

# Description of Module Master of Science

## 628 Photonics

### PO-Version 2013

FRIEDRICH-SCHILLER-  
UNIVERSITÄT  
JENA

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**Note :**

Please note that you can find the information on examinations, courses corresponding to the examinations, and examination dates in the portal Friedolin under the menu item 'Browse module descriptions'. After logging in, please choose your degree, your study programme, and respective module. Any immediate changes made will be displayed promptly.

Modul <b>MedPhoA1.2</b> Optical Engineering	
Module code	MedPhoA1.2
Module title (German)	Optical Engineering
Module title (English)	Optical Engineering
Person responsible for the module	Herbert Gross, Michael Kempe, Maria Dienerowitz
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	--
Prerequisite for what other modules	This module is part of the block „Adjustment” of the 1st semester.
Type of module (compulsory module, required elective module, elective module)	The module is mandatory for students not having a Bachelor degree in physics. Students of physics having passed the corresponding modules during their studies do not need to participate in this course.
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	lectures: 2h/week exercises: 1h/week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<ul style="list-style-type: none"> <li>• Introduction to optics</li> <li>• Geometrical optics: postulates of ray optics, paraxial optics, matrix approach, raytracing</li> <li>• Simple optical components: lenses, mirrors, stops • Wave optics: postulates of wave optics, relation between wave optics and ray optics</li> <li>• Optical imaging: field and pupil, magnification, lens maker's formula, afocal systems</li> <li>• Photometry and illumination, color</li> <li>• Optical instruments</li> <li>• Image quality: primary aberrations, wave aberrations, correction of systems</li> <li>• Beam optics: the Gaussian beam, transmission of a Gaussian beam through optical components, beam shaping</li> <li>• Optical properties of materials: metals, ceramics, glass, polymers and composites</li> <li>• Electromagnetic optics: electromagnetic theory of light, dielectric media, elementary electromagnetic waves, absorption and dispersion</li> <li>• Optical components II: Fibers, prisms, sensors, aspheres, arrays</li> <li>• Special topics: scanning, adaptive optics, gradient index optics</li> </ul>
Intended learning outcomes	<p>This module provides an introduction into the fundamentals of optics and photonics which are necessary to understand optical phenomena in modern science and technology.</p> <p>Topics include an introduction into the theory of light (ray optics, wave optics, electromagnetic optics, photon optics), the theory of interaction of light with matter and the theory of semiconductor materials and their optical properties.</p>
Prerequisites for admission to the module examination	none
Requirements for awarding credit points (type of examination)	written examination at the end of the semester
Additional information on the module	<p>Used media:</p> <p>Lectures/exercises: blackboard, projector</p>
Recommended reading	<ul style="list-style-type: none"> <li>• E. Hecht: Optics, 4th ed., Addison-Wesley 2001</li> <li>• B.E.A. Saleh, M.C. Teich: Fundamentals of Photonics 2nd ed., Wiley 2007.</li> </ul>
Language of instruction	English

Modul <b>PAFMF002</b> Electronic Structure Theory	
Module code	PAFMF002
Module title (German)	Theorie der Elektronenstruktur
Module title (English)	Electronic Structure Theory
Person responsible for the module	Prof. Dr. U. Peschel
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 3 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 75 h 165 h
Content	Introduction to the many-body problem; Wavefunction-based approaches for electronic structure; Density functional theory; Electronic excitations: beyond density functional theory.
Intended learning outcomes	Electronic structure theory is a successful and ever-growing field, shared by theoretical physics and theoretical chemistry, that takes advantage from the increasing availability of high-performance computers. Starting only from the knowledge of the types of atoms that constitute a material (molecule, solid, nanostructure,...) students will learn how to determine without further experimental input, i.e. using only the laws of quantum physics, its structural and electronic properties. The lecture will initiate the students to the state-of-the-art theoretical and computational approaches used for electronic structure calculations. In the practical classes the students will learn through tutorials to use different software for electronic structure simulations. During the last month they will realize a small independent scientific project.

Prerequisites for admission to the module examination	Course exercises to be submitted; Further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	128 M.Sc.Physics: Specialization "Solid state physics / Material science". If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMF003</b> Solid State Optics	
Module code	PAFMF003
Module title (German)	Solid State Optics
Module title (English)	Solid State Optics
Person responsible for the module	Prof. Dr. H. Krüger
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology: Required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	2 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> <li>• Introduction to the many-body problem;</li> <li>• Wavefunction-based approaches for electronic structure;</li> <li>• Density functional theory;</li> <li>• Electronic excitations: beyond density functional theory.</li> </ul>
Intended learning outcomes	Electronic structure theory is a successful and ever-growing field, shared by theoretical physics and theoretical chemistry, that takes advantage from the increasing availability of high-performance computers. Starting only from the knowledge of the types of atoms that constitute a material (molecule, solid, nanostructure,..) we will learn how to determine without further experimental input, i.e. using only the laws of quantum physics, its structural and electronic properties. The lecture will initiate the students to the state-of-the-art theoretical and computational approaches used for electronic structure calculations. In the practical classes the students will learn through tutorials to use different software for electronic structure simulations. During the last month they will realize a small independent scientific project.



Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMF009</b> Optoelectronics	
Module code	PAFMF009
Module title (German)	Optoelektronik
Module title (English)	Optoelectronics
Person responsible for the module	Prof. Dr. G. Soavi
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization" 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Semiconductors</li> <li>• Optoelectronic devices</li> <li>• Photodiodes</li> <li>• Light emitting diodes</li> <li>• Semiconductor optical amplifier</li> </ul>
Intended learning outcomes	In this course the student will learn how to solve problems related to the fundamentals of semiconductor optical devices such as photodiodes, solar cells, LEDs, laser diodes and semiconductor optical amplifiers.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul <b>PAFMF018</b> Quantum Information Theory	
Module code	PAFMF018
Module title (German)	Quanteninformationstheorie
Module title (English)	Quantum Information Theory
Person responsible for the module	Prof. Dr. M. Gärttner
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Quantum mechanics, linear algebra
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module specialization "Quantum and Gravitational Theory" 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	At irregular intervals
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<p>Lecture of Drs. Eilenberger, Steinlechner</p> <ul style="list-style-type: none"> <li>• Basic introduction to quantum optics;</li> <li>• Quantum light sources;</li> <li>• Encoding,</li> <li>• transmission and detection of information with quantum light;</li> <li>• Quantum communication and cryptography;</li> <li>• Quantum communication networks;</li> <li>• Outlook on Quantum metrology and Quantum imaging;</li> </ul> <p>Lecture of Dr. Sondenheimer</p> <ul style="list-style-type: none"> <li>• Open quantum systems, Density matrix formalism, Generalized measurements, Quantum channels</li> <li>• Superdense coding, quantum teleportation</li> <li>• Entanglement theory, Bell inequalities,</li> <li>• CHSH inequalities</li> <li>• Quantum circuits, universal gates</li> <li>• Quantum error correction</li> </ul>
Intended learning outcomes	<p>The course will give a basic introduction into the usage of quantum states of light for the exchange of information. It will introduce contemporary methods for the generation of quantum light and schemes that leverage these states for the exchange of information, ranging from fundamental concepts and experiments to state of the art implementations for secure communication networks. The course will also give an outlook to aspects of Quantum metrology and imaging. After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum information exchange and some aspects related to the practical implementation thereof. They will be able to apply their knowledge in the assessment and setup of experiments and devices for applications of quantum information processing.</p> <p>Vermittlung grundlegender Kenntnisse zur Übertragung und Verarbeitung von Information mit Hilfe von Quantensystemen als Informationsträger. Informationstheoretische Beherrschung der Verschränktheit von Quantensystemen.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	<p>Written or oral examination (100%);</p> <p>The selected form of the exam will be announced at the beginning of the semester.</p>
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMF021</b> 2D materials	
Module code	PAFMF021
Module title (German)	Zweidimensionale Materialien
Module title (English)	2D materials
Person responsible for the module	Prof. Dr. G. Soavi
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> <li>• Graphene: electrical and optical properties. Applications in electronic and optoelectronic.</li> <li>• Semiconducting 2D materials: Coulomb screening and the concept of excitons. Optical spectroscopy of excitons. Optoelectronic applications.</li> <li>• Heterostructures: electron and exciton interactions in layered heterostructures</li> </ul>
Intended learning outcomes	<ul style="list-style-type: none"> <li>• Mastering the basics and methods of two-dimensional materials</li> <li>• Ability to work independently on problems in the field of two-dimensional materials</li> </ul>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	

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Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0001</b> Fundamentals of Modern Optics	
Module code	PAFM0001
Module title (German)	Fundamentals of Modern Optics
Module title (English)	Fundamentals of Modern Optics
Person responsible for the module	Prof. Dr. T. Pertsch
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	628 M.Sc. Photonics: Compulsory Module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "adjustment"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> <li>• Basic concepts of wave optics</li> <li>• Dielectric function to describe light-matter interaction</li> <li>• Propagation of beams and pulses</li> <li>• Diffraction theory- Elements of Fourier optics</li> <li>• Polarization of light</li> <li>• Light in structured media</li> <li>• Optics in crystals</li> </ul>
Intended learning outcomes	The course covers the fundamentals of modern optics which are necessary for the understanding of optical phenomena in modern science and technology. The students will acquire a thorough knowledge of the most important concepts of modern optics. At the same time the importance and applications of optics in technology will be taught. This will enable students to solve advanced problems in general optics and follow more specialized courses in photonics.
Prerequisites for admission to the module examination	-



Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO002</b> Structure of Matter	
Module code	PAFMO002
Module title (German)	Structure of Matter
Module title (English)	Structure of Matter
Person responsible for the module	Prof. Dr. A. Tünnermann (FSU), Dr. O. Stenzel (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Module Adjustment 628 M.Sc. Photonics: Compulsory Module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> <li>• Classical interaction of light with matter</li> <li>• Basic knowledge on quantum mechanics</li> <li>• Einstein coefficients and Plancks formula</li> <li>• Selection rules</li> <li>• Hydrogen atom and helium atom</li> <li>• Introduction to molecular spectroscopy</li> <li>• Dielectric function and linear optical constants</li> <li>• Kramers-Kronig-Relations</li> <li>• Linear optical properties of crystalline and amorphous solids</li> <li>• Basic nonlinear optical effects</li> </ul>

Intended learning outcomes	<p>The students</p> <ul style="list-style-type: none"> <li>• understand the classical interaction of light with matter and basic quantum mechanics</li> <li>• can apply Einstein coefficients, Planck's formula, and selection rules</li> <li>• have a solid understanding of the hydrogen and helium atoms</li> <li>• can analyze molecular spectroscopy data and optical properties of materials</li> <li>• understand the dielectric function, Kramers-Kronig relations, and basic nonlinear optical effects</li> </ul>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	
Recommended reading	<p>Demtröder, "Experimental physics II"</p> <p>Demtröder, "Experimental physics III – atoms, molecules and solids"</p> <p>R. Feynman, "Feynman lectures on physics III quantum mechanics"</p> <p>Jackson, "Classical Electrodynamics"</p> <p>E. Hecht, "Optics"</p>
Language of instruction	English

Modul <b>PAFMO004</b> Laser Physics	
Module code	PAFMO004
Module title (German)	Laser Physics
Module title (English)	Laser Physics
Person responsible for the module	Prof. Dr. J. Limpert (FSU), Prof. Dr. S. Nolte (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective Module 628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 4 SWS and exercise 2 SWS
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<ul style="list-style-type: none"> <li>• Introduction to laser physics (stimulated emission, atomic rate equations, laser pumping and population inversion);</li> <li>• Optical beams and laser resonators;</li> <li>• Laser dynamics;</li> <li>• Q-switching;</li> <li>• Mode locking;</li> <li>• Wavelength tuning and single frequency operation;</li> <li>• Laser systems;</li> <li>• Selected industrial and scientific applications.</li> </ul>
Intended learning outcomes	<p>The students</p> <p>understand the fundamental equations and concepts of laser theory</p> <p>can explain the working principles of different laser types, including gas, ruby, and diode-pumped solid-state lasers</p> <p>are familiar with key laser applications and their underlying physical principles</p> <p>can analyze and compare laser systems in terms of design, performance, and application areas</p>

