analysis	V	30	60	P	approx. 120
b	Surface and Interface Spectroscopic Analysis	Ü	15	45	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

Contents:

Optical spectroscopy of material interfaces and thin films (application of FTIR and Raman spectroscopy and ellipsometry), electron and ion spectroscopy of interfaces and thin films (application of Auger spectroscopy, X-ray and UV photoelectron spectroscopy, ion scattering); advanced application of spectroscopic methods (combined analysis methods, surface-sensitive X-ray scattering and X-ray spectroscopy methods, atomic force and scanning tunneling microscopy, in-situ spectroscopy at interfaces, spectroscopic microscopy, spectroelectrochemistry)

5 Learning outcomes / competences:

Students acquire knowledge of the most commonly used spectroscopic methods for the characterization of surfaces and interfaces in materials research.

In detail, these are

- Selection of the appropriate method for characterizing different materials
- Critical evaluation of the measurement results
- Development of measurement strategies according to the requirements of the materials to be examined
- Application of such spectroscopic methods for the in-situ analysis of interfacial processes

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Written exam or Oral examination	120 min. 30 min.	100 %

7 Academic achievement / qualified participation:

none

8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Junior Professor Dr. Hans-Georg Steinrück / Dr. Teresa de los Arcos
13	**Other notes:** none
14	**Recommended reading:** J. M. Hollas, Modern Spectroscopy, John Wiley & Sons 2004. G. Ertl and J. Küppers, Low Energy Electrons and Surface Chemistry, VCH 1985 D. Briggs and M. P. Seah, Practical Surface Analysis I and II, John Wiley & Sons 1990 W. Suetaka, Surface Infrared and Raman spectroscopy -methods and applications, Plenum Press 1995 J. Als Nielsen and D. McMorrow, Elements of modern X ray physics, John Wiley & Sons, New York, USA 2011 B. D. Cullity, S. R. Stock, Elements of X ray Diffraction, Pearson, Harlow 2014 D. S. Sivia, Elementary scattering theory: For X ray and neutron users, Oxford University Press, New York, USA 2011 Keith, Foster, Spectroelectrochemistry, in Handbook of Electrochemical Energy Fauster, Thomas, et al. "Surface Physics." Surface Physics, De Gruyter Oldenbourg 2019

Atomistic Dynamics and Artificial Intelligence in Materials Science							
Atomistic Dynamics of Materials & Artificial Intelligence in Materials Science							
Module number: 14	**Workload (h):** 180	**LP:** 6	**Semester of study:** 1. or 3.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
Ia	Atomistic Dynamics of Materials	V	30	60	P	approx. 120
Ib	Atomistic Dynamics of Materials	Ü	15	30	P	up to 30
II	Artificial Intelligence in Materials Science	V	15	30	P	approx. 120

2 Elective options within the module:

none

3 Participation requirements:

none; basic knowledge of quantum mechanics is recommended

4 Contents:

I:

- Some basic concepts of classical mechanics: Equations of motion; Hamilton function for many-particle systems.
- Basic concepts of statistical mechanics: Statistics in phase space; distribution functions; Liouville's theorem; Gibbs' virtual totals; measurement, time and ensemble averages; thermodynamic quantities from the sum of states; thermodynamic quantities from the radial distribution function; transport quantities from correlation functions.
- Intra- and intermolecular interaction potentials: classical intermolecular interaction; ab initio potentials; the potential of external fields.
- Molecular Dynamics (MD): Aims, tasks, methods.
- Classic Monte Carlo simulations

II:

- Supervised, unsupervised and reinforcement machine learning
- Classification and regression
- Neural networks

5 Learning outcomes / competencies:

I: The aim of this course is to illustrate how macroscopic properties of a material can be calculated from the properties of atoms and molecules and their structure.

Students learn the basics of computer simulation, in particular molecular dynamics and Monte Carlo methods. This enables the treatment of many-body systems by calculating statistical variables such as state sums, pair distribution and correlation functions.

II: Students are introduced to modern methods of machine learning and neural networks and their application within materials science.

