Notice:

This English translation of the Examination Regulations for the Master's Degree Program in Optoelectronics & Photonics is solely provided for the convenience of international students. While care has been taken to ensure that the translation is accurate, only the German version of these Examination Regulations, which has been published in the Official Bulletin of Paderborn University, is legally binding.

Special provisions of the examination regulations for the Master's program in Optoelectronics and Photonics at the Faculty of Natural Sciences at Paderborn University

of April 11, 2024

On the basis of Section 2 (4) and Section 64 (1) of the Law on Higher Education Institutions in North Rhine-Westphalia (Higher Education Act – HG) of September 16, 2014 (GV.NRW. p. 547), last amended by Article 2 of the Law of December 5, 2023 (GV. NRW. p. 1278), Paderborn University has issued the following regulations:

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§ 31
General and Special Provisions

These Special Provisions apply in conjunction with the General Provisions for the examination regulations of the Master's programs of the Faculty of Natural Sciences at Paderborn University in their currently valid version (General Provisions). A study plan is included in the appendix to ensure the proper structure of the program. Details on the modules can be found in the module descriptions in the appendix, which form part of these Special Provisions.

§ 32
Acquisition of skills and language regulations

(1) The Master's program in Optoelectronics and Photonics provides candidates with in-depth knowledge of physics and engineering fundamentals as well as specialized knowledge, skills, and methods in the field of optoelectronics and photonics. In addition to the general study objectives of § 58 (1) HG, the program teaches students the ability to apply and further develop the scientific methods of the field of optoelectronics and photonics in their work and to act responsibly, taking into account the effects of technological change. The program consists of a combination of courses (mainly in the first year of study) in which students participate, as well as practical and research-oriented components (mainly in the second year of study) that provide students with targeted and focused training for independent research work in the field of optical technologies. Building on the exemplary treatment of the fundamentals and applications based on the forward-looking research areas in Paderborn, graduates will be able to find employment in many areas of modern optical technologies and optoelectronic information processing. This application and technology orientation is particularly supported by the interdisciplinary nature of the program, which includes significant components of natural sciences and engineering. The master's examination is designed to determine whether students have mastered the fundamental content of the subject of optoelectronics and photonics and have acquired a systematic overview and a methodological toolkit for independent research in the field of optoelectronics and photonics and its technological applications.

(2) The master's program and master's examination are conducted in English.

§ 33
Academic degree

Upon successful completion of the master's program, the academic degree "Master of Science" (M.Sc.) is awarded.

§ 34
Start of studies

The program can be started in the winter semester.

§ 35
Admission requirements

(1) In accordance with § 5 (1) No. 2 b) of the General Provisions, the program requires a degree that includes the following competencies:

- Physical fundamentals: Mastery of the physical fundamentals in the fields of semiconductor physics and semiconductor devices, electrodynamics, wave optics, and basic spectroscopic techniques, quantum theory, combined with the ability to model and formulate physical phenomena in abstract mathematical terms.

e practical work: Recognizing and extracting essential physical relationships on the basis of experiments carried out independently, recording and critically evaluating the results of the experiments.

Advanced mathematics: Mastery of the fundamental mathematical concepts and methods required to understand and solve problems in the Master's program in Optoelectronics and Photonics. This involves in-depth knowledge of linear algebra, analysis, Fourier series, differential equations, and vector analysis.

The examination board will determine whether the requirements have been met.

(2) The degree must have been completed with an overall grade of at least 3.0 (or an equivalent foreign degree grade).

(3) If requirements are not met, enrollment may be granted on the condition that the requirements are made up through appropriate studies and demonstrated by passing the relevant examinations before registering for the master's thesis. The examination board decides on this and on the type and scope of the studies and examinations on the basis of the previous degree. Examinations successfully completed outside the degree program may also be taken into account. The missing and make-up studies may not exceed 30 credit points. The studies and examinations should be completed in the first semester of the master's program.

(4) In addition to the requirements specified in § 5 (1) of the General Provisions, the following further admission requirements apply:

Foreign language skills in English at level B2 of the Common European Framework of Reference for Languages (CEFR) are required. English language skills must be demonstrated as follows:

a. Bachelor's degree from an English-speaking country or from a domestic degree program accredited as English-speaking, or
b. Test of English as a Foreign Language (TOEFL) "internet-based" test (iBT, including Home Edition and Paper Edition) with a score of at least 80 points, or
c. IELTS test with a score of at least 6.0 or
d. Cambridge Test – First Certificate in English (FCE) or
e. equivalent tests or
f. corresponding school education.

As a foreign applicant who is not treated as equivalent to a German citizen under international law, you must prove your ability to study by submitting the results of a GRE Revised General Test. Required are usually at least 157 points in the "Quantitative Reasoning" section and at least 4.5 points in the "Analytical Writing" section of the GRE Revised General Test. If you have a good or very good final grade in accordance with § 5 (1) No. 2, proof of the GRE Revised General Test is not required. Applicants with a German university entrance qualification are exempt from providing proof of their ability to study.

(5) Contrary to Section 5 (1) No. 3 of the General Provisions, German language skills are not required.

(6) In the event that the applicant has definitively failed an examination required by the examination regulations in their previous degree program at a university within the scope of the Basic Law, and the previous degree program is very similar in content to the Master's degree program in Optoelectronics and Photonics, enrollment will be refused under the conditions of § 5 (3) of the General Provisions.

§ 36
Structure, course content, modules

The following modules must be completed in the Master's program in Optoelectronics and Photonics:

- From the Fundamentals of Optoelectronics module group:
  Module Analysis and Design of Electronic Circuits (6 CP) (compulsory
  module) Module Modelling and Simulation (6 CP) (compulsory module)
- From the module group Core Subjects I:
  Module Optoelectronic Semiconductor Devices (6 CP) (compulsory module)
  Computational Optoelectronics and Photonics I module (6 CP) (compulsory module)
- From the module group Core Subjects II:
  Module Electromagnetic Waves and Waveguides (9 CP) (compulsory module)
  Module Integrated Optics and Photonics (6 CP) (compulsory module)
- Module Lab Courses (5 CP) (compulsory module)
- Four modules from the Specialization module group (elective modules) (6 CP each)
- Module Topics in Optoelectronics and Photonics (4 CP) (compulsory module)
- Module General Studies (4 CP) (elective module)
- Module Lab Project (14 CP) (compulsory module)
- Module Master's Thesis (30 CP) (compulsory module)

§ 37
Participation requirements, admission

(1) The module descriptions regulate the participation requirements for a module in accordance with § 7 (2) sentence 5 of the General Provisions.

(2) Only those who have successfully completed the Lab Project module at the time of application for admission, have achieved at least 74 CP, and, in the case of conditional enrollment pursuant to § 35 (2), have demonstrated that they have passed the relevant examinations, may be admitted to the Master's thesis.

(3) Further requirements for participation in examinations in accordance with § 12 (2) of the General Regulations are regulated in the module descriptions.

§ 38 Examiners

The group of examiners may be expanded within the scope of § 65 HG.

§ 39
Achievements in the modules

(1) Performance in the modules must be in accordance with the module descriptions.

(2) Examination performance shall be provided in accordance with § 15 of the General Provisions in the form of written examinations, oral examinations, or in other forms. The following other forms are specifically provided for:

1. Presentation:
   Presentations are presentations on a topic that has been independently researched within the thematic scope of a course. Students should demonstrate that they are capable of researching and academically elaborating on a given topic and that they can communicate the results. The topic is agreed upon with the instructor.

2. All exams:
   An experiment comprises preparation (including literature research), implementation (including reflections on comments from supervisors), written elaboration (internship report of approx. 10 pages without appendices, including literature research), presentation, and a discussion of the written elaboration lasting approx. 15 minutes. A grade is awarded for the entirety of the written reports (including presentations and discussions) for the experiments. The written reports (including presentations and discussions) for the experiments are weighted equally in the assessment of the examination.

3. In the practical training, candidates should demonstrate that they can adequately prepare, carry out, evaluate, and document an experimental task, taking safety aspects into account. In order to practice cooperation and for safety reasons, the experiments are usually carried out in small groups of two to four students. Participation in the practical training days is mandatory.

   Before the start of each experiment, the supervisor ensures that the students are sufficiently prepared to carry out the experiment successfully and safely. If this is not the case, the experiment can only be carried out at a later date.

Further details are specified in the module descriptions. If the module descriptions contain framework specifications, the respective instructor determines what specifically must be achieved in order to qualify for participation. This will be announced by the respective instructor and in the Campus Management System of Paderborn University or in another suitable manner no later than the first three weeks of the lecture period.

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

The duration of an oral examination is 30-45 minutes. The

duration of a presentation is approximately 30 minutes.

Further details are specified in the module descriptions.