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	<ul style="list-style-type: none"><li>• Siegman, Lasers;</li><li>• W. Koechner, Solid-State Laser Engineering;</li><li>• W. Demtröder, Laser Spectroscopy;</li><li>• D. Bäuerle, Laser Processing and Chemistry;</li><li>• H.-G. Rubahn, Laser Applications in Surface Science and Technology.</li></ul>
Language of instruction	English

Modul <b>PAFMO005</b> Optical Metrology and Sensing	
Module code	PAFMO005
Module title (German)	Optical Metrology and Sensing
Module title (English)	Optical Metrology and Sensing
Person responsible for the module	Prof. Dr. Isabelle Staude (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 628 M.Sc. Photonics: compulsory module 128 MSc. Physics: required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Basic principles</li> <li>• Wave optical fundamentals</li> <li>• Sensors</li> <li>• Fringe projection, triangulation</li> <li>• Interferometry and wave front sensing</li> <li>• Holography</li> <li>• Speckle methods and OCT</li> <li>• Phase retrieval</li> <li>• Metrology of aspheres and freeform surfaces</li> <li>• Confocal methods</li> </ul>

Intended learning outcomes	The students understand the basic principles and wave optical fundamentals of optical metrology are familiar with key sensor technologies and measurement techniques can apply interferometry, holography, and speckle methods for precise measurements understand phase retrieval and its role in optical metrology can analyze and compare metrology techniques for aspheres, freeform surfaces, and confocal methods
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul <b>PAFM0006</b> Introduction to Optical Modeling	
Module code	PAFM0006
Module title (German)	Introduction to Optical Modeling
Module title (English)	Introduction to Optical Modeling
Person responsible for the module	Prof. Dr. F. Wyrowski (FSU), apl. Prof. Dr. U. W. Zeitner (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective Module 628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Concepts of ray tracing; Modeling and design of lens systems; Image formation; Physical properties of lenses and lens materials in optical design; Image aberrations and methods to avoid them; Vectorial harmonic fields; Plane waves; Fourier transformation and spectrum of plane waves representation; Concepts of field tracing; Propagation techniques through homogeneous and isotropic media; Numerical properties of propagation techniques.
Intended learning outcomes	The course enables students to solve problems related to the modeling and design of optical elements and systems. In the first part of the lecture we focus on ray-tracing techniques and its application through image formation. Then we combine the concepts with physical optics and obtain field tracing. It enables the propagation of vectorial harmonic fields through optical systems. In practical exercises the students will get an introduction to the use of commercial optics modeling and design software.



Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Specialization in „Optics”. This module is regularly offered in parallel on-site and online (hybrid).
Recommended reading	<ul style="list-style-type: none"><li>• H. Gross, Handbook of Optical Systems Vol.1: Fundamentals of Technical Optics, Wiley-VCH;</li><li>• L. Mandel and E. Wolf, Optical Coherence and Quantum Optics;</li><li>• L. Novotny and B. Hecht, Principles of Nano-Optics.</li></ul>
Language of instruction	English

Modul <b>PAFMO007</b> Experimental Optics	
Module code	PAFMO007
Module title (German)	Experimental Optics
Module title (English)	Experimental Optics
Person responsible for the module	Prof. Dr. Stefan Nolte
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Practical course
ECTS credits	6 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	180 h - h - h
Content	Practical training in optics. Topics cover a broad range, including refraction, optical lenses, interferometry, laser fundamentals, spectroscopy, optical tweezers, adaptive optics, etc.
Intended learning outcomes	Students are enabled to solve problems related to experimental techniques in optics, the planning and preparation of a scientific measuring task, carrying out scientific labwork in optics together with a research team as well as preparation of a scientific report.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Lab Work mark (100%) Consists of acceptance tests and written reports
Additional information on the module	This module is regularly offered in parallel on-site and online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO008</b> Internship	
Module code	PAFMO008
Module title (German)	Internship
Module title (English)	Internship
Person responsible for the module	Prof. Dr. Stefan Nolte
Prerequisites for admission to the module	Completion of the practical Module Experimental Optics
Recommended or expected prior knowledge	Experimental Optics PAFMO007
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	<p>Practical course 300 h</p> <p>depending on the topic this total workload should be distributed approximately as:</p> <p>50 h introduction to the research topic (study of relevant literature, ...)</p> <p>190 h research work (in the lab for experimental topics and at computer etc. for theoretical topics)</p> <p>50 h preparation of the final report</p> <p>10 h preparation and carrying out presentation of the results</p>
ECTS credits	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	<p>300 h</p> <p>- h</p> <p>- h</p>
Content	Internship in industry or a research laboratory
Intended learning outcomes	The students are enabled to carrying out scientific work in an optical research laboratory together with a research team. They will learn how to prepare a written scientific report as well as how to present their research results in an oral presentation and to defend their results in scientific discussions.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	The students have to submit a written report (approximately 15-20 pages) and deliver a final presentation (10-20 minutes) with subsequent discussion. The final grade will be determined (100%) based on the research performance, the final report, and the presentation.

Additional information on the module -	
Recommended reading	specifically defined by the instructor of the internship
Language of instruction	English

Modul <b>PAFMO009</b> Research Lab	
Module code	PAFMO009
Module title (German)	Research Lab
Module title (English)	Research Lab
Person responsible for the module	Prof. Dr. Thomas Pertsch
Prerequisites for admission to the module	
Recommended or expected prior knowledge	Completion of the 2 practical Modules Experimental Optics PAFMO007 and Internship PAFMO008
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	<p>Practical course total workload: 540 h depending on the topic this total workload should be distributed approximately as:</p> <p>150 h introduction to the research topic (study of relevant literature, ...)</p> <p>270 h research work (in the lab for experimental topics and at computer etc. for theoretical topics)</p> <p>100 h preparation of the final report</p> <p>20 h preparation and carrying out presentation of the results</p>
ECTS credits	18 CP
Work load:	540 h
- In-class studying	- h
- Independent studying (incl. preparations for examination)	- h
Content	Advanced scientific work in a research laboratory
Intended learning outcomes	The students are enabled to carrying out advanced scientific work in an optical research laboratory with a substantial level of independence. They will learn how to prepare an extended written scientific report as well as how to present their complex research results in an oral presentation and to defend their results in scientific discussions.
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	The students have to submit a written report (approximately 20-30 pages) and deliver a final presentation (15-25 minutes) with subsequent discussion. The final grade will be determined (100%) based on the research performance, the final report, and the presentation.
Additional information on the module -	
Recommended reading	specifically defined by the instructor of the research team
Language of instruction	English

Modul <b>PAFMO100</b> Accelerator-based Modern Physics	
Module code	PAFMO100
Module title (German)	Beschleunigerbasierte moderne Physik
Module title (English)	Accelerator-based Modern Physics
Person responsible for the module	Prof. Dr. T. Stöhlker
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamentals of atomic physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week, Exercise: 1 h per week or seminar: 2 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	Basic concepts of particle accelerators, application of accelerators in basic science and medicine, landmark experiments
Intended learning outcomes	Students gain an overview of the various applications of particle accelerators, in particular for basic science and acquire the ability to solve related exercise problems and to prepare a presentation.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester or seminar talk.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	128 M.Sc. Physics: required elective module (Specialization in „Optics“ and “Solid State Physics/Material Science”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English (German on request)
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Modul <b>PAFM0101</b> Active Photonic Devices	
Module code	PAFM0101
Module title (German)	Active Photonic Devices
Module title (English)	Active Photonic Devices
Person responsible for the module	Prof. Dr. M. Schmidt
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 40 h 80 h
Content	Electro-optical modulation; Acousto-optical devices; Magneto-optics and optical isolation; Integrated lasers; Non-Linear devices for light generation;
Intended learning outcomes	Based on this course the students will acquire a comprehensive overview about active photonic devices such as switches or modulators. The course starts by an introduction to the most important parameters and physical principles. The Lecture will then focus onto real-world devices including the areas of electro-optics, waveguides, acousto-optics, magneto-optics and non-linear optics. During this lecture the fundamental principles as well as devices currently employed in photonics will be discussed to provide the students with the ability to solve related problems and to perform research in related fields.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0102</b> Analytical Instrumentations	
Module code	PAFM0102
Module title (German)	Analytical Instrumentations
Module title (English)	Analytical Instrumentations
Person responsible for the module	Prof. Dr. A. Tünnermann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Atomic and molecular structure, Basics of atomic spectroscopy techniques, Molecular spectroscopy: absorption, emission, vibrational and spectroscopy and microspectroscopy, basics of magnetic resonance spectroscopy, Hardware of spectrometers/ microscopes: light sources, detectors, optics, material point of view, Current applications and relevance in material and life sciences
Intended learning outcomes	In this course, the student will acquire the knowledge and analytical methods to investigate the structure and composition of matter. Basic principles of atomic and molecular structure will be refreshed towards better understanding experimental analysis techniques such as spectrophotometry, ellipsometry, fluorescence, infrared, Raman, etc. spectroscopy or microscopy. The course will focus on technological aspects of the experimental setup in analytical instrumentations. Modern applications of analytical instrumentations in material and life sciences will be discussed. After successful completion, the student will know their capabilities and limitations.
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0103</b> Applied Laser Technology I	
Module code	PAFM0103
Module title (German)	Applied Laser Technology I
Module title (English)	Applied Laser Technology I
Person responsible for the module	Prof. Dr. C. Eggeling, Prof. Dr. R. Heintzmann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	Overview over laser beam applications as a contactless and remote probe (macroscopic and microscopic, cw and ultrafast, dealing with spectroscopy, metrology, sensing, and multi-dimensional microscopy); Fundamental concepts of related physical and physico-chemical effects; Absorption and emission of light (selection rules); Ultrafast coherent excitation and relaxation (linear and non-linear optical processes); Light reflection and elastic/inelastic scattering.
Intended learning outcomes	The course covers the fundamentals and concepts of the selected laser applications. The students will acquire the knowledge to develop own solutions for challenges in laser applications.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester and/or seminar talk on topic of own choice
Requirements for awarding credit points (type of examination)	Oral examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0104</b> Applied Laser Technology II	
Module code	PAFM0104
Module title (German)	Applied Laser Technology II
Module title (English)	Applied Laser Technology II
Person responsible for the module	Prof. Dr. C. Eggeling, Prof. Dr. R. Heintzmann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 2 h (bi-weekly)
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Applied Laser Technology using the laser as a tool, microscopic and macroscopic light-materials-interactions, material preparation and modification (with the exception of classical laser materials' processing)
Intended learning outcomes	In various selected topics out of the broad field of laser applications, the students will acquire the knowledge to solve problems related to laser-material interactions (e.g. atom cooling and optical tweezer), laser induced processes in gases, liquids, and matrices (incl. laser isotope separation), materials' preparation and structuring by ablation, deposition and/or modification.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English