6	**Examination performance:** [ ] Final module examination (MAP) [ ] Module examination (MP) [x] Module part examinations (MTP) <table><tr><th>to</th><th>Form of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>Ia and Ib</td><td>Written exam or oral examination</td><td>90-120 min. or 30-45 min.</td><td>66,5%</td></tr><tr><td>II</td><td>Written exam or oral examination</td><td>60-90 min. or 30-45 min.</td><td>33,5%</td></tr></table>
7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded when the module examinations have been passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Dr. Hossam Elgabarty
13	**Other notes:** none
14	**Recommended reading:** M. Tuckerman, Statistical Mechanics: Theory and Molecular Simulation, Oxford University Press. M. P. Allen, D. J. Tildesley, Computer Simulation of Liquids, Oxford University Press. D. Marx and J. Hutter, Ab Initio Molecular Dynamics, Cambridge University Press.

Computational Spectroscopy							
Computational Spectroscopy							
Module number: 15	**Workload (h):** 180	**LP:** 6	**Semester of study:** 2.	**Rotation:** SS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Computational Spectroscopy	V	30	60	P	approx. 120
b	Computational Spectroscopy	Ü	30	60	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

- General principles for calculating the response of microscopic systems to external perturbations: time-independent 2nd order perturbation theory ("*double perturbation theory*"), time-dependent perturbation theory, Fermi's golden rule, linear response function, principle of the adiabatic geometric phase, Berry phases
- Formulation and calculation in the context of density functional theory: time-dependent density functional theory, *constrained* density functional theory, wave function-based methods
- Linear and non-linear optical spectroscopy, core-level spectroscopy, X-ray absorption, magnetic resonance, infrared and Raman spectroscopy
- Concrete application to example systems, both finite structures (molecules) and periodic systems in 3D (solids) and 2D (surfaces, layered and heterostructures)

5 Learning outcomes / competencies:

Students should be able to understand the basic concepts of computer-aided calculation (simulation) of spectroscopic material properties and be able to use their methods for numerical prediction and compare them with experimental measurement results.

The students

- can identify and analyze material science issues related to spectroscopy,
- are aware that modern spectroscopic experiments can often only be fully evaluated with the aid of theoretical comparative values,
- know the basic quantum mechanical strategies and technical concepts that are necessary for the atomistic description of materials and the prediction of their spectroscopic properties in the computer,
- can select an adequate level of approximation for given atomistic structures (taking into account computational effort and accuracy) and apply this to selected problems,
- are able to discuss the theoretical results obtained in the context of experimental data and establish links to current research questions in materials science.

6	**Examination performance:** [x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP) <table><tr><th>to</th><th>Form of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a) and b)</td><td>Written exam or Oral examination</td><td>120-180 min. 30-45 min.</td><td>100%</td></tr></table>
7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Physics
12	**Module coordinator:** Dr. Uwe Gerstmann / Prof. Dr. Arno Schindlmayr
13	**Other notes:** none
14	**Recommended reading:** J. Grunenberg, *Computational Spectroscopy: Methods, Experiments and Applications,* Wiley-VCH P. Jensen, P. R. Bunker: *Computational Molecular Spectroscopy,* Wiley-VCH S. Wilson, G. H. F. Diercksen, *Methods in Computational Molecular Physics,* Springer M. Kaupp, M. Bühl, V. G. Malkin, *Calculation of NMR and EPR parameters,* Wiley-VCH L. Valkunas, D. Abramavicius, Thomás Mancal, *Molecular Excitation Dynamics and Relaxation, Quantum Theory and Spectroscopy,* Wiley-VCH

Simulation of Materials at the Meso- and Macroscale

Finite element modeling

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
16	180	6	2.	SS	1	en	WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	FEM in Materials Science	V	30	90	P	approx. 120
b	FEM in Materials Science	Ü	15	45	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

- Model equations of elastoplasticity, viscoelasticity and viscoplasticity
- One- and multi-dimensional formulation of the constitutive equations
- Applications of FEM in pre- and post-processing with Abaqus CAE
- Implementation in MATLAB: One-dimensional elastoplasticity with linear and non-linear isotropic hardening

5 Learning outcomes / competences:

Students can explain calculation methods of numerical mechanics and can work on various mechanical engineering tasks using the finite element method (FEM). They are also able to name the most important material models for evaluating components with small deformations and apply them in a targeted manner.