(4) The following are considered qualified participation:

- Short exam (15–45 minutes)

Further details are specified in the module descriptions. If the module descriptions contain framework specifications, the respective lecturer determines what specifically must be achieved within the scope of qualified participation. This will be announced by the respective lecturer and in the Campus Management System of Paderborn University or in another suitable manner no later than the first three weeks of the lecture period.

§ 40
Master's thesis

(1) The master's thesis should be between 50 and 70 pages long (excluding appendices). The processing time for the master's thesis is 5 months.

(2) An oral defense in accordance with § 19 of the General Provisions is required. The oral defense lasts 30-45 minutes. The master's thesis and oral defense are weighted 5:1 in the calculation of the grade for the final module.

§ 41
Overall grade

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

§ 42
Additional credits

Students may perform additional services in accordance with § 20 of the General Provisions in modules of the degree program that are not limited in terms of participant numbers.

Section 43
Repeating examinations

The number of examination attempts in accordance with § 22 (1) of the General Provisions is limited to four.

§ 44
Transitional

(1) These examination regulations apply to all students who are enrolled for the first time in the Master's program in Optoelectronics and Photonics at the Faculty of Natural Sciences at the University of Paderborn starting in the winter semester 2024/25.

(2) Students who enrolled in the Master's program in Optoelectronics and Photonics at the Paderborn University before the winter semester 2024/2025 at the University of Paderborn for the Master's program in Optoelectronics and Photonics may take their Master's examination, including repeat examinations, for the last time in the summer semester 2027 in accordance with the examination regulations for the Master's program in Optoelectronics and Photonics of the Faculty of Natural Sciences at Paderborn University dated June 16, 2017 (AM.Uni.Pb. 49.17), last amended by the statutes of October 30, 2018 (AM.Uni.Pb 54.18). Starting in the winter semester

2027/2028 will the Master's examination including repeat examinations in accordance with these examination regulations.

(3) Upon application to the examination board, students may switch to these examination regulations. The switch is irrevocable.

§ 45
Entry into force, expiry, and publication

(1) The Special Provisions shall enter into force on October 1, 2024.

(2) The Special Provisions shall be published in the Official Communications of the University of Paderborn (AM.Uni.Pb.).

(3) Upon entry into force of these Special Provisions, the Special Provisions of the Examination Regulations for the Master's program in Optoelectronics and Photonics of the Faculty of Natural Sciences at Paderborn University, as amended on October 30, 2018, shall cease to be in force. § 44 remains unaffected.

(3) In accordance with § 12 (5) HG, after one year has elapsed since the announcement of these regulations, violations of procedural or formal requirements of the Higher Education Act or the regulations or other autonomous law of the university can no longer be asserted against these regulations, unless

1. the rules have not been properly announced,
2. the presidium has previously objected to the decision of the body adopting the regulations,
3. the formal or procedural defect has been previously reported to the university, specifying the legal provision that has been violated and the fact that constitutes the defect, or
4. the legal consequence of the exclusion of complaints was not pointed out in the public announcement of the regulations.

Issued on the basis of the decision of the Faculty Council of the Faculty of Natural Sciences on

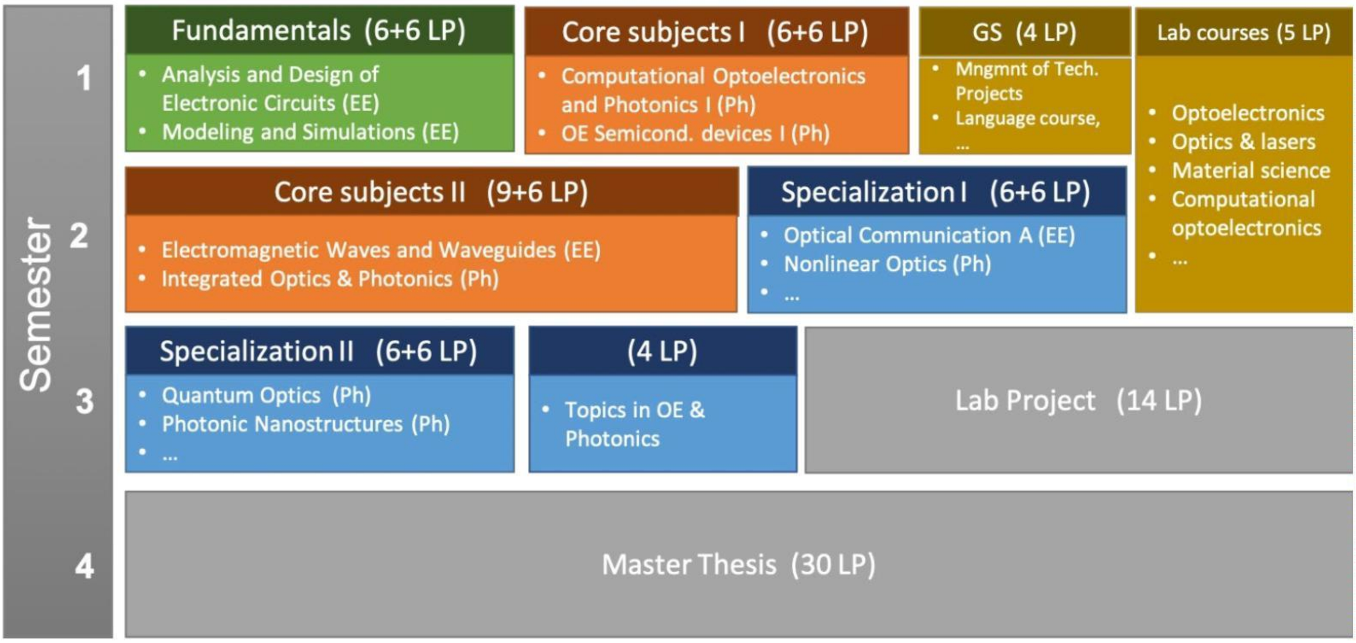
May 3, 2023, and after review of the legality by the Presidium of Paderborn University on

June 28, 2023.

Appendix 1: Study plan

Semester	Module or module group	Module	CP	Workload (h)
1	Fundamentals	Analysis and Design of Electronic Circuits	6	180
	Fundamentals	Modeling and Simulations	6	180
	Core Subjects I	Optoelectronic Semiconductor Devices	6	180
	Core Subjects I	Computational Optoelectronics and Photonics I	6	180
	Lab courses	Lab courses	3	90
	General Studies	General Studies	4	120
Total			**31**	**930**
2	Core Subjects II	Integrated Optics and Photonics	6	180
	Core Subjects II	Electromagnetic Waves and Waveguides	9	270
	Specialization I	1 module from the elective options	6	180
	Specialization I	1 module from elective options	6	18
	Lab courses	Lab courses	2	60
Total			**29**	**870**
3	Specialization II	1 module from the elective options	6	180
	Specialization II	1 module from elective options	6	180
	Topics in Optoelectronics and Photonics	Topics in Optoelectronics and Photonics	4	120
	Lab Project	Lab Project	14	420
Total			**30**	**900**
4	Thesis	Master's thesis	30	900
Total			**30**	**90**

The study plan is intended as a recommendation and guide and can be customized to suit individual needs. Please note the prerequisites for enrolling in certain modules as specified in the module descriptions.


Semester
1
2
3
4
Fundamentals (6+6 LP)
• Analysis and Design of Electronic Circuits (EE)
• Modeling and Simulations (EE)
Core subjects I (6+6 LP)
• Computational Optoelectronics and Photonics I (Ph)
• OE Semicond. devices I (Ph)
GS (4 LP)
• Mngmnt of Tech. Projects
• Language course, …
Lab courses (5 LP)
• Optoelectronics
• Optics & lasers
• Material science
• Computational optoelectronics
• …
Core subjects II (9+6 LP)
• Electromagnetic Waves and Waveguides (EE)
• Integrated Optics & Photonics (Ph)
Specialization I (6+6 LP)
• Optical Communication A (EE)
• Nonlinear Optics (Ph)
• …
Specialization II (6+6 LP)
• Quantum Optics (Ph)
• Photonic Nanostructures (Ph)
• …
(4 LP)
• Topics in OE & Photonics
Lab Project (14 LP)
Master Thesis (30 LP)

Module overview Master

Module group Fundamentals of Optoelectronics	SWS	Credit
Analysis and Design of Electronic Circuits	L2; E2	6
Modeling and Simulation	L 2; E 2	6

Module group Core Subjects I	SWS	Credit
Optoelectronic Semiconductor Devices	L2; E2	6
Computational Optoelectronics and Photonics I	L 2; P 2	6

Module group Core Subjects II	SWS	Credit
Integrated Optics and Photonics	L2; E2	6
Electromagnetic Waves and Waveguides	L 2; E 4	9