Modul <b>PAFM0106</b> Atomic Physics at High Field Strengths	
Module code	PAFM0106
Module title (German)	Atomic Physics at High Field Strengths
Module title (English)	Atomic Physics at High Field Strengths
Person responsible for the module	Prof. Dr. T. Stöhlker
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in atomic physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization" 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Strong field effects on the atomic structure</li> <li>• Relativistic and QED effects on the structure of heavy ions</li> <li>• X-ray spectroscopy of high-Z ions</li> <li>• Application in x-ray astronomy</li> <li>• Penetration of charged particles through matter</li> <li>• Particle dynamics in of atoms and ions in strong laser fields</li> <li>• Relativistic ion-atom and ion-electron collisions</li> <li>• Fundamental interaction processes</li> <li>• Scattering, absorption and energy loss</li> <li>• Detection methods</li> <li>• Particle creation</li> </ul>

Intended learning outcomes	The Module provides insight into the basic techniques and concepts in physics related to extreme electromagnetic fields. Their relevance to nowadays applications will be discussed in addition. The Module also introduces the basic interaction processes of high-energy photon and particle beams with matter, including recent developments of high intensity radiation sources, such as free electron lasers and modern particle accelerators. Experimental methods and the related theoretical description will be reviewed in great detail.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English (German on request)

Modul <b>PAFM0107</b> Attosecond Laser Physics	
Module code	PAFM0107
Module title (German)	Attosecond Laser Physics
Module title (English)	Attosecond Laser Physics
Person responsible for the module	Dr. A. Pfeiffer
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Strong-Field Laser Physics PAFMO266 or equivalent
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Coherent electron dynamics in atoms and molecules; Strong field effects and ionization; High harmonic generation and phase matching; Techniques for attosecond pulse generation; Transient absorption; Attosecond quantum optics with few-level quantum models.
Intended learning outcomes	The course gives an introduction into the young research field of attosecond physics. Electron dynamics in atoms and molecules on the attosecond time scale (which is the natural timescale for bound electrons) will be discussed, along with modern techniques for attosecond pulse generation and characterization to enable the students to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0120</b> Biomedical Imaging - Ionizing Radiation	
Module code	PAFM0120
Module title (German)	Biomedical Imaging - Ionizing Radiation
Module title (English)	Biomedical Imaging - Ionizing Radiation
Person responsible for the module	Prof. Dr. J. R. Reichenbach
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	Introduction to biomedical and medical imaging systems; Physical principles behind the design of selected imaging systems; Technological aspects of each modality; Spatial and temporal resolution; Importance of each modality concerning physical, biological and clinical applications.
Intended learning outcomes	The course introduces the physical principles, properties and technical concepts of imaging systems as they are applied today in medicine and physics. The focus is laid on the use and application of ionizing radiation, which has always been an important aspect of the application of physics to medicine. Applications and current developments will be presented. After having actively participated the students should demonstrate a critical understanding of the theoretical basis and technologies of these imaging systems and have acquired an appreciation of instrumentation and practical issues with different imaging systems. The course is independent of the course Biomedical Imaging – Non-Ionizing Radiation offered in the 2nd semester and does not require previous participation of that course.
Prerequisites for admission to the module examination	students must have earned points in the exercises and assignments (type and extent will be announced at the beginning of the semester)

Requirements for awarding credit points (type of examination)	Written or oral examination. The selected form of the exam will be announced at the beginning of the semester
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0121</b> Biomedical Imaging - Non Ionizing Radiation	
Module code	PAFM0121
Module title (German)	Biomedical Imaging - Non Ionizing Radiation
Module title (English)	Biomedical Imaging - Non Ionizing Radiation
Person responsible for the module	Prof. Dr. J. R. Reichenbach
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction to imaging systems; Physical principles behind the design of selected biomedical imaging systems, including magnetic resonance imaging, ultrasound imaging; Technological aspects of each modality; Importance of each modality concerning physical, biological and clinical applications.
Intended learning outcomes	The course introduces physical principles, properties and technical concepts of imaging systems as they are applied today in medicine and physics. The focus is laid on the use and application of non-ionizing radiation, as utilized, e.g., with magnetic resonance imaging or ultrasound imaging. Applications and current developments will be presented. After active participation the students should demonstrate a critical understanding of the theoretical basis and technologies of these imaging systems and have acquired an appreciation of instrumentation and practical issues with different imaging systems. The course is independent of the course Biomedical Imaging – Ionizing Radiation offered in the 3rd semester.
Prerequisites for admission to the module examination	Students must have earned points in the exercises and assignments (type and extent will be announced at the beginning of the semester)

Requirements for awarding credit points (type of examination)	Written or oral examination. The selected form of the exam will be announced at the beginning of the semester
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“). If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English



Modul <b>PAFM0122</b> Biophotonics	
Module code	PAFM0122
Module title (German)	Biophotonics
Module title (English)	Biophotonics
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU), Prof. Dr. Ralf Ehricht (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<p>The Module provides a deep introduction into the multitude of possible linear and non-linear light biological matter interaction phenomena and thus in modern techniques and applications of frequency-, spatially-, and time-resolved bio-spectroscopy. The course presents a comprehensive overview over modern spectroscopic and optical imaging techniques inclusive specific theoretical methodologies to analyze the experimental spectroscopic data to resolve problems in life sciences. The biological part introduces to molecular and cellular properties of living organisms. It explains the basic structures and functions of prokaryotic and eukaryotic cells as well as the most important biochemical substance classes and biochemical pathways where they are involved. Furthermore, basics in microbiology, especially in antimicrobial resistant bacteria will be provided and combined with the introduction of diagnostic principles and selected infectious diseases. Examples for molecular and serological assay and test development and basic methods for diagnostics and epidemiology will be discussed. This sets the stage for biophotonic applications by showing several examples of how biophotonics can help to shed light on biologically and clinically relevant processes. The Module spans aspects of the scientific disciplines chemistry, physics, biology and medicine. The Exercises will be partly calculating examples and partly in the form a seminar talks of the students presenting current research publications. Intended learning outcomes: The aim of this course is to present modern methods in spectroscopy, microscopy, molecular biology, microbiology and imaging dedicated to biological samples. After the course the students will be able to choose and to apply appropriate spectroscopic methods and imaging technologies to resolve special biophotonics problems.</p>
Intended learning outcomes	<p>The aim of this course is to present modern methods in spectroscopy, microscopy and imaging dedicated to biological samples. After the course the students will be able to choose and to apply appropriate spectroscopic methods and imaging technologies to resolve special biophotonic problems.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	<ul style="list-style-type: none"> <li>• Paras N. Prasad, Introduction to Biophotonics</li> <li>• Textbooks on laser spectroscopy, e.g. Demtröder; on quantum mechanics, e.g. Atkins and on optics, e.g. Zinth/Zinth</li> <li>• Jerome Mertz: Introduction to Optical Microscopy, Roberts &amp; Company Publishers, 2010</li> <li>• Selected chapters of Handbook of Biophotonics (Ed. J. Popp) WILEY</li> </ul>
Language of instruction	English

Modul <b>PAFM0129</b> Computational Imaging	
Module code	PAFM0129
Module title (German)	Computational Imaging
Module title (English)	Computational Imaging
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU), Dr. Lars Lötgering (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 MSc. Physics specialisation „Optics”: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and Programming Lab 1 SWS
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	

Content	<p>Review: Linear Algebra, Calculus, Python</p> <ul style="list-style-type: none"> <li>• Optimization part 1: Continuous (Euler Lagrange) and Discrete (multivariate calculus)</li> <li>• Programming lab: genetic algorithms + Fermat principle</li> <li>• Optimization part 2: nonlinear optimization, regularization, Lagrange multipliers</li> <li>• Optimization part 3: Convex techniques, l1 minimization</li> <li>• Programming lab: single pixel camera</li> <li>• Optimization part 4: Automatic differentiation</li> <li>• Matrix representation of coherent optical systems Programming lab: keras toolbox, optical eigenmodes</li> <li>• Multiple scattering: Born / Rytov series, beam propagation method</li> <li>• Tomographic inversion</li> <li>• Programming lab: Foldy-Lax scattering theory</li> <li>• Phase retrieval part 1: coherent diffraction imaging (CDI)</li> <li>• Phase retrieval part 2: ptychography</li> <li>• Programming lab: hybrid input output, shrink wrap, ptychography</li> <li>• Phase retrieval part 3: Fourier ptychography</li> <li>• Image deconvolution: structured illumination microscopy, pupil engineering</li> <li>• Programming lab: extended depth-of-field systems</li> <li>• Imaging with spatially partially coherent light</li> <li>• Parameter estimation: Fisher information and Cramer Rao lower bound</li> <li>• Programming lab: Coded aperture imaging, resolution assessment, edge responses, modulation transfer function, Fourier ring correlation</li> <li>• Neural networks part 1: Image classification</li> <li>• Neural networks part 2: Image regression</li> <li>• Programming lab: digit recognition, counting red blood cells</li> </ul>
Intended learning outcomes	Understanding the interplay between forward and inverse modeling in optical systems. Hands-on programming skills.
Requirements for awarding credit points (type of examination)	30 min oral exam
Additional information on the module	If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Language of instruction	English

Modul <b>PAFM0130</b> Computational Photonics	
Module code	PAFM0130
Module title (German)	Computational Photonics
Module title (English)	Computational Photonics
Person responsible for the module	Prof. Dr. T. Pertsch (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge of a computer programming language and computational physics will be helpful.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Introduction to the problem – Maxwell's equations and the wave equation; Free space propagation techniques; Beam propagation methods applied to problems in integrated optics; Mode expansion techniques applied to stratified media; Mode expansion techniques applied to spherical and cylindrical objects; Multiple multipole technique; Boundary integral method; Finite-Difference Time-Domain method; Finite Element Method; Computation of the dispersion relation (band structure) of periodic media; Mode expansion techniques applied to gratings; Other grating techniques; Contemporary problems in computational photonics.
Intended learning outcomes	The course aims at an introduction to various techniques used for computer based optical simulation. Therefore, the student should learn how to solve Maxwell's equations in homogenous and inhomogeneous media rigorously as well as on different levels of approximation. The course concentrates predominantly on teaching numerical techniques that are useful in the field of micro- and nanooptics.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	Taflove and S.C. Hagness, Computational Electrodynamics
Language of instruction	English

Modul <b>PAFM0131</b> Fundamental Atomic and Nuclear Processes in Highly Ionized Matter	
Module code	PAFM0131
Module title (German)	Fundamental Atomic and Nuclear Processes in Highly Ionized Matter
Module title (English)	Fundamental Atomic and Nuclear Processes in Highly Ionized Matter
Person responsible for the module	Prof. Dr. T. Stöhlker
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in atomic and nuclear physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Lecture 1: "X-ray spectroscopy of hot plasmas" basic properties of atomic systems (level structure, transition rates, etc.) atomic charge-exchange processes in plasmas, charge state distributions creation of plasmas: facilities for stored and trapped ions x-ray detectors and techniques for spectroscopy and polarimetry x-ray diagnosis of plasmas in the laboratory and nature  Lecture 2: "Nuclear matter and the formation of elements" Properties of nuclear matter Stability of the atomic nucleus Nuclear models and masses of atomic nuclei Nuclear processes related to the creation of the elements Nuclear radiation and radiation detectors Experimental techniques
Intended learning outcomes	The students will gain an overview of experiments addressing astrophysical topics, in particular concerning ionized matter and will be enabled to solve respective problems.
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.

Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	The above mentioned lectures are offered alternately. 128 M.Sc. Physics: Required elective module (Specialization in „Optics“ and “Solid State Physics/Material Science”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English (German on request)



Modul <b>PAFM0132</b> Optical system design fundamentals	
Module code	PAFM0132
Module title (German)	Optical system design fundamentals
Module title (English)	Optical system design fundamentals
Person responsible for the module	Prof. Dr. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>• Basic technical optics;</li> <li>• Paraxial optics;</li> <li>• Imaging systems;</li> <li>• Aberrations;</li> <li>• Performance evaluation of optical systems;</li> <li>• Correction of optical systems;</li> <li>• Optical system classification;</li> <li>• Special system considerations.</li> </ul>
Intended learning outcomes	This course covers the fundamental principles of classical optical system design, the performance assessment and the correction of aberrations. In combination of geometrical optics and physical theory the students will learn the basics to understand optical systems, which can be important for experimental work and enable them to solve related problems.
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	Written examination (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0150</b> Renewable Energies	
Module code	PAFM0150
Module title (German)	Erneuerbare Energien
Module title (English)	Renewable Energies
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 128 LA Regelschule Physik: Required elective module 128 LA Gymnasium Physik: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Basics of energy supply in Germany; Potential of renewable energies; Principles of the energy balance of planets; Thermodynamics of the atmosphere; Physics of wind energy systems; Elements of solar power generation.
Intended learning outcomes	After acquiring of knowledge on the fundamentals of renewable energies the students will develop the skills for the independent evaluation of different types of renewable energies.
Prerequisites for admission to the module examination	Details will be defined at the beginning of the semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English or German (depending on audience)

Modul <b>PAFM0151</b> Experimental Nonlinear Optics	
Module code	PAFM0151
Module title (German)	Experimental Nonlinear Optics
Module title (English)	Experimental Nonlinear Optics
Person responsible for the module	Prof. Dr. G. G. Paulus (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Propagation of light in crystals;</li> <li>• Properties of the non-linear susceptibility tensor;</li> <li>• Description of light propagation in non-linear media;</li> <li>• Parametric effects;</li> <li>• Second harmonic generation;</li> <li>• Phase-matching;</li> <li>• Propagation of ultrashort pulses;</li> <li>• High-harmonic generation;</li> <li>• Solitons</li> </ul>

Intended learning outcomes	The students understand light propagation in nonlinear media and the role of the nonlinear susceptibility tensor can describe and analyze parametric effects and second harmonic generation grasp the concept of phase-matching and its importance in nonlinear optical processes are familiar with ultrashort pulse propagation and high-harmonic generation can explain soliton formation and its relevance in nonlinear optics
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“)
Recommended reading	
Language of instruction	English

Modul <b>PAFM0160</b> Fiber Optics	
Module code	PAFM0160
Module title (German)	Fiber Optics
Module title (English)	Fiber Optics
Person responsible for the module	Prof. Dr. M. Schmidt (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Properties of optical fibers;</li> <li>• Light propagation in optical fibers;</li> <li>• Technology and characterization techniques;</li> <li>• Special fiber types (photonic crystal fibers, hollow fibers, polarization maintaining fibers);</li> <li>• Fiber devices (e.g. fiber amplifiers and lasers);</li> <li>• Applications</li> </ul>
Intended learning outcomes	<p>Students</p> <p>understand the fundamental properties and light propagation in optical fibers</p> <p>are familiar with fiber fabrication, characterization techniques, and special fiber types</p> <p>can analyze fiber-based devices such as amplifiers and lasers</p> <p>understand key applications of optical fibers in communication, sensing, and laser technology</p>

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	Snyder/Love, Optical Waveguide Theory; Okamoto, Fundamentals of Optical Waveguides.
Language of instruction	English



Modul <b>PAFM0170</b> High-Intensity/Relativistic Optics	
Module code	PAFM0170
Module title (German)	High-Intensity/Relativistic Optics
Module title (English)	High-Intensity/Relativistic Optics
Person responsible for the module	Prof. Dr. M. Kaluza (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• High-intensity laser technology;</li> <li>• Laser plasma physics;</li> <li>• Laser accelerated particles and applications.</li> </ul>
Intended learning outcomes	<p>The students understand the principles of high-intensity laser technology and its key components are familiar with laser-plasma interactions and their physical foundations</p> <p>can analyze laser-driven particle acceleration and its applications in science and technology</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	<ul style="list-style-type: none"><li>• W. L. Kruer, The Physics of Laser Plasma Interactions, Westview press (2003), Boulder Colorado;</li><li>• P. Gibbon, Short Pulse Laser Interactions with Matter, Imperial College Press (2005), London;</li><li>• F. F. Chen, Introduction to Plasma Physics and Controlled Fusion, Vol. 1: Plasma Physics, Springer (1984).</li></ul>
Language of instruction	English

Modul <b>PAFM0171</b> Milestones in Optics	
Module code	PAFM0171
Module title (German)	Milestones in Optics
Module title (English)	Milestones in Optics
Person responsible for the module	Prof. Dr. C. Spielmann, Dr. C. Forstner
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Seminar: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 30 h 90 h
Content	The seminar covers the history of optics from the antiquity to the 20th century: Starting with Greek theories of vision and ending with quantum optics. A strong focus will be given on the development of concepts and experiments that influenced today's thinking about light and optics, such as wave particle dualism or the Abbe diffraction limit. An excursion to the Jena's Optical Museum is part of the seminar.
Intended learning outcomes	In close collaboration with the supervisor, the student will work on an independent project. The students will develop the ability to evaluate critically the arguments and analytical methods of historians. They will learn developing their own interpretations based on critical assessments of primary source evidence and independent research.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Scientific Talk (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	German, English

Modul <b>PAFM0180</b> Image Processing	
Module code	PAFM0180
Module title (German)	Image Processing
Module title (English)	Image Processing
Person responsible for the module	Prof. Dr. Joachim Denzler (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 2 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Digital image fundamentals (Image Sensing and Acquisition, Image Sampling and Quantization)</li> <li>• Image Enhancement in the Spatial Domain (Basic Gray Level Transformations, Histogram Processing, Spatial Filtering)</li> <li>• Image Enhancement in the Frequency Domain (Introduction to the Fourier-Transform and the Frequency Domain, Frequency Domain Filtering, Homomorphic Filtering)</li> <li>• Image Restoration (Noise Models, Inverse Filtering, Geometric Distortion)</li> <li>• Color Image Processing Image Segmentation (Detection of Discontinuities, Edge Linking and Boundary Detection, Thresholding, Region-Based Segmentation)</li> <li>• Representation and Description Applications</li> </ul>

Intended learning outcomes	The course covers the fundamentals of digital image processing. Based on this the students should be able to identify standard problems in image processing to develop individual solutions for given problems and to implement image processing algorithms for use in the experimental fields of modern optics.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	Gonzalez, Woods, Digital Image Processing, Prentice Hall, 2001
Language of instruction	English

Modul <b>PAFM0181</b> Image Processing in Microscopy	
Module code	PAFM0181
Module title (German)	Image Processing in Microscopy
Module title (English)	Image Processing in Microscopy
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	All the image processing and simulations will be practiced in exercises using MatLab and the free image processing toolbox DIPImage ( <a href="http://www.diplib.org">www.diplib.org</a> ). The student needs to be familiar with MatLab at a basic level and with basic concepts of image processing such as filtering and thresholding. The Image Processing lecture by Prof. Denzler in the second term forms a good basis for this course.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	We will show different methodologies to extract specific information such as for example the average speed of diffusing particles or the locations and areas of cells from the multidimensional image data. Also fitting quantitative models to extracted data will be treated. Simulation of far-field intensity distribution by using simple Fourier-space based approaches is treated with and without considering the vectorial nature of the oscillating electro-magnetic field.

Intended learning outcomes	Current microscopy often acquires a large amount of image data from which the biological or clinical researcher often needs to answer very specific questions. A major topic is the reconstruction of the sample from the acquired, often complex, microscopy data. To solve such inverse problems, a good model of the data acquisition process is required, ranging from assumptions about the sample (e.g. a positive concentration of molecules per voxel), assumptions about the imaging process (e.g. the existence of an incoherent spatially invariant point spread function) to modeling the noise characteristics of the detection process (e.g. read noise and photon noise).
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English



Modul <b>PAFM0182</b> Advanced Optical Design	
Module code	PAFM0182
Module title (German)	Advanced Optical Design
Module title (English)	Advanced Optical Design
Person responsible for the module	Prof. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in geometrical and physical optics.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>• Paraxial imaging;</li> <li>• Basics of optical systems;</li> <li>• Eikonal theory;</li> <li>• Geometrical aberrations, representations, expansion;</li> <li>• Detailed discussion of primary aberrations;</li> <li>• Sine condition, isoplanatism, afocal cases;</li> <li>• Wave aberrations and Zernike representation;</li> <li>• Miscellaneous aspects of aberration theory.</li> </ul>
Intended learning outcomes	This course covers the fundamental principles of classical optical imaging and aberration theory of optical systems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0183</b> Introduction to Nanooptics	
Module code	PAFM0183
Module title (German)	Introduction to Nanooptics
Module title (English)	Introduction to Nanooptics
Person responsible for the module	Prof. Dr. I. Staude (FSU), Prof. Dr. T. Pertsch (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying	75 h
(incl. preparations for examination)	
Content	<ul style="list-style-type: none"> <li>• Surface-plasmon-polaritons;</li> <li>• Plasmonics;</li> <li>• Photonic crystals;</li> <li>• Fabrication and optical characterization of nanostructures;</li> <li>• Photonic nanomaterials / metamaterials / metasurfaces;</li> <li>• Optical nanoemitters;</li> <li>• Optical nanoantennas.</li> </ul>

Intended learning outcomes	The course provides an introduction to the broad research field of nanooptics. The students will learn about different concepts which are applied to control the emission, propagation, and absorption of light at subwavelength spatial dimensions. Furthermore, they will learn how nanostructures can be used to optically interact selectively with nanoscale matter, a capability not achievable with standard diffraction limited microscopy. After successful completion of the course the students should be capable of understanding present problems of the research field and should be able to solve basic problems using advanced literature.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	L. Novotny and B. Hecht, Principles of Nano-Optics, Cambridge 2006; P. Prasad, Nanophotonics, Wiley 2004; J. D. Joannopoulos, S. G. Johnson, J. N. Winn, R. D. Meade, Photonic Crystals – Molding the Flow of Light, Princeton University Press (2008) list of selected journal publications given during the lecture.
Language of instruction	English

Modul <b>PAFM0184</b> Integrated Optics	
Module code	PAFM0184
Module title (German)	Integrated Optics
Module title (English)	Integrated Optics
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture 2 SWS and exercise 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The lecture will cover a significant part of integrated quantum photonics, which is one of the pillars of the current quantum technology development. In particular, the lecture will cover the following topics <ul style="list-style-type: none"> <li>• Integrated optics on a single photon level</li> <li>• Generation and manipulation of quantum states of light using integrated waveguides</li> <li>• Overview over integrated photonic platforms and fabrication of passive and active waveguide structures</li> <li>• Quantum walks in linear and non-linear waveguide lattices</li> <li>• Introduction to photonic quantum computation and simulation</li> <li>• Measurements using superconducting nanowire single photon detectors and transition edge sensors</li> </ul>

Intended learning outcomes	<p>The course should provide the participating students with a profound knowledge on the state of the art of integrated optics used for the realization of quantum optical devices.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of integrated quantum photonics and will be able to develop own concepts for integrated quantum circuitry.</p> <p>The intended learning outcome is that the students are introduced to the basics on the field of integrated quantum optics and its applications. Therefore, course starts with an overview on the generation of non-classical states of light with special attention on integrated solutions. Afterwards several integrated photonic platforms will be discussed ranging from fabrication to performance and useability.</p> <p>Based on that the on-chip manipulation of non-classical states of light will be discussed. This starts with the very general concept of quantum walks and continues towards quantum simulation. It ends with an introductory to photonic quantum computing with a clear focus on practical implementation of quantum photonic gate structures.</p> <p>The course closes with the discussion on non-classical light detection in integrated photonics.</p>
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0185</b> Innovation Methods in Photonics	
Module code	PAFM0185
Module title (German)	Innovation Methods in Photonics
Module title (English)	Innovation Methods in Photonics
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. V. Gili (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Rapid prototyping technologies in photonics</li> <li>• Innovation management and design thinking</li> <li>• Hands-on/practical examples of photonics prototyping</li> <li>• Entrepreneurial skills and business modelling</li> <li>• Basics of intellectual property rights</li> </ul>