Students will be able to explain the relevant relationships for specific calculation examples in materials mechanics. They are also able to deal with forming processes and material behavior using computer-aided simulation. Students will also be able to independently implement numerical methods for one-dimensional problems in materials mechanics.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Written exam or Oral examination	90-120 min. 20-30 min.	100 %

7 Academic achievement / qualified participation:

none

8 Prerequisites for participation in examinations:

none

9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Mechanical Engineering, M.Sc. Industrial Engineering (Mechanical Engineering)
12	**Module coordinator:** Prof. Dr. Rolf Mahnken
13	**Other notes:** none
14	**Recommended reading:** J. C. Simo, T. J. R. Hughes, *Computational Inelasticity*, Springer New York 1998 N. Ottosen, M. Ristinmaa, *The Mechanics of Constitutive Modeling*, Elsevier 2005

Spintronics							
Spintronics							
Module number: 17	**Workload (h):** 180	**LP:** 6	**Semester of study:** 2.	**Rotation:** SS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Spintronics	V	30	60	P	approx. 120
b	Spintronics	Ü	30	60	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

- General principles of the quantum mechanical description of spin: Dirac equation, spin Pauli matrices, density matrix, Bloch sphere
- Spin dynamics and Rabi formula, spin relaxation and dephasing
- Spectroscopy of spins: NMR, EPR, ENDOR, EDMR, STM-EPR
- Writing and reading qubits (spin injection and spectroscopy)
- Passive components in magneto-electronics: GMR, TMR, MRAM
- Active components: Spin field effect transistor
- Fundamentals of spin-based quantum information

5 Learning outcomes / competences:

Students should be able to understand basic concepts of spin physics, in particular spin dynamics, and to use them to describe spin-based devices against the background of the interaction of experiment and theory.

The students

- have mastered the quantum mechanical fundamentals of spin physics, in particular spin dynamics,
- are aware of the conceptual differences that arise when describing quantum mechanical ensembles and single spins,
- have detailed knowledge of measurement methods based on spin interactions and their multidisciplinary application in biology, chemistry, physics and medicine as well as their use for the readout of spin-based quantum bits ("qubits"),
- can analyze questions on the general topic of spin-based electronics and apply the mathematical models developed to specific components,
- know the physical properties and special features of spin-based qubits and can place them in a wider context (electronics, computer science, quantum information).

6	**Examination performance:** [x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP) <table><tr><th>to</th><th>Form of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>a) and b)</td><td>Written exam or Oral examination</td><td>120-180 min. 30-45 min.</td><td>100 %</td></tr></table>
7	**Academic achievement / qualified participation:** none
8	**Prerequisites for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Physics
12	**Module coordinator:** Prof. Dr. Uwe Gerstmann
13	**Other notes:** none
14	**Recommended reading:** T. Schäpers, *Semiconductor Spintronics,* De Gruyter Textbook T. Blachowicz. A. Erdmann, *Spintronics: Theory, Modeling, Devices,* Graduate Texts in Condensed Matter S. Bandyopadhyay, M. Cahay, *Introduction to Spintronics,* CRC Press A. Bencini, D. Gatteschi, *EPR of Exchange Coupled Systems*, Dover Books on Chemistry D. Gatteschi, R. Sessoli, Jacques Villain, *Molecular Nanomagnets,* Mesoscopic Physics and Nanotechnology, Oxford University Press Awschalom, Loss, Samarth, *Semiconductor Spintronics and Quantum Computation,* NanoScience and Technology, Springer W. Scherer, *Mathematics of Quantum Computing: An Introduction,* Springer

Particles and Composites							
Particles and Composites							
Module number: 18	**Workload (h):** 150	**LP:** 5	**Semester of study:** 1. or 3.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Particle synthesis	V	30	45	P	approx. 120
b	Particle synthesis	Ü	15	30	P	up to 30
c	Seminar lecture	Ü	5	25	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

- Elementary processes of particle synthesis (supersaturation, nucleation, growth, agglomeration, sintering, Ostwald ripening)
- Population balance modeling (basics of PBM, kernels for relevant processes of particle synthesis, solution of PBM)
- Gas-phase processes for particle synthesis (key features, flame processes, plasma processes, hot-wall reactors)
- Liquid phase processes for particle synthesis (essential features, precipitation processes, crystallization processes, influence on crystal form)

5 Learning outcomes / competences:

- Students master the elementary processes of particle synthesis, understand the relevant technical literature and are able to apply this knowledge to various processes and to analyze and understand the phenomena occurring there with the help of this knowledge.
- Students know and master the basic methods of population balance modeling and are able to classify the sensible application of these methods for particle synthesis processes.
- Students know and understand the most important processes of particle synthesis. They are able to analyze these processes. In particular, students can analyze the development of product properties as a function of the process parameters and optimize the process design accordingly.