Module group Specialization in Optoelectronics and Photonics	SWS	Credit
Offered in the spring semester:		
Nonlinear Optics	L2; E2	6
Optical Communication A	L 2; E 2	6
Optical Communication B	L 2; E 2	6
Computational Optoelectronics & Photonics II	L2; E2	6
Quantum Communication and Information	L2; E2	6
Optics of Solid-State Systems and Nanostructures	L 2; E 2	6
Quantum Information Theory	L2; E2	6
Theoretical Quantum Optics	L 2; E 2	6
Sensor Technology	L 2; E 2	6
Optical Waveguide Theory	L2; E2	6
Quantum Electronics	L 2; E 2	6
Offered in the winter semester:		
Quantum Optics	L2; E2	6
Physics and Technology of Nanomaterials	L 3; E 1	6
Fast Integrated Circuits for Wireline Communications	L2; E2	6
Data Science for Dynamical Systems	L2; E2	6
Photonic Nanostructures	L2; E2	6
Semiconductor Heterostructures: Fundamentals and Applications	L2; E2	6

Additional modules	SWS	Credit
Lab Courses	P 4	5
Topics in Optoelectronics & Photonics	S 2	4
Lab Project		14
Master's Thesis (Master's thesis incl. colloquium)		30
General Studies, from the course offerings of the Paderborn University		4

Appendix 2: Module descriptions

<table>
<tr><td colspan="8">Analysis and Design of Electronic Circuits</td></tr>
<tr><td colspan="8">Analysis and Design of Electronic Circuits</td></tr>
<tr><td>Module group:
Fundamentals</td><td>Workload (h):
180</td><td>CP:
6</td><td>Semester:
1</td><td>Rotation:
Every winter semester</td><td>Duration (in semesters):
1</td><td>Language:
English</td><td>C/E:
C</td></tr>
</table>

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Analysis and Design of Electronic Circuits	L	30	60	C	5
b)	Analysis and Design of Electronic Circuits	E	30	60	C	50

2 Options within the module:

None

3 Participation requirements:

None

Recommended:

Good knowledge of differential equations, Laplace transform, Fourier transform, analysis of electrical networks (Kirchhoff's laws, Norton equivalent, Thevenin equivalent, transfer functions, Bode diagram, etc.), physics of semiconductor devices (band diagram, conduction mechanisms in semiconductors, minority and majority charge carriers, physics of the pn junction, physics of MOS capacitance)), physics of semiconductor devices (band diagram, conduction mechanisms in semiconductors, minority and majority charge carriers, n-type and p-type semiconductors, physics of the pn junction, physics of MOS capacitance), semiconductor devices (physical functioning and device equations of pn diodes, MOS transistors, and bipolar transistors), basic knowledge of digital technology (Boolean algebra, truth tables,
combinatorial logic)

4 Contents:

The lecture provides an introduction to the analysis and design of analog and digital circuits and systems. It builds on basic knowledge of electronic components (bachelor's level). The lecture presents a modern approach to the analysis and design of electronic circuits and systems that combines mathematical analysis and circuit simulation.
Contents

- Nonlinear large-signal modeling of pn diodes, bipolar junction transistors (BJT), and MOS transistors
- Nonlinear large-signal analysis of circuits with diodes, BJTs, and MOS transistors
- Linear modeling and one- or two-port representation of diodes, transistors, and amplifiers
- Linear small-signal analysis of BJT and MOS transistor amplifiers
- Analysis of single-transistor amplifiers

	• Analysis of differential amplifiers • Modeling and analysis of operational amplifier circuits • CMOS logic • Analysis and design of combinational logic circuits • Analysis and design of sequential logic circuits • Application examples
5	**Learning outcomes / Competencies:** Students will be able to • describe suitable methods for analyzing and designing analog systems • Describe suitable methods for analyzing and designing digital systems • assess the limitations of the various methods • understand and calculate the behavior of simple analog and digital circuits • Apply a numerical simulation tool (SPICE) for electronic systems and circuit simulations • Describe typical components and subsystems Key qualifications: The lecture teaches skills in the area of the interaction of various modeling techniques, mathematical analysis approaches, and numerical simulation, as well as their effective application for the design of electronic systems. The methods for analog electronics design are transferable to the design of time- and amplitude-continuous systems. The methods for digital design are transferable to the design of time- and amplitude-discrete systems.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written examor Oral examination or presentation	120–180 min. 30–45 min. 30 min.	100%

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Electrical Systems Engineering master's program and the Computer Engineering master's program.
12	**Module coordinator:** Prof. Dr.-Ing. J. Christoph Scheytt

13	**Other information:** Course homepage https://www.hni.uni-paderborn.de/en/system-and-circuit-technology/teaching/ circuit-and-system-design/ Methodological implementation • Lecture with PowerPoint presentation and handwritten mathematical derivations using tablet and projector • Part of the exercises as handwritten calculations using a tablet and projector • The second part of the exercises as practical design tasks using LTspice simulation Learning materials, bibliography Lecture slides and videos; exercise slides. Additional references will be provided in the first lecture • Richard C. Jaeger, Travis N. Blalock, "Microelectronic Circuit Design," McGraw Hill, 4th edition, 2010 • Neil H. E. Weste, David Money Harris, "CMOS VLSI Design," Addison Wesley, 4th edition, 2010

Modeling and Simulation

Modeling and Simulation

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	C/E:
Fundamentals	180	6	1	Every winter semester	1	English	C

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Modeling and Simulation	L	30	60	C	100
b)	Modeling and Simulation	E	30	60	C	100

2 **Options within the module:**

None

3 **Participation requirements:**

None

Recommended:

- Prior knowledge of programming in Matlab is required
- Knowledge of mathematics and physics at university entrance level

4 **Contents:**

This lecture introduces and implements techniques for constructing models and simulations of technical systems. Content

- Introduction to the modeling process
- Numerical representation in digital computers
- Numerical schemes for ordinary differential equations
- Numerical methods for partial differential equations
- Discrete simulations

5 **Learning outcomes / competencies:**

After completing the course, students will be able to

- Classify and analyze modeling schemes and numerical methods
- Identify and apply numerical methods for technical-physical systems
- illustrate and physically evaluate the results obtained
- Expand, develop, and validate numerical algorithms

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written exam or oral examor presentation	120–180 min 30–45 min 30 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Electrical Systems Engineering master's program.
12	**Module coordinator:** Prof. Dr. Jens Förstner
13	**Additional information:** Implementation The theoretical concepts are taught in the form of lectures. The exercises consist of simple discussion questions and classic mathematical problems that students are expected to solve independently. In addition, students will use self-written and commercial software for selected topics.

Optoelectronic Semiconductor Devices

Optoelectronic Semiconductor Devices

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	C/E:
Core Subjects I	180	6	1	Every winter semester	1	English	C

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Optoelectronic Semiconductor Devices	L	30	60	C	up to 60
b)	Optoelectronic Semiconductor Devices	E	30	60	C	up to 30

2 Options within the module:

None

3 Participation requirements:

none

4 Contents:

The first part of the lecture provides an overview of the physics of light-emitting diodes and the static properties of semiconductor lasers, starting with the fundamentals of solid-state physics and continuing with the design and operation of the most important semiconductor LEDs and laser diodes. The second part deals with the dynamic properties of semiconductor lasers, their spectral properties, and the fundamentals of various semiconductor photodetectors.

- Significance of optoelectronic semiconductor devices
- Light-emitting diodes – LEDs
- Laser diodes – static properties
- Laser diodes – dynamic properties
- Optoelectronic detectors

5 Learning outcomes / Competencies:

The students should be able to to the basic concepts of optoelectronic semiconductor devices and apply themindependently to problem solving.

Students

- have a sound basic knowledge of light-emitting semiconductor devices such as LEDs and laser diodes,
- and possess a physical understanding of the static, dynamic, and spectral properties of LEDs and semiconductor lasers.
- can apply basic knowledge of the influence of quantumstructures on the properties of modern optoelectronic semiconductor devices,
- have the ability to apply this knowledge in the design and operation of optoelectronic semiconductor devices,
- possess fundamental knowledge of the functioning and applicability of various semiconductor photodetectors.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** **Prof. Dr. Dirk Reuter**, Prof. Dr. Donat As
13	**Other information:** None

Computational Optoelectronics and Photonics I

Computational Optoelectronics and Photonics I

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	C/E:
Core Subjects I	180	6	1	Every winter semester	1	English	C

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Computational Optoelectronics and Photonics I	L	30	60	C	up to 60
b)	Computational Optoelectronics and Photonics I	E	30	60	C	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Application-oriented introduction to the practical numerical implementation of mathematical problems and the graphical presentation of calculated data
- Light propagation in nanostructured solids
- Quantum mechanical oscillator in an optical resonator
- Excitons in low-dimensional semiconductor systems coupled to propagating light fields
- Localized electronic states and their properties in nanostructures
- Simple models for quantum optics and quantuminformation