Intended learning outcomes	<p>The students will learn how the results of their scientific research can be turned into relevant innovations as an important part of their future career. On the one hand, the course will enable students to understand and to drive innovation processes in photonics companies. On the other hand, students will develop an entrepreneurial skill set for the independent economical exploitation of scientific ideas.</p> <p>Therefore, the course introduces the basic knowledge on innovation management, entrepreneurship, and intellectual property rights. To practice their skills, the students will also conduct their own photonics innovation project during the semester by working hands-on in small teams in the photonics makerspace Lichtwerkstatt. During this practical part, they acquire and apply a thorough knowledge of photonic rapid prototyping technologies (e.g. 3d- scanning and printing, laser cutting, microcontrollers, ...) and the most important creativity methods and project management skills. To cover this range of topics, the course will be supported by guest lecturers from different sectors (academia, industry).</p>
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English



Modul <b>PAFM0187</b> Ion traps and precision experiments	
Module code	PAFM0187
Module title (German)	Ionenfallen und Präzisionsexperimente
Module title (English)	Ion traps and precision experiments
Person responsible for the module	Jun.-Prof. Dr. P. Mücke
Recommended or expected prior knowledge	Basics in electrodynamics, quantum mechanics, and atomic physics
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics specialization "Optics": Required elective module 128 LA Gymnasium Physik: Required elective module 528 M.Sc. Quantum Science and Technology: Required elective module, subject area "specialization" 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Basics of ion trap physics; Paul and Penning traps; Cooling techniques, in particular laser cooling methods; Coherent manipulation of electronic and motional states; detection techniques; Application of ion traps for precision experiments: optical clocks, quantum logic spectroscopy, ion traps as a platform for quantum computing, high-resolution mass spectrometry, measurements of g-factors and magnetic moments
Intended learning outcomes	Understanding the concepts of Paul and Penning traps as well as the applied techniques; knowledge of the discussed precision experiments; ability to deepen knowledge independently through latest scientific literature
Prerequisites for admission to the module examination	50% of the points of the exercise sheets; active participation in the exercises by presenting own solutions and discussing content
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Recommended reading	An up-to-date literature list will be announced at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO200</b> Laser Driven Radiation Sources	
Module code	PAFMO200
Module title (German)	Laser Driven Radiation Sources
Module title (English)	Laser Driven Radiation Sources
Person responsible for the module	Prof. Dr. M. Zepf
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in plasma physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>• Laser Plasma Interactions</li> <li>• Principles of Plasma Accelerators</li> <li>• Ultrafast Photon Sources</li> <li>• Scattering of photons from particle beams</li> </ul>
Intended learning outcomes	The course introduces the basic interaction processes of high-energy lasers with plasmas and particle beams with a particular emphasis on the extremely intense sources of proton, electron and photons with pulse durations in the femtosecond regime. Students will be enabled to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	presentation and/or oral examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English/German depending on participants

Modul <b>PAFM0201</b> Laser Engineering	
Module code	PAFM0201
Module title (German)	Laser Engineering
Module title (English)	Laser Engineering
Person responsible for the module	Prof. Dr. M. Kaluza
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Prior knowledge in laser physics is strongly recommended.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• origin and dependencies of absorption and emission cross sections</li> <li>• Ytterbium based laser media</li> <li>• design of laser diode pump engines,</li> <li>• special topics in geometrical optics for amplifier design</li> <li>• basic calculations for layout of diode pumped high energy amplifiers</li> <li>• Ytterbium based laser materials and cryogenic cooling</li> <li>• limitations and special topics (laser induced damage threshold (LIDT), amplified spontaneous emission (ASE) ... )</li> </ul>
Intended learning outcomes	This is an application-oriented course focusing on topics needed for development and design of diode pumped high energy class laser systems. Besides general topics the main part of this lecture is dedicated to ytterbium-based laser systems. Besides basic knowledge like the spectral properties of laser materials and their significance for a laser system, further key topics like laser induced damage thresholds, laser diode pump engines, modeling of amplification and amplified spontaneous emission will be discussed. Students will be enabled to solve related problems.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO203</b> Lens Design I	
Module code	PAFMO203
Module title (German)	Lens Design I
Module title (English)	Lens Design I
Person responsible for the module	Prof. Dr. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Introduction and user interface;</li> <li>• Description and properties of optical systems;</li> <li>• Geometrical and wave optical aberrations;</li> <li>• Optimization;</li> <li>• Imaging simulation;</li> <li>• Introduction into illumination systems;</li> <li>• Correction of simple systems;</li> <li>• More advanced handling and correction methods.</li> </ul>
Intended learning outcomes	This course gives an introduction in layout, performance analysis and optimization of optical systems with the software Zemax and enables the students to solve problems of optical system design.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO204</b> Lens Design II	
Module code	PAFMO204
Module title (German)	Lens Design II
Module title (English)	Lens Design II
Person responsible for the module	Prof. Dr. V. Blahnik
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in aberration theory and optical design as acquired in the course on "Lens Design I".
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Paraxial imaging and basic properties of optical systems;</li> <li>• Initial systems and structural modifications;</li> <li>• Chromatical correction;</li> <li>• Aspheres and freeform surfaces;</li> <li>• Optimization strategy and constraints;</li> <li>• Special correction features and methods;</li> <li>• Tolerancing and adjustment.</li> </ul>
Intended learning outcomes	This course covers the advanced principles of the development of optical systems and enables the students to solve advanced problems of optical system design.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%)



Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO205</b> Light Microscopy	
Module code	PAFMO205
Module title (German)	Light Microscopy
Module title (English)	Light Microscopy
Person responsible for the module	Prof. Dr. Rainer Heintzmann (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>Starting from geometrical optics the imaging system will be described and optical aberrations will be discussed. Moving on to wave optics monochromatic waves will be taken as the basis for the description of coherent imaging. Combined with scattering theory in the 1st Born approximation a fundamental understanding of the possibilities and limitations in imaging is gained. The concept of the amplitude transfer function and McCutchens 3-dimensional pupil function are introduced. On this basis various coherent imaging modes are discussed including holographic approaches and their limitations, and optical coherent tomography.</p> <p>The working principles of light-detectors are discussed and the requirements for appropriate sampling of images.</p> <p>Finally various modes of fluorescence microscopy and high-resolution microscopy will be covered.</p> <p>The exercises will be calculating examples, also involving hands-on computer based modeling using Matlab and other tools.</p>

Intended learning outcomes	The students understand imaging principles, including optical aberrations and coherent imaging can describe key concepts like the amplitude transfer function and 3D pupil function are familiar with holography, optical coherence tomography, and fluorescence microscopy understand light detectors and image sampling requirements can apply computational tools for modeling optical imaging systems
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO210</b> Machine Learning for Quantum Science	
Module code	PAFMO210
Module title (German)	Machine Learning for Quantum Science
Module title (English)	Machine Learning for Quantum Science
Person responsible for the module	Dr. X. Gu
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology: required elective module 128 M.Sc. Physics focus "Optics": required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Tutorial: 2 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 60 h 60 h
Content	<p>Artificial intelligence has become as a powerful tool in quantum science, enabling researchers to simulate complex systems, optimize experimental procedures, and discover new ideas and experiments. This course introduces the principles and practice of applying artificial intelligence (AI) and machine learning (ML) techniques to quantum physics, providing students with both theoretical foundations and hands-on computational skills. Topics include:</p> <ul style="list-style-type: none"> <li>• Basic AI/ML techniques for physicists</li> <li>• Differentiable programming</li> <li>• Generative models and reinforcement learning</li> <li>• Quantum circuit optimization and design</li> <li>• Quantum parameter estimation and measurement strategies</li> <li>• Quantum experiments design and discovery</li> <li>• Interpretable AI in quantum physics</li> </ul>

Intended learning outcomes	<p>This course introduces and deepens students' understanding of artificial intelligence techniques applied to quantum information science. By actively participating in this course, students will:</p> <ul style="list-style-type: none"> <li>• Develop both theoretical understanding and practical skills at the intersection of quantum science and artificial intelligence.</li> <li>• Understand how artificial intelligence and machine learning can address challenges in quantum physics, such as quantum state estimation and experimental design.</li> <li>• Gain hands-on experience implementing AI/ML methods in Python (using frameworks like PyTorch and JAX).</li> <li>• Engage with current research literature to identify open questions and design AI systems for quantum tasks.</li> </ul>
Prerequisites for admission to the module examination	none
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	<p>Students are encouraged to explore the following papers relevant to the course topics:</p> <ul style="list-style-type: none"> <li>• Krenn, M. et al., Computer-inspired quantum experiments. Nat Rev Phys 2, 649–661 (2020)</li> <li>• Krenn, M. et al., Artificial intelligence and machine learning for quantum technologies, Phys. Rev. A 107, 010101 (2023)</li> <li>• Dawid, A. et al., Modern applications of machine learning in quantum sciences, arXiv:2204.04198 (2022)</li> <li>• Acampora, G. et al., Quantum computing and artificial intelligence: status and perspectives, arXiv:2505.23860 (2025)</li> </ul> <p>A more detailed and regularly updated list of supplementary literature and resources will be provided at the beginning of the semester and throughout the course.</p>
Language of instruction	English

Modul <b>PAFM0220</b> Micro/Nanotechnology	
Module code	PAFM0220
Module title (German)	Micro/Nanotechnology
Module title (English)	Micro/Nanotechnology
Person responsible for the module	Apl. Prof. Uwe Zeitner (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• demands of micro- and nano-optics on fabrication technology</li> <li>• basic optical effects of micro- and nano-structures and their description</li> <li>• typical structure geometries in micro- and nano-optics</li> <li>• coating technologies</li> <li>• lithography (photo-, laser-, electron-beam) and its basic physical principles</li> <li>• sputtering and dry etching</li> <li>• special technologies (melting, reflow, ...)</li> <li>• applications and examples</li> </ul>

Intended learning outcomes	In this course the student will learn about the fundamental fabrication technologies which are used in microoptics and nanooptics. This includes an overview of the physical principles of the different lithography techniques, thin film coating and etching technologies. After successful completion of the course the students should have a good overview and understanding of the common technologies used for the fabrication of optical micro- and nano-structures. They know their capabilities and limitations.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	
Language of instruction	English

Modul <b>PAFM0221</b> Microscopy	
Module code	PAFM0221
Module title (German)	Microscopy
Module title (English)	Microscopy
Person responsible for the module	Prof. Dr. R. Heintzmann (FSU), Prof. Dr. C. Eggeling (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Optical microscopy</li> <li>• Circumventing the resolution limit</li> <li>• Electron microscopy</li> <li>• Atomic force microscopy</li> </ul>
Intended learning outcomes	This Module provides an introduction into the fundamentals of modern light and electron microscopy and enables the students to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).