6 Examination performance:

[ ] Final module examination (MAP) [x] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Oral examination	30 min.	100%

7	**Academic achievement / qualified participation:** <table><tr><th>to</th><th>Shape</th><th>Duration or scope</th><th>SL / QT</th></tr><tr><td>c</td><td>Lecture on an exemplary topic / process from the field of particle synthesis</td><td>30 min.</td><td>SL</td></tr></table>
8	**Prerequisites for participation in examinations:** The prerequisite for participation in the module examination is passing the coursework.
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr.-Ing. Hans-Joachim Schmid
13	**Other notes:** none
14	**Recommended reading:** T. T. Kodas, M. J. Hampden-Smith, *Aerosol-Processing of Materials*, Wiley-VCH, 1999 A. Mersmann (ed.), *Crystallization Technology Handbook*, CRC Press, 2001

Additive manufacturing

Additive manufacturing

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
19	150	5	2.	SS	1	en	WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Additive manufacturing	V	30	60	P	approx. 120
b	Additive manufacturing	Ü	15	45	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

- Basics of additive manufacturing
  - Classification of different processes
  - Basic process chain for AM
  - Overview of the most important additive manufacturing processes
- Polymer laser sintering
  - Basics
  - Process chain
  - Materials
  - Component properties & quality assurance
- Fused Deposition Modeling / Fused Filament Fabrication
  - Basics
  - Process chain
  - Materials
  - Component properties & quality assurance
- Metal laser melting
  - Basics
  - Process chain
  - Materials
  - Component properties & quality assurance
- Electron beam melting

5 Learning outcomes / competences:

Students are basically able to classify the various additive manufacturing processes based on different criteria.

Students have a deeper understanding of the most important additive manufacturing processes: Polymer Laser Sintering, Fused Deposition Modeling / Fused Filament Fabrication, Metal Laser Melting, Electron Beam Melting. They know the physical principles and can apply them.

Students know the specific strengths and weaknesses of the processes and can critically evaluate the respective applicability for given problems. They are able to understand the entire process chain and derive the properties that can be achieved in each case.

<table>
<tr><td></td><td>In the exercises, students apply what they have learned in the lecture to simple problems and present their solutions, e.g. by presenting them on the blackboard. In this way, they practise linguistically and logically correct argumentation and the ability to present scientific facts appropriately.</td></tr>
<tr><td>6</td><td>Examination performance:
[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)
<table>
<tr><th>to</th><th>Form of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr>
<tr><td>a) and b)</td><td>Written exam or
oral examination</td><td>90-120 min.
45-60 min.</td><td>100%</td></tr>
</table></td></tr>
<tr><td>7</td><td>Academic achievement / qualified participation:
none</td></tr>
<tr><td>8</td><td>Requirements for participation in examinations:
none</td></tr>
<tr><td>9</td><td>Requirements for the awarding of credit points:
Credit points are awarded if the final module examination is passed.</td></tr>
<tr><td>10</td><td>Weighting for overall grade:
The module is weighted with the number of credit points (factor: 1).</td></tr>
<tr><td>11</td><td>Use of the module in other degree programs:
none</td></tr>
<tr><td>12</td><td>Module coordinator:
Prof. Dr.-Ing. Hans-Joachim Schmid</td></tr>
<tr><td>13</td><td>Other notes:
none</td></tr>
<tr><td>14</td><td>Recommended reading:
M. Schmid, Selective laser sintering (SLS) with plastics, Hanser Verlag</td></tr>
</table>

Sustainable Electrochemistry							
Sustainable Electrochemistry							
Module number: 20	**Workload (h):** 180	**LP:** 6	**Semester of study:** 1. or 3.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
I	Corrosion Science and Engineering	V	30	60	P	approx. 120
II	Current Topics of Energy Conversion and Storage	V	30	60	P	approx. 120

2 Elective options within the module:

none

3 Participation requirements:

none; basics of electrochemical thermodynamics and kinetics are recommended

4 Contents:

I: General corrosion principles; electrochemical mechanisms; Pourbaix diagrams; kinetics of aqueous corrosion; Evans diagrams; uniform corrosion; galvanic corrosion; localized corrosion (pitting, crevice corrosion); stress corrosion cracking; hydrogen-induced damage; intercrystalline corrosion; atmospheric corrosion; corrosion at polymer/metal interfaces; corrosion of implant materials; corrosion protection measures; applied corrosion analysis; guidelines for corrosion protection-compliant design.