5 Learning outcomes / competencies:

Students

- acquire a fundamental understanding of nanostructured solids and their use in photonic structures based on concrete examples.
- can numerically implement the relevant equations in abstract form based on the mathematical description of physical systems,
- are able to develop program codes under supervision and use software packages to numerically analyze the issues covered in the lecture,
- are able to numerically implement and analyze nonlinear systems of equations of motion under supervision,
- can graphically represent complex physical phenomena and present the results in a meaningful way.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** **Prof. Dr. Stefan Schumacher**, Dr. Matthias Reichelt
13	**Other information:** None

Integrated Optics and Photonics

Integrated Optics and Photonics

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	C/E:
Core Subjects II	180	6	2	SS	1	English	C

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Integrated Optics and Photonics	L	30	60	C	up to 60
b)	Integrated Optics and Photonics	E	30	60	C	up to 30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

- Propagation of electromagnetic waves in optical waveguides (wave equation, boundary conditions, and mode dispersion relations for planar waveguides)
- Selected materials and manufacturing processes (ion exchange in glasses and crystals, diffusion waveguides in $LiNbO_3$, epitaxially grown waveguides in semiconductor materials)
- Theory of coupled modes (description with eigenmodes of the undisturbed system, description with local normal modes of the real system)
- Electro-optical components (electro-optical effect in dielectric crystals, modulators, and switches)
- Nonlinear optical components

5 **Learning outcomes / Competencies:**

Students will learn the basic concepts of integrated optics and photonics and their applications.

Students

- will be able to identify and analyze issues in the field of integrated optics and distinguish them from conventional classical optics.
- can quantitatively describe wave propagation in guided structures and independently apply this description (approximately) to a wide variety of waveguide geometries,
- be able to describe the functional principle of integrated optical components based on the physical fundamentals and independently perform analytical or numerical modeling of simple components using methods from coupled mode theory,
- can independently analyze more complex integrated optical structures, identify their functional components, and describe their function,
- can independently engage with current English-language specialist literature on the subject of integrated optical components and photonic structures.

6	**Examination:** [X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module exam has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** **Prof. Dr. Christine Silberhorn**, Prof. Dr. Tim Bartley
13	**Other information:** None

Electromagnetic Waves and Waveguides

Electromagnetic Waves and Waveguides

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	C/E:
Core Subjects II	270	9	2	Every summer semester	1	English	C

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Electromagnetic Waves and Waveguides	L	30	60	C	50
b)	Electromagnetic Waves and Waveguides	E	30	60	C	50
c)	Electromagnetic Waves and Waveguides - Practical Exercise	E	30	60	C	50

2 Options within the module:

None

3 Participation requirements:

None

4 Course content:

Contents of the course Electromagnetic Waves and Waveguides

- Review of fundamentals: Maxwell's equations, constitutive relations, continuity conditions, energy,
- Fundamentals: Frequency space, linear material models, Kramer-Kronig relation, Poynting theorem
- The wave equation and its solutions: plane waves, optical polarization, attenuation, standing waves,
- dispersion: phase and group velocity, group velocity dispersion,
- Interfaces: Fresnel formulas for normal and oblique incidence, Snell's law, transfer matrix method,
- Waveguides: mode classification, hollow waveguides (rectangular and axially symmetric), planar dielectric waveguides and optical fibers, attenuation in waveguides, line theory, S-parameters,
- Resonators: Fundamentals, cavity resonators, losses in resonators, dielectric resonators
- wave radiation: far-field approximation, dipole and linear antennas, antenna characteristics, antenna arrays
- Application of the methods taught in the lecture to a specific classification or regression task and evaluation and discussion of the results obtained.

5 Learning outcomes / competencies:

Technical competence:
After attending the course, students will be able to

- mathematically model time-harmonic electromagnetic fields
- identify and apply suitable analytical methods
- interpret and visualize the results obtained in physical terms
- expand, develop, and validatetheoretical models for electromagnetic field problems

	Key qualifications: Students • learn to transfer the skills they have acquired to other disciplines • expand their ability to cooperate and work in a team, as well as their presentation skills, in the context of solving the exercises • learn strategies for acquiring knowledge from literature and the Internet • acquire subject-specific foreign language skills
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) to c)	Written examor Oral exam or presentation	120–180 min 30–45 min. 30 min	100%

7 Coursework/qualified participation:

to	Form	Duration or scope	CW / QP
c)	2 short exams	15–45 min	QP

8	**Requirements for participation in examinations:** None
9	**Requirements for the awarding of credit points:** Credit points are awarded if the final module examination has been passed and qualified participation in course c) of the module has been demonstrated.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Electrical Systems Engineering master's program.
12	**Module coordinator:** Prof. Dr. Jens Förstner
13	**Additional information:** Notes on the course Electromagnetic Waves and Waveguides: Implementation The theoretical concepts are taught in the form of lectures. The exercises consist of simple discussion questions and classic field problems with mathematical solutions, which students are expected to solve independently. Teaching materials, literature • Slides and lecture notes, additional recommendations for textbooks will be provided in the lecture .

Optical Waveguide Theory

Optical Waveguide Theory

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	C/E:
Specialization	180	6	2	SS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Optical Waveguide Theory	L	30	60	E	50
b)	Optical Waveguide Theory	E	30	60	E	50

2 **Options within the module:**

None

3 **Participation requirements:**

None

Recommended: Fundamentals of electrodynamics (at the level of the course "Electromagnetic Waves"), mathematical fundamentals (bachelor's level).

4 **Contents:**

Brief description

Dielectric optical waveguides are key elements of today's integrated optical/photonic circuits. This course provides an introduction to the theoretical treatment and a basis for advanced modeling, simulation, and design of waveguides. Content

- Photonics, integrated optics, dielectric waveguides: examples, motivation.
- Brief review of the necessary mathematical tools.
- Maxwell's equations in various formulations, classes of problems.
- Normal modes in dielectric optical waveguides, orthogonality, completeness, scattering matrices, reciprocal circuits.
- Examples of dielectric optical waveguides (multilayer systems, integrated optical channels, glass fibers), curved waveguides, whispering gallery modes.
- Coupled mode theory in conventional codirectional and hybrid analytical/numerical variants, perturbation theory for optical waveguides.
- Optional: Treatment of boundary conditions, initial conditions (beam propagation method), waveguide discontinuities (BEP/QUEP simulations), photonic crystal waveguides and fibers, plasmonic waveguides.

5 **Learning outcomes / Competencies:**

Subject-specific competence:

After attending the course, students will be able to

- Formulate integrated optics and photonics systems mathematically (modeling, analysis)
- identify, apply, and validate analytical solution methods and approximation methods (application, synthesis, evaluation)
- illustrate and physically evaluate the results obtained (evaluation)
- develop theoretical models for integrated optics and photonics systems and validate their validity (synthesize, evaluate) Interdisciplinary skills:

	Students • learn to apply the knowledge and skills they have acquired in an interdisciplinary manner (elements of electrical engineering, physics, and mathematics are addressed), • expand their ability to cooperate and work in teams as well as their presentation skills when working on exercises and presenting and discussing their own solutions, • learn strategies for acquiring knowledge through literature study and internet use, • acquire further subject-related foreign language skills.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written exam or oral examor presentation	120–180 min 30–45 min 30 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Electrical Systems Engineering master's program.
12	**Module coordinator:** Dr. Manfred Hammer
13	**Additional information:** Notes on the course Optical Waveguide Theory: Course page http://ei.uni-paderborn.de/tet/ Methodological implementation The theoretical concepts are presented in the form of a lecture; exercises and homework assignments deepen and supplement the theory.

Quantum Electronics

Quantum Electronics

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in Semesters):	Language:	C/E:
Specialization	180	6	2	SS	1	English	E

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size
a)	Quantum Electronics	L	30	60	E	up to 60
b)	Quantum Electronics	E	30	60	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

Fundamental concepts of quantum electronics, their optical, electrical, and optoelectronic principles, and their applications. Understanding and mathematical formulation of physical phenomena and models.

- Experimental approach to quantum systems
- Atoms and quantumstructures as two-level systems
- Coherent light-matter interaction
- Solid-state-based quantum bits
- Semiconductor quantum dots
- Quantum bits in strong optical fields and resonators
- Functional structures and applications

5 Learning outcomes / competencies:

Students

- have in-depth knowledge in the field of quantumelectronics,
- have in-depth knowledge of two-level systems,
- have in-depth knowledge of light-matter interaction in strong fields,
- are able to describe the laws of physics mathematically,
- are able to derive fundamental laws of quantumelectronics,
- can clearly communicate the physical and technical fundamentals and applications of quantum electronics.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** **Prof. Dr. Klaus Jöns**, Prof. Dr. Christine Silberhorn
13	**Other information:** None

Nonlinear Optics

Nonlinear Optics

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	C/E:
Specialization	180	6	2	SS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Nonlinear Optics	L	30	60	E	up to 60
b)	Nonlinear Optics	E	30	60	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Nonlinear optical susceptibility (description of nonlinear optical processes, formal definition and properties of nonlinear susceptibility)
- Wave optical description of nonlinear interactions (wave equation for nonlinear optical media, phase matching, Manley-Rowe relation, SHG and SFG, nonlinear optics at interfaces)
- Intensity-dependent refractive index (semiconductor nonlinearities, pulse propagation and solitons, optical phase conjugation, optical bistability)
- Electro-optic and photorefractive effects (electro-optic effect, electro-optic modulators, photorefractive effect)

5 Learning outcomes / competencies:

Students should be able to apply the fundamental concepts of nonlinear optics correctly and soundly to problems in physics and work on them independently.