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Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0222</b> Modern Methods of Spectroscopy	
Module code	PAFM0222
Module title (German)	Moderne Methoden der Spektroskopie
Module title (English)	Modern Methods of Spectroscopy
Person responsible for the module	Prof. Dr. C. Spielmann
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>• Fundamentals of light-matter interaction;</li> <li>• Experimental tools of spectroscopy;</li> <li>• laser spectroscopy;</li> <li>• Time-resolved spectroscopy;</li> <li>• Laser cooling;</li> <li>• THz and X-ray spectroscopy;</li> <li>• photoelectron spectroscopy;</li> <li>• Applications of laser spectroscopy in physics, chemistry, medicine.</li> </ul>
Intended learning outcomes	Understanding the methods of spectroscopy based on new developments in optics; impart knowledge about the design of a spectroscopic experiment; Ability to independently solve spectroscopic questions.
Prerequisites for admission to the module examination	
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	German, English

Modul <b>PAFMO230</b> Nano Engineering	
Module code	PAFMO230
Module title (German)	Nano Engineering
Module title (English)	Nano Engineering
Person responsible for the module	Dr. S. Höppener, Prof. Dr. U. S. Schubert
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Building with Molecules</li> <li>• Self-organization and self-assembled coatings</li> <li>• Chemically sensitive characterization methods</li> <li>• Nanomaterials for optical applications</li> <li>• Nanowires and nanoparticles</li> <li>• Nanomaterials in optoelectronics</li> <li>• Bottom-up synthesis strategies and nanolithography</li> <li>• Polymers and self-healing coatings</li> <li>• Molecular motors</li> <li>• Controlled polymerization techniques</li> </ul>

Intended learning outcomes	<p>A large diversity of nanomaterials can be efficiently produced by utilizing chemical synthesis strategies. The wide range of nanomaterials, i.e., nanoparticles, nanotubes, micelles, vesicles, nanostructured phase separated surface layers etc. opens on the one hand versatile possibilities to build functional systems, on the other hand also the large variety of techniques and processes to fabricate such systems is also difficult to overlook.</p> <p>Traditionally the communication in the interdisciplinary field of nanotechnology is difficult, as expertise from different research areas is combined. This course aims on the creation of a common basic level for communication and knowledge of researchers of different research fields and to highlight interdisciplinary approaches which lead to new fabrication strategies. The course includes basic chemical synthesis strategies, molecular self-assembly processes, chemical surface structuring, nanofabrication and surface chemistry to create a pool of knowledge to be able to use molecular building blocks in future research projects.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0231</b> Nonlinear Dynamics in Optical Systems	
Module code	PAFM0231
Module title (German)	Nonlinear Dynamics in Optical Systems
Module title (English)	Nonlinear Dynamics in Optical Systems
Person responsible for the module	Prof. Dr. U. Peschel
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in electrodynamics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>• Non-Linear dynamics in optical fibers and waveguides</li> <li>• Solution of non-linear partial differential equations</li> <li>• Solitons and collapse in optical systems</li> <li>• Super continuum generation</li> </ul>
Intended learning outcomes	Understanding the theoretical fundamentals of non-linear dynamics in optical systems the students are enabled to solve related problems.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Examination mark (100%) The mark is composed by an Exercise mark (25%) and an oral examination (75%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

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Language of instruction	German or English on request
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Modul <b>PAFM0233</b> Neuromorphic Photonics - Platforms & Applications	
Module code	PAFM0233
Module title (German)	Neuromorphe Photonik - Plattformen und Anwendung
Module title (English)	Neuromorphic Photonics - Platforms & Applications
Person responsible for the module	Dr. Elena Goi and Prof. Thomas Pertsch
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	attendance of "Fundamentals of Modern Optics" module or equivalent
Type of module (compulsory module, required elective module, elective module)	128 MSc. Physics focus „Optics”: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Tutorial: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>The course will cover the following topics:</p> <ul style="list-style-type: none"> <li>• Notions of brain physiology.</li> <li>• Introduction to AI, machine learning, neuromorphic computing and analog computing.</li> <li>• Comprehensive overview of neuromorphic photonics field background and historical development.</li> <li>• Review of the recent developments in photonic neuromorphic models, photonic platforms and accelerators for neuromorphic computing.</li> <li>• Discuss fields and applications that can leverage on these new platforms.</li> <li>• Analyze the current challenges faced in advancing the field and the emerging directions in neuromorphic photonic and AI applied to photonic problems, such as AI photonic chips, quantum neural networks, 3D optical neural networks etc..</li> <li>• The tutorials will focus on design and training of diffractive neural networks and photonic integrated neural network.</li> </ul>



Intended learning outcomes	<ul style="list-style-type: none"> <li>• Fundamentals of neurological structures and neuromorphic models in machine learning and deep learning.</li> <li>• Knowledge of the historical and most recent developments of the neuromorphic photonics field.</li> <li>• Understanding of the applications of neuromorphic photonic technologies and the emerging directions in the field.</li> <li>• Practical implementation of diffractive neural network design and training.</li> <li>• Practical implementation of integrated photonic neural networks with cascades of Mach-Zehnder interferometers.</li> <li>• Capacity to analyze scientific articles, expand understanding through contemporary research, and effectively present project work.</li> </ul>
Prerequisites for admission to the module examination	None
Requirements for awarding credit points (type of examination)	Project team report (50%), oral examination (50%)
Additional information on the module	<ul style="list-style-type: none"> <li>• Neuromorphic Photonic Devices and Applications, Edited by Min Gu et al., 2024, SPIE – Elsevier</li> <li>• Neuromorphic Photonics, Edited by P. R. Prucnal and B. J. Shastri, 2017, CRC Press</li> <li>• Modern Optics: Edition 2. B. D. Guenther, Oct 2015, OUP Oxford</li> </ul> <p>The suggested key literature list will be provided at the beginning of each lecture.</p>
Recommended reading	<ul style="list-style-type: none"> <li>• Neuromorphic Photonic Devices and Applications, Edited by Min Gu et al., 2024, SPIE – Elsevier</li> <li>• Neuromorphic Photonics, Edited by P. R. Prucnal and B. J. Shastri, 2017, CRC Press</li> <li>• Modern Optics: Edition 2. B. D. Guenther, Oct 2015, OUP Oxford</li> </ul> <p>The suggested key literature list will be provided at the beginning of each lecture.</p>
Language of instruction	English

Modul <b>PAFM0240</b> Optical Engineering	
Module code	PAFM0240
Module title (German)	Optical Engineering
Module title (English)	Optical Engineering
Person responsible for the module	Prof. Dr. C. Franke
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
ECTS credits	4 CP
Work load:	120 h
- In-class studying	30 h
- Independent studying	90 h
(incl. preparations for examination)	

Modul <b>PAFM0242</b> Optics for Spectroscopists: Optical Waves in Solids	
Module code	PAFM0242
Module title (German)	Optics for Spectroscopists: Optical Waves in Solids
Module title (English)	Optics for Spectroscopists: Optical Waves in Solids
Person responsible for the module	Dr. habil. T. Mayerhöfer
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	30 h
- Independent studying (incl. preparations for examination)	90 h
Content	<ul style="list-style-type: none"> <li>• Limitations and non-linearities of the (Bouguer-)Beer-Lambert law derived from wave-optics based approaches.</li> <li>• Reflection and Refraction at isotropic and anisotropic interfaces (Yeh's formalism, Berreman formalism, special cases, Euler orientation representations, example spectra etc.)</li> <li>• Dispersion relations in isotropic and anisotropic media (Lorentz-model, Lorentz-profile, coupled oscillator model, semi-empirical 4-Parameter model, inverse dielectric function modelling, Kramers-Kronig relations etc.)</li> <li>• Spectral analysis of media and layered systems down to triclinic symmetry and, ultimately, without prior knowledge of orientation; consequences for randomly-oriented or partly-oriented systems.</li> </ul>
Intended learning outcomes	The students will acquire an understanding about how pre-Maxwell spectroscopic concepts and quantities like the Beer-Lambert law, linear dichroism and absorbance are properly modified by their wave-optics based analogues. The final goal is to be able to quantitatively understand and analyze spectral patterns based on dispersion theory and matrix formalisms for media of arbitrary symmetry and orientation.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0250</b> Particles in Strong Electromagnetic Fields	
Module code	PAFM0250
Module title (German)	Particles in Strong Electromagnetic Fields
Module title (English)	Particles in Strong Electromagnetic Fields
Person responsible for the module	Prof. Dr. M. Zepf
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on quantum mechanics und special relativity
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Electrons in constant fields</li> <li>• Electrons in electromagnetic pulses</li> <li>• Radiation produced by particles in extreme motion</li> <li>• Radiation reaction</li> <li>• QED effects in strong laser fields</li> </ul>
Intended learning outcomes	This course is devoted to the dynamics of charged particles in electromagnetic fields. Starting with motion of electrons in constant magnetic and electric fields, the course continues with the electron motion in electromagnetic pulses (i.e. laser pulses) of high strength (i.e. when laser pressure becomes dominant). Radiation produced by electrons in extreme motion will be calculated for several most important cases: synchrotron radiation, Thomson scattering, undulator radiation. Effects of radiation reaction on electron motion will be discussed. The last part of the course will briefly discuss the QED effects in strong laser fields: stochasticity in radiation reaction, pair production by focused laser pulses and QED cascades. Analytical framework will be complemented with the help of numerical calculations.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Presentation or oral Exam (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0253</b> Physics of Free-Electron Laser	
Module code	PAFM0253
Module title (German)	Physics of Free-Electron Laser
Module title (English)	Physics of Free-Electron Laser
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• physical foundations of X-ray lasers</li> <li>• undulators</li> <li>• FEL differential equation</li> <li>• Instrumentation</li> <li>• selected applications</li> </ul>
Intended learning outcomes	<p>The student understands the physical foundations, instrumentation, and selected applications of FELs.</p> <p>Acquisition of the competence to judge the applicability and significance of FELs to address problems in X-ray physics.</p>
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Oral examination (100%).
Additional information on the module	<p>128 M.Sc. Physics: Required elective module (Specialization in „Optics“)</p> <p>If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).</p>

Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English



Modul <b>PAFM0254</b> Physics of Ultrafast Optical Discharge and Filamentation	
Module code	PAFM0254
Module title (German)	Physics of Ultrafast Optical Discharge and Filamentation
Module title (English)	Physics of Ultrafast Optical Discharge and Filamentation
Person responsible for the module	Prof. Dr. C. Spielmann, Dr. D. Kartashov
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>• physics of photoionization</li> <li>• optical breakdown</li> <li>• basics of plasma kinetics</li> <li>• LIBS Laser induced breakdown spectroscopy</li> <li>• physics of filamentation</li> <li>• applications: LIDAR, lightning discharge, supercontinuum generation</li> </ul>
Intended learning outcomes	In a selected number of topics out of the broad field of high power laser matter interactions the students should acquire knowledge of ionization, plasma kinetics, filamentation and applications in spectroscopy metrology and atmospheric science.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0255</b> Plasma Physics	
Module code	PAFM0255
Module title (German)	Plasma Physics
Module title (English)	Plasma Physics
Person responsible for the module	Prof. Dr. M. Kaluza
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on laser physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>• Fundamentals of plasma physics;</li> <li>• Single particle and fluid description of plasmas;</li> <li>• Waves in plasmas;</li> <li>• Interaction of electromagnetic radiation with plasmas;</li> <li>• Plasma instabilities;</li> <li>• Non-linear effects (shock waves, parametric instabilities, ponderomotive effects, ...).</li> </ul>
Intended learning outcomes	This course offers an introduction to the fundamental effects and processes relevant for the physics of ionized matter. After actively participating in this course, the students will be familiar with the fundamental physical concepts of plasma physics, especially concerning astrophysical phenomena but also with questions concerning the energy production based on nuclear fusion in magnetically or inertially confined plasmas.
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0256</b> Physics of Photovoltaics	
Module code	PAFM0256
Module title (German)	Photovoltaik
Module title (English)	Physics of Photovoltaics
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Pertinent elements of thermodynamics and statistical mechanics (diffusion, Boltzmann factor, free energy)</li> <li>• Fundamental concepts of solid state physics</li> <li>• Semiconductors and pn-junction</li> <li>• Diode equation</li> <li>• Shockley-Queisser limit</li> <li>• Design criteria for solar cells</li> </ul>
Intended learning outcomes	<ul style="list-style-type: none"> <li>• Profound understanding of the physics underlying the performance of solar cells</li> <li>• Development of an understanding of the role of photovoltaics for covering the energy demand of modern societies.</li> <li>• Capability to solve complex problems pertinent to solar cells</li> </ul>
Prerequisites for admission to the module examination	Processing of exercise sheets (kind and extend will be announced at the beginning of the semester)
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics” and "Solid-state Physics") If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMO260</b> Quantum Optics	
Module code	PAFMO260
Module title (German)	Quantum Optics
Module title (English)	Quantum Optics
Person responsible for the module	Prof. Dr. T. Pertsch (FSU), Dr. F. Setzpfandt (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on quantum theory and theoretical optics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Basic introduction to quantum mechanics;</li> <li>• Quantization of the free electromagnetic field;</li> <li>• Non-classical states of light and their statistics;</li> <li>• Experiments in quantum optics;</li> <li>• Semi-classical and fully quantized light-matter interaction;</li> <li>• Non-Linear optics.</li> </ul>
Intended learning outcomes	<p>The course will give a basic introduction into the theoretical description of quantized light and quantized light-matter interaction. The derived formalism is then used to examine the properties of quantized light and to understand a number of peculiar quantum optical effects.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum optics and will be able to apply the derived formalism to other problems.</p>