II: Electrochemical energy storage and conversion: history and sustainability, types and applications, components and materials, thermodynamic principles, kinetics, electrode reactions, processes in the electrolyte, surface electrochemistry, characterization, combination with water desalination, current topics.

5 Learning outcomes / competences:

I: Students have advanced knowledge of the corrosion of metals and alloys as well as the analysis of corrosion processes in various corrosive media. This includes homogeneous and localized corrosion processes. In addition, they have a broad overview of various corrosion protection technologies in the field of construction materials and the control of corrosion kinetics of alloys in medical technology.

II: Students have in-depth knowledge of sustainable electrochemical energy storage and conversion. They have an advanced understanding of the underlying mechanisms and processes and their practical application. They are familiar with various basic and advanced analytical methods for characterizing electrochemical energy storage systems.

6	**Examination performance:** [x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP) <table><tr><th>to</th><th>Form of examination</th><th>Duration or scope</th><th>Weighting for the module grade</th></tr><tr><td>I and II</td><td>Written exam or Oral examination</td><td>120 min. or 30-45 min.</td><td>100%</td></tr></table>
7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Guido Grundmeier / Junior Prof. Dr. Hans-Georg Steinrück / Junior Prof. Dr. Nieves Lopez Salas
13	**Other notes:** none
14	**Recommended literature** **I:** W. Schmickler, E. Santos: *Interfacial Electrochemistry*, Springer K. Oldham, J. Myland, A. Bond: *Electrochemical Science and Technology: Fundamentals and Applications*, Wiley P. Pedeferri: "Corrosion Science and Engineering", Springer 2018 H. Kaesche: "Corrosion of Metals: Physicochemical Principles and Current Problems, Springer **II:** K. W. Beard: *Linden's handbook of batteries* R. A. Huggins: *Advanced Batteries* R. Job: Electrochemical energy storage E. Worch: *Drinking water treatment: an introduction* A. J. Bard, L. R. Faulkner, H. S. White: *Electrochemical methods: fundamentals and applications*

Biomaterials							
Biomaterials							
Module number: 21	**Workload (h):** 150	**LP:** 5	**Semester of study:** 2.	**Rotation:** SS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Biointerfaces and Nanobiomaterials	V	30	60	P	approx. 120
b	Biointerfaces and Nanobiomaterials	S	15	45	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

Contents:

Ia: protein structure, membrane systems, protein adsorption on surfaces and nanoparticles, protein patterning, protein misfolding and aggregation, antimicrobial surfaces, DNA and RNA structure, self-assembled DNA monolayers, structural DNA nanotechnology, DNA nanostructures at interfaces, DNA-based machines and robots.

Ib: Current topics in the fields of artificial membrane systems, protein adsorption on surfaces and nanoparticles, protein patterning, protein misfolding and aggregation, antimicrobial surfaces, self-assembled DNA monolayers, structural DNA nanotechnology, DNA nanostructures at interfaces, DNA-based machines and robots.

5 Learning outcomes / competences:

Ia: Students have in-depth knowledge of the interaction of biomolecules with biological and artificial interfaces. They have an advanced understanding of biomolecular adsorption, aggregation and self-assembly and the resulting potential applications in materials research, sensor technology and nanotechnology.

Ib: Students can independently familiarize themselves with complex issues and new subject areas, selectively process and present data and results, critically question published results and conclusions and communicate new results and findings from current research to a broad audience.