Students

- can identify and analyze problems in the field of nonlinear optics and distinguish them fromlinear optics,
- can apply approximations to solve nonlinear wave equations,
- can independently identify problems in nonlinear optics and develop appropriate solution strategies for standard problems involving nonlinear effects,
- are able to apply simple abstractions of more complex problems when dealing with nonlinear optics and transfer these to approximations for solving the problem,
- have the ability to independently assess more complex physical relationships in the field of nonlinear optics and, using the knowledge they have acquired, evaluate numerical or analytical approaches to solutions in terms of their approximations,
- can independently engage with current English-language specialist literature on the subject of nonlinear optics.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** **Prof. Dr. Thomas Zentgraf**, Prof. Dr. Christine Silberhorn
13	**Other information:** None

Optical Communication A

Optical Communication A

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1 Module structure:

	Course	Teaching format	Contact time (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Optical Communication A	L	30	60	E	50
b)	Optical Communication A	E	30	60	E	50

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

Brief description

The lecture Optical Communications A provides basic knowledge in the field of optical communications and the optical components used in this field.

Content

- Fundamentals: Maxwell's equations, wave propagation, polarization, dielectric layer waveguides and circular cylindrical waveguides, dispersion, lasers, photodiodes, optical amplifiers, modulation, signal formats, optical receivers, noise, regenerators, wavelength multiplexing. The most important relationships are taught.

5 Learning outcomes / competencies:

Professional competence:

After attending the course, students will be able to, within the scope covered

- understand, model, and apply the functioning of components, phenomena, and systems in optical communications engineering, and
- apply knowledge of optoelectronics.

Interdisciplinary skills:

Students

- can apply their knowledge and skills across disciplines,
- can use method-oriented approaches in systematic analysis and are able to further their own education through the abstract and precise treatment of content

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written examor Oral exam or presentation	120–180 min 30–45 min 30 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Electrical Systems Engineering master's program and the Computer Engineering master's program.
12	**Module coordinator:** Prof. Dr. Reinhold Noé
13	**Additional information:** Learning materials, bibliography Lecture notes, exercise sheets, and further reading (excerpt): • R. Noe, Essentials of Modern Optical Fiber Communication, Springer, 2nd edition, 2016, ISBN 978-3-662-49621-3, ISBN ISBN 978-3-662-49623-7 • Petermann/Voges, Optische Kommunikationstechnik, Springer-Verlag (modern reference work) 2002 • D. As, Univ. Paderborn, Lecture on Optoelectronics • W. Sohler, Paderborn University, Lecture on Integrated Optics • G. Grau, W. Freude, Optical Communications, Springer-Verlag, Heidelberg, 1991, (comprehensive, many intermediate steps are missing) • K.J. Ebeling, Integrated Optoelectronics, Springer-Verlag, Heidelberg, 1992 • H.-G. Unger, Optical Communications Engineering, Parts I and II, Hüthig-Verlag Heidelberg, 1984 and 1985, (focus on optical waveguides) • Yariv, Optical Electronics, Holt, 1984 (and other works, very physics-oriented, hardly any communications engineering) • R. Th. Kersten, Introduction to Optical Communications, Springer-Verlag

Optical Communication B

Optical Communication B

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1

	Course	Teaching format	Contact time (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Optical Communication B	L	30	60	E	50
b)	Optical Communication B	E	30	60	E	50

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

Brief description

The lecture Optical Communications B imparts knowledge in the field of mode coupling in optical communications and explains the function of many optical components.

Content

Mode coupling: polarization mode dispersion, mode orthogonality, constant and periodic, co- and contra-directional mode coupling, differential group delay profiles, electro-optical effect. The function of many passive and active optical elements is explained, including amplitude and phase modulators, broadband and wavelength-selective couplers, Bragg gratings, polarization-maintaining optical fibers, polarization transformers, equalizers for polarization mode dispersion and chromatic dispersion.

5 **Learning outcomes / Competencies:**

Professional competence:

After attending the course, students will be able to

- understand, model, and apply the functioning of components, phenomena, and systems of optical communications technology, and
- apply their knowledge of optoelectronics.

Interdisciplinary skills:

Students

- can apply their knowledge and skills across disciplines,
- can use method-oriented approaches in systematic analysis, and are able to continue their own education thanks to the abstract and precise treatment of the content.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written examor Oral exam or presentation	120–180 min 30–45 min 30 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Electrical Systems Engineering master's program and the Computer Engineering master's program.
12	**Module coordinator:** Prof. Dr. Reinhold Noé
13	**Additional information:** Learning materials, bibliography Lecture notes, exercise sheets, and further reading (excerpt): • Noe, Essentials of Modern Optical Fiber Communication, Springer, 2nd Edition, 2016, ISBN 978-3-662-49621-3, ISBN ISBN 978-3-662-49623-7 • Petermann/Voges, Optical Communication Technology, Springer-Verlag (modern reference work) 2002 • D. As, Univ. Paderborn, Lecture on Optoelectronics • W. Sohler, Univ. Paderborn, Lecture on Integrated Optics • G. Grau, W. Freude, Optical Communications Engineering, Springer-Verlag, Heidelberg, 1991, (comprehensive, many intermediate steps are missing) • K.J. Ebeling, Integrated Optoelectronics, Springer-Verlag, Heidelberg, 1992 • H.-G. Unger, Optical Communications Engineering, Parts I and II, Hüthig-Verlag Heidelberg, 1984 and 1985, (focus on optical waveguides) • Yariv, Optical Electronics, Holt, 1984 (and other works, very physics-oriented, hardly any communications engineering) • R. Th. Kersten, Introduction to Optical Communications, Springer-Verlag

Computational Optoelectronics and Photonics II

Computational Optoelectronics and Photonics II

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1 Module structure:

	Course	Teaching format	Contact time (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Computational Optoelectronics and Photonics II	L	30	60	E	up to 60
b)	Computational Optoelectronics and Photonics II	E	30	60	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Application of many-particle methods to nanostructured photonic systems
- Numerical analysis of electronic states in low-dimensional structures
- Numerical analysis of optical nonlinearities in low-dimensional structures
- Light propagation coupled to nonlinear optical excitations in the medium
- Applications of nonlinear optical propagation effects such as bistability and solitons

5 Learning outcomes / competencies:

Students

- build on the module Computational Optoelectronics I to deepen their understanding of nanostructured solids and their use in photonic structures using concrete examples.
- have the ability to apply many-particle methods to nanostructured solid-state systems and to evaluate the resulting equations numerically,
- have the ability to numerically calculate the nonlinear optical excitation behavior of nanostructured solid-state systems,
- be able to independently implement mathematical formulations of physical model systems numerically,
- canindependently develop program codes to numerically analyze the content covered.

6 Examination:

[X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

to	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** Prof. Dr. Stefan Schumacher, Dr. Matthias Reichelt
13	**Other information:** None

Quantum Communication and Information

Quantum Communication and Information

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	QuantumCommunication and Information	L	30	60	E	up to 60
b)	QuantumCommunication and Information	E	30	60	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

This module teaches the basic concepts and protocols of quantum communication and quantum information processing.

- Introduction to the fundamentals of quantuminformation (mathematical formulation of the concept of information, axioms of quantum mechanics)
- Qubits and quantum measurements
- Entangled systems, no-cloning theorem, entangled states, Bell inequalities
- Quantumcryptography (protocols, experimental implementations, security proofs, and eavesdropping attacks)
- Quantumteleportation, quantum gates, quantum dense coding (protocols and implementation)
- Entanglement distillation and quantum repeaters

5 Learning outcomes / competencies:

Mastery of the fundamental concepts of quantumcommunication, including knowledge of important protocols and their practical implementations.