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	Grynberg / Aspect / Fabre "Introduction to Quantum Optics"; Garrison / Chiao "Quantum Optics"; Fox "Quantum Optics – An Introduction"; Loudon "The Quantum Theory of Light"; Bachor / Ralph "A Guide to Experiments in Quantum Optics".
Language of instruction	English



Modul <b>PAFMO261</b> Quantum Computing	
Module code	PAFMO261
Module title (German)	Quantum Computing
Module title (English)	Quantum Computing
Person responsible for the module	Dr. F. Steinlechner (FSU), Dr. F. Eilenberger (FSU), Prof. Dr. T. Pertsch (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Basic introduction to algorithms and computing</li> <li>• The Qubit and entanglement thereof</li> <li>• Basics of quantum algorithms</li> <li>• Advanced quantum algorithms</li> <li>• Implementation of QuBits and quantum computers</li> <li>• Hands-on circuits</li> </ul>

Intended learning outcomes	<p>After active participation in the course, the students will be familiar with the basic concepts of quantum computation and the implementation of quantum algorithms. They will be able to apply their knowledge in the assessment and creation of quantum algorithms and the development of quantum information systems.</p> <p>The intended learning outcome is to introduce the students to the basic usage of quantum bits for information processing. To provide further insight, the course will expand this concept on multipartite systems and introduce the concept of entanglement.</p> <p>In a further step we shall see how individual quantum operations tie together to create algorithms. Important algorithms, such as the quantum Fourier transformation, the algorithms of Shor and Grover will be discussed. To relate the abstract knowledge on quantum algorithms to practical applications, real-world implementations of quantum computers will be discussed.</p>
Requirements for awarding credit points (type of examination)	90 min written exam
Additional information on the module	
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0263</b> Quantum Imaging and Sensing	
Module code	PAFM0263
Module title (German)	Quantum Imaging and Sensing
Module title (English)	Quantum Imaging and Sensing
Person responsible for the module	Dr. M. Gräfe (FSU), Dr. F. Setzpfandt (FSU), Prof. Dr. A. Tünnermann (FSU)
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics focus „Optics”: required elective module 628 M.Sc. Photonics: required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Basic introduction to relevant concepts of quantumoptics</li> <li>• Generation of photon pairs</li> <li>• Fundamentals of two-photon interference</li> <li>• Applications of two-photon interference</li> <li>• Optical quantum metrology</li> <li>• Ghost Imaging</li> <li>• Quantum microscopy</li> </ul>
Intended learning outcomes	<p>Goals: The course will give a basic introduction into the usage of quantum light, in particular photon pairs, for imaging and sensing. To this end, many basic concepts and applications will be introduced and discussed. Furthermore, students will learn how to mathematically describe quantum sensing schemes in order to understand and predict their properties.</p> <p>After active participation in the course, the students will be familiar with the basic concepts and phenomena of quantum imaging and sensing and will be able to apply the derived formalism to similar problems.</p>
Requirements for awarding credit points (type of examination)	<p>Written or oral examination (100%)</p> <p>The form of the exam will be announced at the beginning of the semester</p>
Additional information on the module	

Recommended reading	A list of literature and materials will be provided at the beginning of the semester
Language of instruction	English

Modul <b>PAFM0265</b> Semiconductor Nanomaterials	
Module code	PAFM0265
Module title (German)	Semiconductor Nanomaterials
Module title (English)	Semiconductor Nanomaterials
Person responsible for the module	Prof. Dr. Isabelle Staude (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The course will cover the following topics: <ul style="list-style-type: none"> <li>• Review of fundamentals of semiconductors</li> <li>• Optical and optoelectronic properties of semiconductors</li> <li>• Effects of quantum confinement</li> <li>• Photonic effects in semiconductor nanomaterials</li> <li>• Physical implementations of semiconductor nanomaterials, including epitaxial structures, semiconductor quantum dots and quantum wires</li> <li>• Advanced topics of current research, including 2D semiconductors and hybrid nanosystems</li> </ul>

Intended learning outcomes	This course aims to convey a fundamental understanding of the physics governing the optical and optoelectronic properties of semiconductor nanomaterials. First, the fundamental optical and optoelectronic properties of bulk semiconductors are reviewed, deepening and extending previously obtained knowledge in condensed matter physics. The students will then learn about the effects of quantum confinement in semiconductor systems in one, two or three spatial dimensions, as well as about photonic effects in nanostructured semiconductors. Finally, several relevant examples of semiconductor nanomaterial systems and their applications in photonics are discussed in detail. After successful completion of the course, the students should be capable of understanding present research directions and of solving basic problems within this field of research.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination at the end of the semester and oral presentation on a current research topic
Additional information on the module	
Recommended reading	P. Y. Yu and M. Cardona, Fundamentals of Semiconductors, Springer 2010 C. F. Klingshirn, Semiconductor Optics, Springer 1995 M. Fox, Quantum Optics – An Introduction, Oxford University Press 2006
Language of instruction	English

Modul <b>PAFM0266</b> Strong-Field Laser Physics	
Module code	PAFM0266
Module title (German)	Strong-Field Laser Physics
Module title (English)	Strong-Field Laser Physics
Person responsible for the module	Prof. Dr. G. G. Paulus (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• characteristic quantities in attosecond laser physics</li> <li>• characteristic effects (above-threshold generation, high-harmonic generation, non-sequential double ionization)</li> <li>• experimental techniques</li> <li>• theoretical description of strong-field electron dynamics</li> <li>• recollision as a fundamental process in strong-field and attosecond laser physics</li> <li>• generation and measurement of attosecond pulses</li> </ul>
Intended learning outcomes	Knowledge of the fundamentals of high-field laser physics and attosecond laser physics based on it. Development of skills for the independent treatment of questions of these fields.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	30 min oral exam

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	Review-Artikel Z. Chang: Fundamentals of Attosecond Optics
Language of instruction	English



Modul <b>PAFM0267</b> Structured Light and Wavefront Shaping	
Module code	PAFM0267
Module title (German)	Structured Light and Wavefront Shaping
Module title (English)	Structured Light and Wavefront Shaping
Person responsible for the module	Prof. T. Cizmár
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	128 MSc. Physics focus „Optics”: required elective module 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Tutorial: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>Light can be structured to carry complex patterns in intensity, phase, polarization, time, and even frequency. The ability to "sculpt" light is transforming science and technology, enabling applications from high-resolution microscopy to quantum communication.</p> <p>Devices, such as Spatial Light Modulators and Digital Micromirror Devices, now enable dynamic beam shaping into exotic optical structures. Further, they offer ways to beat optical aberrations of real-life optical systems as well as the scrambling of light by optically complex media, such as diffusers and biological tissues.</p> <p>The prospect can make use of intriguing properties of light such as the orbital angular momentum, opening new horizons in microscopy, optical tweezers, quantum information, and high-capacity data links. Further, a primitive multimode optical fibre can, with the technology, be turned into hair-thin endoscope exploring previously inaccessible locations within the living brain.</p>
Intended learning outcomes	Students will acquire the competence to independently generate, control, and apply structured light in practical contexts. By combining theoretical foundations with live demonstrations and hands-on experiments, they will develop the ability to purposefully use these technologies in research and industry, as well as to critically assess their potential.
Prerequisites for admission to the module examination	none

Requirements for awarding credit points (type of examination)	Presentation (100%)
Recommended reading	<ul style="list-style-type: none"><li>• Rubinsztein-Dunlop, Halina, et al. "Roadmap on structured light." Journal of Optics 19.1 (2016): 013001.</li><li>• Andrews, David L. Structured light and its applications: An introduction to phase-structured beams and nanoscale optical forces. Academic press, 2011.</li><li>• Cao, Hui, et al. "Controlling light propagation in multimode fibers for imaging, spectroscopy, and beyond." Advances in Optics and Photonics 15.2 (2023): 524-612.</li></ul>
Language of instruction	English

Modul <b>PAFM0270</b> Theory of Nonlinear Optics	
Module code	PAFM0270
Module title (German)	Theory of Nonlinear Optics
Module title (English)	Theory of Nonlinear Optics
Person responsible for the module	Prof. Dr. U. Peschel (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module 528 M.Sc. Quantum Science and Technology, required elective module, subject area "specialization"
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Types and symmetries of non-linear polarization;</li> <li>• Non-Linear optics in waveguides;</li> <li>• Solutions of non-linear evolution equations;</li> <li>• Temporal and spatial solitons;</li> <li>• Super continuum generation.</li> </ul>
Intended learning outcomes	The course provides the theoretical background of non-linear optics and quantum optics.
Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100 %). Written examination (100 %). The final grade will be determined by the exercise performance (25%)and an oral exam (75%).
Additional information on the module	

Recommended reading	<ul style="list-style-type: none"><li>• Agrawal, Govind P.: Contemporary non-linear optics;</li><li>• Moloney, Jerome V., Newell Alan C.: Non-Linear Optics ;</li><li>• Sutherland, Richard Lee: Handbook of non-linear optics.</li></ul>
Language of instruction	English

Modul <b>PAFM0271</b> Thin Film Optics	
Module code	PAFM0271
Module title (German)	Thin Film Optics
Module title (English)	Thin Film Optics
Person responsible for the module	Prof. Dr. A. Tünnermann (FSU), Dr. O. Stenzel (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Basic dispersion models in Thin Film Optics</li> <li>• Optical properties of material mixtures</li> <li>• Interfaces: Fresnels equations</li> <li>• Multiple internal reflections in layered systems</li> <li>• Optical spectra of single thin films</li> <li>• Wave propagation in stratified media</li> <li>• Matrix formalism</li> <li>• Multilayer systems: Quarterwave-stacks and derived systems</li> <li>• Coatings for ultrashort light pulses</li> <li>• Remarks on coating design</li> </ul>
Intended learning outcomes	This course is of use for anyone who needs to learn how optical coatings are used to tailor the optical properties of surfaces. After an introduction about the theoretical fundamentals of optical coatings the student should learn to calculate the optical properties of uncoated and coated surfaces. Based on this, typical design concepts and applications will be presented.