6 Examination performance:

[ ] Final module examination (MAP) [ ] Module examination (MP) [x] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
Ia	Exam	60 minutes	70%
Ib	Seminar lecture	15 minutes	30%

7 Academic achievement / qualified participation:

none

8 Prerequisites for participation in examinations:

	none
9	**Requirements for the awarding of credit points:** Credit points are awarded when the module examinations have been passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Guido Grundmeier / PD Dr. Adrian Keller
13	**Other notes:** none
14	**Recommended reading:** H. Lodish et al, *Molecular Cell Biology*, Palgrave Macmillan Fifth Edition 2004 B. D. Ratner et al, eds, *Biomaterials Science - An Introduction to Materials in Medicine,* Academic Press 1996 D. S. Goodsell, *Bionanotechnology - Lessons from Nature*, Wiley-Liss, Inc., 2004 T. A. Waigh, *Applied Biophysics - A Molecular Approach for Physical Scientists*, John Wiley & Sons Ltd 2007 C. R. Calladine et al, *Understanding DNA. The Molecule and How It Works*, Academic Pr Inc 2004 M. Malmsteen, *Biopolymers at Interfaces*, Second Edition, Marcel Dekker Inc. 2003 A. D. Bates et al, *DNA Topology*, OUP Oxford 2005

Functional Materials

Functional Materials

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
22	180	6	1. or 3.	WS	1	en	WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
Ia	Physics and Application of Semiconductor- Heterostructures	V	30	30	P	approx. 120
Ib	Physics and Application of Semiconductor- Heterostructures	Ü	30	30	P	up to 30
II	Sustainable Polymer Science	V	30	30	P	approx. 120

2 Elective options within the module:

none

3 Participation requirements:

none; knowledge of solid state and semiconductor physics is recommended

4 Contents:

I:

- Fundamentals of low-dimensional HL systems (quantization energy, density of states, Fermi energies, wave functions, ...)
- Electronic properties of semiconductor heterostructures
- Optical properties of semiconductor heterostructures
- Material systems, manufacturing methods, components

II:

Functional polymers (e.g. biodegradable, water-soluble), shape memory polymers, smart polymers, polyelectrolytes, polymer particles, application examples of polymers (e.g. in sensors; QCM, SPR, photonics and AFM detection)

5 Learning outcomes / competences:

I:

Mastery of the basic concepts in the field of semiconductor heterostructures with the aspects of manufacturing and electrical and optical properties.

The students

-have a comprehensive qualitative understanding of semiconductor heterostructures,
-have knowledge of the basics of the quantitative description of the relevant phenomena,
-have the ability to apply what they have learned to problems in the field of semiconductor heterostructures, to discuss the results and to classify them with reference to the subject area.

II: Students have in-depth knowledge of selected polymer materials and their application, e.g. in sensors.

6 Examination performance:

[ ] Final module examination (MAP) [ ] Module examination (MP) [x] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
I	Written exam or Oral examination	120-180 min. 30-45 min.	75%
II	Written exam or Oral examination	90-120 min. 30-45 min	25%

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

none

9 Requirements for the awarding of credit points:

Credit points are awarded when the module examinations have been passed.

10 Weighting for overall grade:

The module is weighted with the number of credit points (factor: 1).

11 Use of the module in other degree programs:

none

12 Module coordinator:

Prof. Dr. Dirk Reuter / Prof. Dr. Donat As / Prof. Dr. Dirk Kuckling

13 Other notes:

none

14 Recommended reading:

I:

M. Grundmann, *The Physics of Semiconductors*, Springer 2^{nd} Ed. Heidelberg, 2010

O. Manasreh, *Introduction to Nanomaterials and devices*, Wiley, 2011

S. M. Sze, K. K. Ng, *Physics of Semiconductor Devices,* Wiley, 3^{rd} Ed., 2007

J. Singh, *Physics of Semiconductors and their Heterostructures*, McGraw Hill, 1995

U. W. Pohl, *Epitaxy of Semiconductors*, Springer Heidelberg, 2013

II:

Y. Gnanou, M. Fontanille, *Organic and Physical Chemistry of Polymers*, Wiley 2008

J. R. Fried, *Polymer Science and Technology*, Prentice Hall 2007

A. Seidel (Ed.), *Characterization and Analysis of Polymers*, Wiley 2008

Q. Li (Ed.), *Intelligent Stimuli-Responsive Materials*, Wiley 2013.

Photonic Nanostructures

Photonic Nanostructures

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
23	180	6	1. or 3.	WS	1	en	WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Photonic Nanostructures	V	30	60	P	approx. 120
b	Photonic Nanostructures	Ü	30	60	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