Students

- are able to work in an interdisciplinary manner and acquire fundamentals from other subject areas.
- are familiar with abstract concepts from information theory and quantum physics and can demonstrate their connection in relevant physical experiments,
- have internalized the fundamental idea behind novel quantumtechnologies, which is to harness genuine quantum physical properties for practical applications,
- understand the principle of entangled states and its significance for the modern interpretation of quantum physics,
- are familiar with the basic protocols of quantumcommunication and quantum information processing,

	• can familiarize themselves with current research topics that are only partially covered in textbooks, thus finding a starting point for independent research work, • can realistically assess the opportunities and limitations of future technologies.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** Prof. Dr. Christine Silberhorn
13	**Other information:** None

Optics of Solid-State Systems and Nanostructures

Optics of Solid-State Systems and Nanostructures

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Optics of Solid-State Systems and Nanostructures	L	30	60	E	up to 60
b)	Optics of Solid-State Systems and Nanostructures	E	30	60	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Semiclassical description of light-matter interaction in solids and nanostructures
- Linear and nonlinear optical properties of two- and multi-level systems
- Optical Bloch equations
- Rabi oscillations, quantumbeatings
- Theoretical description of pump-probe and four-wave mixing experiments
- Microscopic many-body theory for optical excitations in semiconductors and nanostructures
- Semiconductor Bloch equations
- Excitons and other many-particle effects
- Relaxation and dephasing
- Self-consistent description of light propagation in solids and nanostructures; polaritons

5 Learning outcomes / competencies:

Students

- know the derivation and basic properties of the optical Bloch equations,
- can solve the optical Bloch equations using various approximation strategies and use the results to describe linear and nonlinear optical properties,
- are familiar with concepts for describing many-particle effects in semiconductor optics and can apply them to derive the semiconductor Bloch equations,
- can calculate exciton effects in linear optical spectra within the framework of the semiconductor Bloch equations and describe nonlinear optical properties approximately,
- are familiar with the fundamental physical processes that lead to the dephasing of optical polarization and to the energy relaxation of optically generated charge carrier occupations,
- are familiar with the basic concept of the self-consistent description of light propagation in solids and can use it to approximately calculate fundamental effects for simple geometries,
- are familiar with the possibilities and limitations of semiclassical many-particle theory for solid-state optics and can evaluate results from the specialist literature against this background.

6	**Examination:** [X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** Prof. Dr. Torsten Meier, Prof. Dr. Stefan Schumacher
13	**Other information:** None

Quantum Information Theory

Quantum Information Theory

Module group:	Workload (h):	CP:	Semester:	Frequency:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	QuantumInformation Theory	L	30	60	E	up to 60
b)	QuantumInformation Theory	E	30	60	E	up to 30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

- Quantum mechanics in modern formulation (states, effects, operations, and representationtheorems)
- Separability and non-separability of statistical operators
- Einstein-Podolsky-Rosen paradox
- Quantum cryptography
- Quantum computers
- Quantum teleportation

5 **Learning outcomes / competencies:**

Students should learn the basic concepts of quantum information theory. They should be able to understand current research and perform basic calculations themselves.

Students

- are familiar with the modern formulation of quantummechanics,
- are familiar with the concept of separability/non-separability and can apply it to statistical operators,
- are familiar with the ideas and interpretations underlying the Einstein-Podolsky-Rosen paradox and the quantum mechanical description of entangled states,
- are familiar with the fundamental processes that form the basis for quantumcryptography, quantumcomputers, and quantumteleportation, and can describe the phenomena using model systems.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** Prof. Dr. Jan Sperling, Prof. Dr. Torsten Meier
13	**Other information:** None

Theoretical Quantum Optics

Theoretical Quantum Optics

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Theoretical Quantum Optics	L	30	60	E	up to 60
b)	Theoretical Quantum Optics	E	30	60	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Canonical field quantization
- Fock states, coherent states, squeezed light
- Statistics of light states
- Phase space functions (P, W, Q functions)
- Bunching and antibunching
- Correlation functions
- Quantum theory of light-matter interaction
- Jaynes-Cummings model, dressed states

5 Learning outcomes / competencies:

Students should learn basic concepts of theoretical quantum optics. They should be able to understand current research work and perform basic calculations themselves.

Students

- are familiar with the concept of photons and understand how to use photon operators.
- are familiar with the theoretical description of light states that can be generated in modern experiments,
- are familiar with the theoretical statistical interpretation of light and can thus interpret measurement results,
- are familiar with the phase space functions of the most important light states,
- are familiar with the different behavior of classical and quantized light with regard to light-matter interaction,
- are familiar with the derivation and evaluation of the Jaynes-Cummings model and can apply it to simple extended model systems.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** Dr. Matthias Reichelt, Prof. Dr. Torsten Meier
13	**Other information:** None

Sensor Technology

Sensor Technology

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	2	SS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Sensor Technology	L	30	60	E	50
b)	Sensor Technology	E	30	60	E	50

2 Options within the module:

None

3 Participation requirements:

None

4 Course content:

Contents of the Sensor Technology course:
Brief description
The course "Microsensor Technology" covers concepts and operating principles of microelectronic sensors. The field of application ranges from temperature and radiation sensors to chemical sensors such as lambda probes in the automotive sector and magnetic field sensors, thus covering a broad spectrum. The course also aims to provide a basic understanding of the manufacture of hybrid and integrated sensors. Contents
The following topics are covered in detail:

- Manufacturing processes
- Temperature sensors
- Sensors for force, pressure, and acceleration
- Magnetic field sensors
- Humidity sensors
- Chemical sensors

5 Learning outcomes / Competencies:

Professional competence:
After attending the course, students will be able to

- understand and explain the manufacturing processes of microelectronic components
- comprehend and describe the operating principles of various sensors
- assign areas of application for different sensors for real-world use

Interdisciplinary skills:
Students can

- Findapplication-specific solutions
- apply the problem-solving strategies they have learned across disciplines,
- present their solutions to other participants in exercises, and
- deepen the skills they have acquired through self-study.

<table>
<tr><td>6</td><td colspan="4">Examination:
[X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)</td></tr>
<tr><td></td><td>for</td><td>Examination format</td><td>Duration or scope</td><td>Weighting for the module grade</td></tr>
<tr><td></td><td>a) and b)</td><td>Written examor
Oral exam or presentation</td><td>120–180 min
30–45 min
30 min</td><td>100</td></tr>
<tr><td>7</td><td colspan="4">Coursework/qualified participation:
None</td></tr>
<tr><td>8</td><td colspan="4">Requirements for participation in examinations:
None</td></tr>
<tr><td>9</td><td colspan="4">Requirements for awarding credit points:
Credit points are awarded once the final module examination has been passed.</td></tr>
<tr><td>10</td><td colspan="4">Weighting for overall grade:
The module is weighted by the number of credit points (factor: 1).</td></tr>
<tr><td>11</td><td colspan="4">Use of the module in other degree programs:
The module is also used in the Electrical Systems Engineering master's program.</td></tr>
<tr><td>12</td><td colspan="4">Module coordinator:
Prof. Dr. Ulrich Hilleringmann</td></tr>
<tr><td>13</td><td colspan="4">Additional information:
Methodological implementation
• Lecture with projector and blackboard
• Classroomexercises with worksheets on theoretical principles, presentation of solutions by exercise participants
Learning materials, bibliography Lecture slides
• Hilleringmann: Microsystems Technology
• Elbel: Microsensor Technology
• Current references to supplementary literature and teaching materials on the website</td></tr>
</table>

QuantumOptics

QuantumOptics

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	3	WS	1	English	E

1

	Course	Teaching format	Contact time (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	QuantumOptics	L	30	60	E	up to 60
b)	QuantumOptics	E	30	60	E	up to 30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Contents:**

This module covers the fundamental concepts required to understand quantum optics with light. The following topics are discussed in detail:

- Photon statistics and photodetection of quantum light
- Fundamental ideas of field quantization, Fock states, and single-mode and multi-mode quantum states
- Coherent states and phase space representations of light
- Beam splitters and interferometers in quantum optics, Hong-Ou Mandel interference
- Non-classical light, single-photon states, squeezed states, homodyne detection
- Correlation functions and quantumcoherence, Hanbury-Brown Twiss experiments

5 **Learning outcomes / competencies:**

Mastery of the fundamental concepts of quantum optics, including knowledge of specific phenomena that distinguish quantum optical observation from classical experiments.

The students

- are familiar with the concepts of quantum optics and can link them to experimental setups,
- are able to use computational methods from quantum mechanics to solve practical problems in experimental quantum optics,
- can distinguish quantum optical observations from purely classical optical experiments,
- understand the principle of field quantization and its implications for the definition of a photon and the formally correct description of wave-particle duality,
- understand the modeling of "classical" laser light and the significance of photon statistics,
- are proficient in calculating quantuminterference in various setups,
- can assess the applicability of non-classical light states in practice.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics.
12	**Module coordinator:** Prof. Dr. Christine Silberhorn, Prof. Dr. Tim Bartley
13	**Other information:** None

Semiconductor Heterostructures: Fundamentals and Applications

Semiconductor Heterostructures: Fundamentals and Applications

Module No.:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
01e	180	6	1	WS	1	English	E

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Semiconductor Heterostructures: Fundamentals and Applications	L	30	60	E	up to 60
b)	Semiconductor Heterostructures: Fundamentals and Applications	E	30	60	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

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

5 Learning outcomes / Competencies:

Mastery of the fundamental concepts in the field of semiconductor heterostructures, including aspects of fabrication and electrical and optical properties.