- Light-matter interaction (Maxwell's equations in matter, wave equation and Helmholtz equation, optical response of materials, polarization field, dielectric function of insulators, semiconductors and metals)
- Photonic nanostructures (one-dimensional periodicity: Bragg reflectors, transfer matrix algorithm, optical resonators I: micropillar resonators, optical resonators II: microdisks and ring resonators, electromagnetic fields in periodic media, symmetries and photonics, photonic crystal membranes, optical resonators III: defects in photonic crystals
- Plasmonic nanostructures (boundary and surface plasmon polaritons, metallic nanoparticles, optical metamaterials)

5 Learning outcomes / competences:

Students should be able to apply the basic concepts of light interaction with nanostructures correctly and soundly to current problems in modern physics and to work out solutions to problems independently.

The students

- are able to independently recognize and differentiate between issues in the field of nano-optics and optics on macroscopic objects,
- have the ability to describe and assess the effects that occur when light interacts with dielectric and metallic nanostructures,
- can independently develop solutions to more complex problems when dealing with optical nanostructures and justify them using the knowledge they have acquired,
- can develop and justify reasonable analytical and numerical approximation methods for solving the problem under guidance,
- have the ability to work independently with current English-language specialist literature on the subject of nano-optics.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

	to	**Form of examination**	**Duration or scope**	**Weighting for the module grade**
	a) and b)	Written exam or Oral examination	120-180 min 30-45 min	100 %

7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Optoelectronics and Photonics, M.Sc. Physics
12	**Module coordinator:** Prof. Dr. Cedrik Meier / Prof. Dr. Thomas Zentgraf
13	**Other notes:** none
14	**Recommended reading:** L. Novotny, B. Hecht, *Principles of Nano-Optics*, Cambridge University Press, New York S. Gaponenko, H. V. Demir, *Applied Nanophotonics*, Cambridge University Press, New York S. Meier, *Plasmonics - Fundamentals and Applications*, Springer, New York

Micro Electromechanical Systems							
Micro Electromechanical Systems							
Module number: 24	**Workload (h):** 180	**LP:** 6	**Semester of study:** 1. or 3.	**Rotation:** WS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Micro Electromechanical Systems	V	30	60	P	approx. 120
b	Micro Electromechanical Systems	Ü	30	60	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

Process technology, modeling, characteristic curves of sensor systems and actuators in volume and surface micromechanics: Pressure, acceleration, rotation rate, flow, inclination sensors, valves, relays, actuators in microsystems technology

Tasks to deepen the knowledge acquired in the lecture are given out for voluntary completion.

5 Learning outcomes / competences:

Students are able to describe the production of microsystems. They can calculate the output signals of the sensor systems using the model equations and are able to explain application scenarios for the microsystems or find suitable microsystems for given tasks.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Exam	60 min.	100%

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

none

9 Requirements for the awarding of credit points:

Credit points are awarded if the final module examination is passed.

10 Weighting for overall grade:

	The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Electrical Systems Engineering
12	**Module coordinator:** Prof. Dr. Ulrich Hilleringmann or N. N. (lecturers in electrical engineering)
13	**Other notes:** none
14	**Recommended reading:** Tai-Ran Hsu, *MEMS & Microsystems: Design*, *Manufacture, and Nanoscale Engineering*, 2008 L. Chang, *Foundations of MEMS*, 2012

Semiconductor Epitaxy							
Semiconductor Epitaxy							
Module number: 25	**Workload (h):** 180	**LP:** 6	**Semester of study:** 2.	**Rotation:** SS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Semiconductor Epitaxy	V	30	60	P	approx. 120
b	Semiconductor Epitaxy	Ü	30	60	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none; basic knowledge of solid state physics and semiconductor physics is recommended

4 Contents:

Basics

Fundamentals of crystal structure
Elastic properties of heterostructures
Transfers

Thermodynamics of layer growth

States of equilibrium
Crystal growth

Atomistic aspects of layer growth

Surface structure
Kinetic processes during layer growth
Self-organized nanostructures

Methods of semiconductor epitaxy

Molecular beam epitaxy (MBE)
Metal organic vapor phase epitaxy (MOCVD)

Characterization methods

In-situ analysis methods (RHEED, ...)

5 Learning outcomes / competences:

Students master the basic concepts of semiconductor epitaxy with the aspects of production, properties and characterization. They have an understanding including the mathematical formulation of the physical facts and models.