Students

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

6	**Examination:** [X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a)-b)	Written or oral examination	120–180 min 30–45 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics and the Master's program in Materials Science.
12	**Module coordinator:** Prof. Dr. Dirk Reuter, Prof. Dr. Donat As
13	**Additional information:** Prior knowledge of solid state and semiconductor physics is desirable.

Physics and Technology of Nanomaterials

Physics and Technology of Nanomaterials

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	3	Winter	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Physics and Technology of Nanomaterials	L	45	90	E	up to 60
b)	Physics and Technology of Nanomaterials	E	15	30	E	up to 30

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

- Thermodynamic and crystallographic fundamentals and properties of nanomaterials
- Production of thin films from the liquid phase and vacuum, epitaxy, wetting and de-wetting
- Structuring and modification of thin films using thermal, wet chemical, ion beam-assisted, and plasma-based processes
- Lateral structuring of thin films and surfaces using conventional and modern lithography processes
- Production, processing, and application of one-, two-, and three-dimensional nano-objects (nanowires and tubes, graphene and other 2D materials, nanoclusters, quantum dots, core-shell structures)

5 Learning outcomes / competencies:

Students should be able to develop technological concepts for the production of nanostructured materials and surfaces and assess their prospects of success.

Students

- understand the special properties that materials acquire through nanostructuring,
- are familiar with different basic concepts and processes for producing structures that have nanoscale dimensions in one, two, or three dimensions,
- understand the physical background of these processes on an atomic or molecular basis,
- can apply the qualitative and quantitative models that describe such processes,
- have the ability to apply the methods they have learned to new questions and material systems in an interdisciplinary manner and to combine them in different ways,
- are able to independently acquire additional nanostructure manufacturing technologies by studying specialist literature and Internet sources and to present them in a reflective manner.

6	**Examination:** [X] Module final examination (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) or b)	Written exam or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics and in the Master's program in Materials Science.
12	**Module coordinator:** Prof. Dr. Jörg Lindner, Prof. Dr. Dirk Reuter
13	**Other information:** None

Fast Integrated Circuits for Wireline Communications

Fast Integrated Circuits for Wireline Communications

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	3	WS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Fast Integrated Circuits for Wireline Communications	L	30	60	E	50
b)	Fast Integrated Circuits for Wireline Communications	E	30	60	E	50

2 **Options within the module:**

None

3 **Prerequisites:**

Recommended: Module "Analysis and Design of Electronic Circuits" or comparable modules/lectures

4 **Contents:**

Brief description

In fiber optic communications, commercial systems today achieve very high bit rates of over 100 Gb/s per optical channel and several Tb/s in a single fiber. Similarly, signal transmission between chips now involves high bit rates of more than 10 Gb/s at a single housing pin, which must be transmitted via printed circuit boards and inexpensive serial cable connections. In the future, advances in CMOS technology and optical communication technology will continue to increase data rates. The design of electronic circuits for high bandwidths and bit rates requires a good understanding of the system in terms of typical transmission/reception architectures, components, and signal characteristics. In addition, a good understanding of integrated circuit design and accurate high-frequency modeling of passive and active components is necessary. The aim of the lecture is to give students an understanding of the methodical design of fast integrated electronic circuits for digital wired communication technology. Some of the exercises will be carried out as CAD exercises using modern chip design software.

Content

The lecture teaches the methodical design of fast, integrated electronic circuits for digital wired communication systems. Some of the exercises are carried out as CAD exercises using modern chip design software. The lecture covers:

- Transmission and reception architectures for fiber optic communication
- Transmission and reception architectures for chip-to-chip communication
- System theory fundamentals
- Semiconductor technologies and integrated RF components
- Amplifier circuits
- Logic circuits in current mode logic (CML)
- PLL technology for synthesizers and clock recovery
- Measurement method

5	**Learning outcomes / Competencies:** Technical competence: Students will be able to: Describe and analyze transmission and reception architectures for broadband communication. Understand and describe semiconductor technologies and high-frequency components for broadband communication. Analyze circuit techniques for transmission and reception circuits and describe measures for optimization. Describe circuits in PLL technology for frequency synthesis and clock recovery. Describe measurement methods. Interdisciplinary skills: Students learn how various interdisciplinary scientific fields—such as mathematical signal and system analysis, nonlinear and linear circuit analysis, semiconductor physics, components, and high-frequency technology—are combined to develop communications applications.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written examor Oral exam or presentation	120–180 min 30–45 min 30 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Electrical Systems Engineering master's program.
12	**Module coordinator:** Prof. Dr.-Ing. J. Christoph Scheytt
13	**Additional information:** Methodological implementation Lecture with exercises (including computer-aided design with IC design software) Learning materials, bibliography Handouts and literature references will be provided during the lecture. • E. Säckinger, “Broadband Circuits for Optical Fiber Communication,” Wiley, 2005 • B. Razavi, “Design of Integrated Circuits for Optical Communications,” McGraw-Hill, 2003 Comments As part of the lecture, a two-day excursion to the IHP Leibniz Institute for Innovative Microelectronics in Frankfurt (Oder) will be offered, including a tour of a modern chip manufacturing facility (participation is voluntary).

Photonic Nanostructures

Photonic Nanostructures

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	3	WS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Photonic Nanostructures	L	30	60	E	up to 60
b)	Photonic Nanostructures	E	30	60	E	up to 30

2 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 / competencies:

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

Students

- will be able to independently identify and differentiate issues in the field of nano-optics and distinguish them from optics in macroscopic objects.
- have the ability to describe and evaluate effects that occur when light interacts with dielectric and metallic nanostructures,
- can independently develop solutions to more complex problems involving optical nanostructures and justify them using the knowledge they have acquired,
- can develop and justify meaningful analytical and numerical approximation methods for solving problems in the field of nanophotonics under guidance,
- have the ability to independently engage with current English-language specialist literature on the subject of nano-optics.

6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written or oral exam	120–180 min 30–45 min	100

7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded upon passing the final module examination.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics and in the Master's program in Chemistry.
12	**Module coordinator:** Prof. Dr. Cedrik Meier, Prof. Dr. Thomas Zentgraf
13	**Other information:** None

Data Science for Dynamical Systems

Data Science for Dynamical Systems

Module group:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
Specialization	180	6	3	WS	1	English	E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Data Science for Dynamical Systems	L	30	60	E	up to 30
b)	Data Science for Dynamical Systems	E	30	60	E	up to 30

2 **Options within the module:**

None

3 **Participation requirements:**

None

4 **Course content:**

Contents of the course Data Science for Dynamical Systems:
This course has a modular structure and is offered on an interdisciplinary basis for various degree programs and faculties. Depending on the prior knowledge of the participants, the content will be tailored to the specific degree program. Overarching core topics include

- Fundamentals of modeling dynamic systems using differential and difference equation models
- Data-driven identification methods for linear models based on the least squares approach
- Data-driven identification methods for nonlinear models (e.g., artificial neural networks)
- Learning from data-driven models incorporating a priori systemknowledge
- Identification of underlying model structure equations (topology selection), e.g., by means of regularization or hypothesis testing with regard to competing target criteria
- (Data-driven) model reduction
- Manipulation of available model input data (dimension reduction and augmentation methods), e.g., autoencoders, principal component analysis, and kernel methods
- Statistical evaluation of the available input and output data of dynamic systems and corresponding methods for system excitation
- Statistical evaluation of the achieved model quality (overfitting vs. underfitting) using cross-validation

In addition to teaching methodological knowledge, extensive programming and simulation exercises are carried out using modern software programs (especially in the Julia programming language). A wide range of practical application examples from various domains (e.g., engineering, natural sciences, and economics) round off the course.

5	**Learning outcomes / competencies:** Upon completion of the course, participants will be able to • describe and apply methods for identifying dynamic systems, • critically evaluateidentification results, • understand and analyze complex data-driven modeling tasks in interdisciplinary teams, derive effective solution methods, and evaluate independently developed results.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

for	Examination format	Duration or scope	Weighting for the module grade
a) and b)	Written examor Oral exam or presentation	120–180 min 30–45 min 30 min	100

7	**Coursework/qualified participation:** None
8	**Requirements for participation in examinations:** None
9	**Requirements for awarding credit points:** Credit points are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** None
12	**Module coordinator:** Dr. Oliver Wallscheid, Assistant Professor Sebastian Peitz
13	**Other information:** None

Lab Courses

Lab Courses

Module number:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
	150	5	1st + 2nd	Every semester	2	English	P

1 Module structure:

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Lab courses	P	60	90	P	4 (two groupstaught in parallel)

2 Options within the module:

None

3 Participation requirements:

None

4 Contents:

The lab courses cover experiments in the field of optoelectronics and photonics. Students select three experiments from a list of topics published via the electronic campus management system. Experiments on the following topics are possible: Ellipsometry and angle-resolved optical analysis, waveguide characterization, parametric photon pair sources, diode-pumped solid-state lasers with frequency doubling, optical length measurement, characterization of optoelectronic components: LED lasers, nonlinear optics on the computer, photodetectors, optical communications and high-frequency technology, electromagnetic field simulations, modern light sources, correlated microscopy. The specific list of topics will be announced via the electronic campus management system.

5 Learning outcomes / competencies:

Introduction to independent work and experimentation through small research-related projects with clearly defined tasks. The experiments to be carried out are designed to include a significant amount of independent experimentation and setup. This builds a bridge between the typical experiments in the advanced practical course in the bachelor's program in physics, which are still largely carried out under very detailed guidance with ready-made equipment, and the scientific work required in the Lab Project and Master's Thesis modules. The experiments offered are designed to go well beyond typical textbook topics and effects and to include application-related aspects that are considered professionally qualifying for later work in a research-related professional environment in the field of optoelectronics. Students learn to recognize and extract essential correlations from their own experimental experiences, as well as to evaluate and present the results.

Students

- learn to work and experiment independently by working on small research-related projects with clearly defined tasks.
- learn how to use modern, complex physical experimental methods in a real research environment within a working group,

	• learn how to use specialized scientific literature in English both to prepare for the various experiments and to document the results obtained in the style of a scientific publication, • can explain scientific results obtained in the context of current research.
6	**Examination:** [X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)
7	**Coursework / qualified participation:** None
8	**Requirements for participation in examinations:** The student must have been present on the days of the experiment.
9	**Requirements for the awarding of credits:** Credits are awarded once the final module exam has been passed.
10	**Weighting for overall grade:** The module is weighted according to the number of credit points (factor: 1).
11	**Use of the module in other degree programs:** The module is also used in the Master's program in Physics and in the Master's program in Materials Science.
12	**Module coordinator:** Prof. Dr. Thomas Zentgraf
13	**Other information:** None

Examination table (item 6):

to	Examination format	Duration or scope	Weighting for the module grade
a)	All attempts	3 tests	100

Topics in Optoelectronics and Photonics

Topics in Optoelectronics and Photonics

Module number:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
	120	4	3	Every winter semester	1	English	P

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Topics in Optoelectronics and Photonics	S	30	90	P	20

2 **Options within the module:**
None

3 **Participation requirements:**
None

4 **Contents:**
During the seminar, students are encouraged to explore current topics in modern physics, delve deeper into them, and ultimately present their findings in their own presentations as part of the course. This opportunity to present their own work serves both to further their subject-specific education in current areas of research and to develop their personal presentation skills. Current topics include:
Heterodyne interferometers, white light interferometry, parametric amplifiers, interferometric length measurement, optical incremental encoders, rubidium atomic clocks, optical frequency combs, STED microscopy, erbium-doped fiber amplifiers, single-mode semiconductor lasers, femtosecond lasers: Kerr lens modelocking, FRET energy transfer, single-photon sources, generation of entangled photons, Hong-Ou-Mandel effect, holography, modern solar cells, THz spectroscopy, optical coherence tomography, SHG microscopy, optical gas sensing, Raman spectroscopy, material processing with lasers, photon-counting detectors,
CCD sensors, streak cameras

5 **Learning outcomes / competencies:**
In the preparation phase: Preparation and consolidation of the topic through independent study and research. Recognizing and formulating the connection to related sub-areas of the topic. Preparing the presentation according to didactic and technical criteria.
During**the presentation phase**: Training your presentation and dialogue skills when answering questions. Practicing giving and listening to a scientific presentation as well as leading the discussion. This promotes presentation and moderation skills.

6 **Examination:**

[to	Examination format	Duration or scope	Weighting for the module grade
a)	Presentation	approx. 30 min.	100

7 **Coursework / qualified participation:**
None

8 **Requirements for participation in examinations:**
None.

9	**Requirements for awarding credits:** Credits are awarded once the final module examination has been passed.
10	**Weighting for overall grade:** The module is weighted by the number of credits it carries (factor: 1).
11	**Use of the module in other degree programs:** None.
12	**Module coordinator:** Prof. Dr. Stefan Schumacher, participating university lecturers in physics and electrical engineering
13	**Other information:** None

Lab Project

Lab Project

Module number:	Workload (h):	CP:	Semester:	Rotation:	Duration (in semesters):	Language:	P/E:
	420	14	3	WS/SS	1	English	P

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Lab Project	Vers.	5	415	P	1

2 **Options within the module:**
None.

3 **Participation requirements:**
None.

4 **Contents:**
Thematically narrowly defined project work in aresearch-oriented environment.

5 **Learning outcomes / competencies:**
In project work, students should practice independent scientific and/or engineering work on defined theoretical and practical tasks. This should enable them to solve complex problems, whereby they should learn not only independence but also organizational skills. They should also be able to formulate the research task, document the selection of methods and the analysis, and present the results of their work in a structured manner. After completing the project work, students will have in-depth technical expertise in a selected area and recognize the practical relevance of their course content.

6 **Examination:**
[X] Module final exam (MAP) [] Module examination (MP) [] Module partial examinations (MTP)

on	Examination format	Duration or scope	Weighting for the module grade
a)	Presentation	approx. 30 min.	100

7 **Coursework/qualified participation:**
None

8 **Requirements for participation in examinations:**
None

9 **Requirements for awarding credits:**
Credit points are awarded once the final module examination has been passed.

10 **Weighting for overall grade:**
The module is weighted by the number of credit points (factor: 1).

11 **Use of the module in other degree programs:**
None.

12 **Module coordinator:**
Prof. Dr. Stefan Schumacher, participating university lecturers in physics and electrical engineering

13 **Other information:**
None

General Studies

General Studies

Module number:	Workload (hours): 120	CP: 4	Semester: 1	Rotation: WS	Duration (in semesters): 1	Language: German/English	P/E: E

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	General studies	Vers.	30	90	E	Insurance

2 Options within the module:
Courses outside your own degree program from the range of electives offered by Paderborn University, which are announced in the electronic campus management system.

3 Participation requirements:
None

4 Contents
Courses outside of your own degree program from the range of electives offered by Paderborn University, which are announced in the electronic campus management system.

5 Learning outcomes / competencies:
In General Studies, students acquire key competencies (e.g., communication or foreign languages) on the one hand, and on the other hand, they explore areas of knowledge beyond the boundaries of their own degree program, thereby reflecting on other academic cultures. Selected modules should not be directly related to the field of electrical engineering or physics.

6 Examination:
None.

7 Coursework/qualified participation:
Qualified participation in each course.

8 Requirements for taking exams:
None

9 Requirements for awarding credits:
Credits are awarded once qualified participation in the course has been demonstrated.

10 Weighting for overall grade:
The module is not included in the overall grade.

11 Use of the module in other degree programs:
None

12 Module coordinator:
Prof. Dr. Stefan Schumacher, various (import from various areas)

13 Other notes:
None

Master's thesis

Master's thesis

Module number:	Workload (h):	CP:	Semester:	Cycle:	Duration (in semesters):	Language:	P/E:
	90	30	4	WS/SS	1	English	P

1

	Course	Teaching format	Contact hours (h)	Self-study (h)	Status (C/E)	Group size (participants)
a)	Master's thesis		10	889.5	P	1
b)	Oral defense		0.5		P	1

2 Options within the module:

3 Prerequisites for participation:
Successfully completed Lab Project, at least 74 CPs already earned, in the case of conditional enrollment, proof of passing the corresponding exams.

4 Contents:
Independent work on a research topic, presentation of the topic, the results achieved, and discussion of their relevance in the written master's thesis, presentation, and defense.

5 Learning outcomes / competencies:
In-depth learning of independent scientific work based on a more complex research topic.

6 Examination:
[] Module final exam (MAP) [] Module exam (MP) [X] Module partial examinations (MTP)

for	Examination format	Duration or Scope	Weighting for the module grade
a)	Master's thesis	50 to 70 pages (excluding appendices)	5/6
b)	Oral defense including examination interview	30-45 min	1/6

7 Coursework/qualified participation:
None

8 Requirements for participation in examinations:
The prerequisite for participation in the oral defense is a passing grade on the written master's thesis.

9 Requirements for the awarding of credit points:
The credit points are awarded once the master's thesis and the oral defense, including the examination interview, have been passed.

10 Weighting for overall grade:
The module is weighted by the number of credit points (factor: 1).

11 Use of the module in other degree programs:
None.

12 Module coordinator:
Prof. Dr. Stefan Schumacher, participating university lecturers in physics and electrical engineering

13 Other information:
None