Participants learn to work on practical problems in the field of semiconductor epitaxy and to apply the knowledge acquired in the lecture. In doing so, students should recognize problems, relate them to the lecture, formulate problems mathematically if necessary, discuss results and classify them in an overall physical context.

•

6	**Examination performance:** [x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Written exam or Oral examination	120-180 min. 30-45 min.	100%

7	**Academic achievement / qualified participation:** none
8	**Requirements for participation in examinations:** none
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Physics
12	**Module coordinator:** Prof. Dr. Dirk Reuter / Prof. Dr. Donat As
13	**Other notes:** none
14	**Recommended reading:** U. W. Pohl, *Epitaxy of Semiconductors*, Springer Heidelberg 2013

Semiconductor Technology							
Semiconductor Processing							
Module number: 26	**Workload (h):** 180	**LP:** 6	**Semester of study:** 2.	**Rotation:** SS	**Duration (in sem.):** 1	**Language:** en	**P/WP:** WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Semiconductor Technology	V	30	60	P	approx. 120
b	Semiconductor Technology	Ü	30	60	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none

4 Contents:

Process technology for processing silicon semiconductor materials:

Crystal pulling, oxidation, photolithography, etching techniques, doping processes, layer deposition, contacting, cleaning, MOS processes are discussed in detail with regard to implementation, modeling and system technology

Tasks to deepen the knowledge acquired in the lecture are given out for voluntary completion.

5 Learning outcomes / competences:

Students are able to explain the production of silicon wafers and their processing through to the integration of CMOS components. They can combine process steps into an overall process and create specific structures in the semiconductor material.

Students are able to combine the process steps they have learned to integrate different components and acquire skills in the processing of semiconductor materials and the transfer to alternative materials.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Exam	60 min.	100%

7 Academic achievement / qualified participation:

none

8 Requirements for participation in examinations:

none

9 Requirements for the awarding of credit points:

	Credit points are awarded if the final module examination is passed.
10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** M.Sc. Electrical Systems Engineering
12	**Module coordinator:** Prof. Dr. Ulrich Hilleringmann or N. N. (lecturers in electrical engineering)
13	**Other notes:** none
14	**Recommended reading:** U. Hilleringmann, *Silicon Semiconductor Technology*, Springer 2023

Solid-State Materials Chemistry

Solid-State Materials Chemistry

Module number:	Workload (h):	LP:	Semester of study:	Rotation:	Duration (in sem.):	Language:	P/WP:
27	180	6	2.	SS	1	en	WP

1 Module structure:

	Course	Teaching form	Contact time (h)	Self-study (h)	Status (P/WP)	Group size (TN)
a	Inorganic Materials Chemistry	V	30	90	P	approx. 120
b	Inorganic Materials Chemistry	Ü	15	45	P	up to 30

2 Elective options within the module:

none

3 Participation requirements:

none; basic knowledge of chemical synthesis and solid state chemistry is recommended

4 Contents:

Solid state structures and symmetry, functional materials (e.g. silica, metal oxides, hybrid materials), sol-gel synthesis, ceramics, special methods of material synthesis, selected material classes (e.g. porous materials), biominerals, analytical methods (e.g. X-ray diffraction, physisorption, thermal analysis)

5 Learning outcomes / competences:

The students

- master basic concepts of chemical synthesis and characterization of inorganic functional materials.
- recognize structure/property relationships
- know how product properties can be specifically adjusted during synthesis
- know through laboratory practice how to apply synthesis and characterization methods to selected problems
- learn to critically evaluate original literature.

6 Examination performance:

[x] Final module examination (MAP) [ ] Module examination (MP) [ ] Module part examinations (MTP)

to	Form of examination	Duration or scope	Weighting for the module grade
a) and b)	Written exam or Oral examination	60 min. 30 min.	100 %

7 Academic achievement / qualified participation:

none

8 Prerequisites for participation in examinations:

none

9 Requirements for the awarding of credit points:

Credit points are awarded if the final module examination is passed.

10	**Weighting for overall grade:** The module is weighted with the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** none
12	**Module coordinator:** Prof. Dr. Michael Tiemann
13	**Other notes:** none
14	**Recommended reading:** L. E. Smart, E. A. Moore: *Solid State Chemistry*; U. Schubert, N. Hüsing: *Synthesis of Inorganic Materials*