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	Written examination (100%).
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	<ul style="list-style-type: none"><li>• Born/Wolf: Introduction to optics;</li><li>• H. A. Macleod, Thin Film Optical Filters, Adam Hilger Ltd. 2001;</li><li>• R. Willey, Practical Design and Productions of Optical Thin Films, Marcel Dekker Inc. 2003;</li><li>• N. Kaiser, H. K. Pulker (Eds.), Optical Interference Coatings, Springer Series in Optical Sciences, Vol. 88, 2003;</li><li>• O. Stenzel, The Physics of Thin Film Optical Spectra. An Introduction, Springer Series in Surface Sciences, Vol. 44, 2005.</li></ul>
Language of instruction	English

Modul <b>PAFMO280</b> Ultrafast Optics	
Module code	PAFMO280
Module title (German)	Ultrafast Optics
Module title (English)	Ultrafast Optics
Person responsible for the module	Prof. Dr. S. Nolte (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	Basic knowledge in laser physics.
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Introduction to ultrafast optics;</li> <li>• Fundamentals;</li> <li>• Ultrashort pulse generation;</li> <li>• Amplification of ultrashort pulses;</li> <li>• Measurement of ultrashort pulses;</li> <li>• Applications;</li> <li>• Generation of attosecond pulses.</li> </ul>
Intended learning outcomes	The aim of this course is to provide a detailed understanding of ultrashort laser pulses, their mathematical description as well as their application. The students will learn how to generate, characterize and use ultrashort laser pulses. Special topics will be covered during the seminars.
Prerequisites for admission to the module examination	Talk
Requirements for awarding credit points (type of examination)	Written examination (100%).

Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics”) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	<ul style="list-style-type: none"><li>• Weiner, Ultrafast Optics;</li><li>• Diels/Rudolph, Ultrashort Laser Pulse Phenomena;</li><li>• Rulliere, Femtosecond laser pulses;</li><li>• W. Koechner, Solid-state Laser engineering;</li><li>• A. Siegman, Lasers.</li></ul>
Language of instruction	English



Modul <b>PAFM0281</b> Ultrafast Fibre Laser: Technology and Applications	
Module code	PAFM0281
Module title (German)	Ultrafast Fibre Laser: Technology and Applications
Module title (English)	Ultrafast Fibre Laser: Technology and Applications
Person responsible for the module	Prof. Dr. Markus Schmidt (FSU), Dr. Maria Chernysheva (FSU)
Recommended or expected prior knowledge	Fiber Optics and Ultrafast Optics
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 MSc. Physics specialisation „Optics”: required elective module 628 MSc Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 SWS Exercises: 1 SWS
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<p>The course will cover the following topics:</p> <ul style="list-style-type: none"> <li>• Review of fundamentals of ultrafast fibre lasers (mode-locking and Q-switching)</li> <li>• Engineering of fibre laser cavities</li> <li>• Ultrashort pulse characterization (autocorrelation, FROG, dispersive Fourier transformation, etc.)</li> <li>• Extreme phenomena, exploration of new wavelength ranges and other latest technology advancements in ultrafast fibre laser development</li> <li>• Detailed overview of the ultrafast laser applications in industry, sensing, and medicine (diagnostics and treatment)</li> </ul>

Intended learning outcomes	<p>The aim of the course is to deliver a comprehensive understanding on applied ultrafast laser technology, provide a comparison of solid-state, semiconductor and fibre systems with the focus on the latter, and introduce their modern industrial applications and various research areas.</p> <p>The course, first, will shortly review the basics of fibre optics, rare-earth ion spectroscopy, materials for saturable absorbers and fast modulation techniques, and a variety of operational regimes. The first part of the course will be summarized in pathways towards expected further advancements in the field, covering new research trends, expansion of operation wavelength and operational modalities along with the comparison to existing ultrafast laser technologies.</p> <p>The second and the largest part of the course will be dedicated to the discussion of the existing and emerging applications of ultrafast fibre lasers, including analysis of the corresponding performance requirements and technological goals for a specific application. Starting with high-power industrial applications for material processing, the course will discuss strategies for a further expansion of the ultrafast fibre laser systems towards a more diverse range of applications. These include diagnostics and treatment in medicine, neuroscience field and especially optogenetics, scientific applications for nuclear physics, sensing, metrology and security applications.</p> <p>As the result, students will receive a detailed overview of the road map of the ultrafast fibre laser technology development with further perspectives to employ the knowledge and prospects in their future careers. This will be strengthened during accompanying seminars on latest reported advancements and exercises with practical examples of laser systems.</p>
Prerequisites for admission to the module examination	Completion of the exercises (exact extend will be announced at the beginning of the module)
Recommended reading	Literature will be announced at the beginning of the semester
Language of instruction	English

Modul <b>PAFMO290</b> XUV and X-Ray Optics	
Module code	PAFMO290
Module title (German)	XUV and X-Ray Optics
Module title (English)	XUV and X-Ray Optics
Person responsible for the module	Prof. Dr. C. Spielmann (FSU), Dr. D. Kartashov (FSU)
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	828 MSc. Photon Science and Technology: Required Elective Course Specialization 128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	<ul style="list-style-type: none"> <li>• Complex refractive index in the XUV and X-ray range;</li> <li>• Refractive and grazing incidence optics;</li> <li>• Zone plate optics;</li> <li>• Thomson and Compton scattering;</li> <li>• X-ray diffraction by crystals and synthetic multilayers;</li> <li>• VUV and X-ray optics for plasma diagnostics;</li> <li>• Time-resolved X-ray diffraction;</li> <li>• EUV lithography</li> <li>• XUV- and X-ray microscopy</li> </ul>
Intended learning outcomes	The students understand the complex refractive index in the XUV and X-ray range can analyze refractive, grazing incidence, and zone plate optics are familiar with X-ray diffraction and scattering phenomena understand applications in plasma diagnostics and EUV lithography
Prerequisites for admission to the module examination	-

Requirements for awarding credit points (type of examination)	written or oral exam (100%)
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFM0901</b> Topics of Current Research 1	
Module code	PAFM0901
Module title (German)	Topics of Current Research I
Module title (English)	Topics of Current Research 1
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>Advanced topics of current research in optics and photonics</li> </ul>
Intended learning outcomes	<ul style="list-style-type: none"> <li>Introduction into a field of current research as a basis for further study and research in this field;</li> <li>Independent solution of Exercise problems;</li> <li>Ability to acquire further knowledge by independent literature studies.</li> </ul>
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul <b>PAFM0902</b> Topics of Current Research 2	
Module code	PAFM0902
Module title (German)	Topics of Current Research II
Module title (English)	Topics of Current Research 2
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second year (beginning in summer semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>Advanced topics of current research in optics and photonics</li> </ul>
Intended learning outcomes	<ul style="list-style-type: none"> <li>Introduction into a field of current research as a basis for further study and research in this field;</li> <li>Independent solution of exercise problems;</li> <li>Ability to acquire further knowledge by independent literature studies.</li> </ul>
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul <b>PAFM0903</b> Topics of Current Research 3	
Module code	PAFM0903
Module title (German)	Topics of Current Research III
Module title (English)	Topics of Current Research 3
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>Advanced topics of current research in optics and photonics</li> </ul>
Intended learning outcomes	<ul style="list-style-type: none"> <li>Introduction into a field of current research as a basis for further study and research in this field;</li> <li>Independent solution of Exercise problems;</li> <li>Ability to acquire further knowledge by independent literature studies.</li> </ul>
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul <b>PAFM0904</b> Topics of Current Research 4	
Module code	PAFM0904
Module title (German)	Topics of Current Research IV
Module title (English)	Topics of Current Research 4
Person responsible for the module	N.N.
Prerequisites for admission to the module	-
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	128 M.Sc. Physics: Required elective module 628 M.Sc. Photonics: Required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 2 h per week Exercise: 1 h per week
ECTS credits	4 CP
Work load:	120 h
- In-class studying	45 h
- Independent studying (incl. preparations for examination)	75 h
Content	<ul style="list-style-type: none"> <li>Advanced topics of current research in optics and photonics.</li> </ul>
Intended learning outcomes	<ul style="list-style-type: none"> <li>Introduction into a field of current research as a basis for further study and research in this field;</li> <li>Independent solution of Exercise problems;</li> <li>Ability to acquire further knowledge by independent literature studies.</li> </ul>
Prerequisites for admission to the module examination	Course exercises to be submitted; further information on the kind and scope will be given at the beginning of each semester.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The selected form of the exam will be announced at the beginning of the semester.
Additional information on the module	128 M.Sc. Physics: Required elective module (Specialization in „Optics“) If requested by the participants and agreed on with the responsible teacher, this module can be offered on-site and/or online (hybrid).
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.

Language of instruction	English
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Modul <b>PAFMQ001</b> Fundamentals of Quantum information	
Module code	PAFMQ001
Module title (German)	Grundlagen der Quanteninformation
Module title (English)	Fundamentals of Quantum information
Person responsible for the module	Prof. Dr. F. Steinlechner, PD Dr. F. Setzpfandt, Prof. Dr. M. Gärttner
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	none
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology, compulsory module ("essentials") 128 M.Sc. Physics: required elective module specialisation "optics" 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<b>Concepts of quantum information processing</b> <ul style="list-style-type: none"> <li>• introduction to fundamental concepts and the basic formalism</li> <li>• entanglement</li> <li>• application examples</li> <li>• entanglement characterization</li> </ul> <b>Hardware for quantum information processing</b> <ul style="list-style-type: none"> <li>• brief review of key physical concepts and applications</li> <li>• basic hardware requirements for information processing</li> </ul> optical qubits, gates
Intended learning outcomes	Understanding of fundamental properties of quantum states, their applications and how to characterize them. Knowledge about basic hardware requirements for quantum information processing and example implementations.
Prerequisites for admission to the module examination	Solution of exercise sheets (Scope to be announced at the beginning of the module).

Requirements for awarding credit points (type of examination)	Written examination
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English

Modul <b>PAFMQ002</b> Advanced Quantum Information	
Module code	PAFMQ002
Module title (German)	Fortgeschrittene Quanteninformationstheorie und -hardware
Module title (English)	Advanced Quantum Information
Person responsible for the module	Prof. Dr. F. Steinlechner, PD Dr. F. Setzpfandt, Prof. Dr. M. Gärttner
Recommended or expected prior knowledge	Content of "Introduction to Quantum Information"
Type of module (compulsory module, required elective module, elective module)	528 M.Sc. Quantum Science and Technology, required elective module, subject area "essentials" 128 M.Sc. Physics: required elective module specialization "optics" 628 M.Sc. Photonics: required elective module
Frequency of offer (how often is the module offered?)	Every second semester (beginning in winter semester)
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Lecture: 4 h per week Exercise: 2 h per week
ECTS credits	8 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	240 h 90 h 150 h
Content	<b>Hardware for quantum information processing</b> <ul style="list-style-type: none"> <li>• superconducting qubits, gates, control, manipulation, readout</li> <li>• light-matter interaction</li> <li>• semiconductor qubits (quantum dots, defects)</li> <li>• atoms / quantum Gases</li> <li>• foundations of quantum sensing (sensitivity, noise, standard quantum limit)</li> <li>• Optomechanics</li> </ul> <b>Concepts of quantum information processing</b> <ul style="list-style-type: none"> <li>• decoherence</li> <li>• quantum error correction</li> <li>• many-body entanglement</li> </ul> advanced concepts
Intended learning outcomes	Knowledge of all eminent concepts for implementing quantum-information systems. Understanding advanced concepts that enable treatment of non-ideal quantum systems.
Prerequisites for admission to the module examination	Solution of exercise sheets (Scope to be announced at the beginning of the module).

Requirements for awarding credit points (type of examination)	Written examination.
Recommended reading	A list of literature and materials will be provided at the beginning of the semester.
Language of instruction	English



Modul <b>PAFMO099</b> Master thesis	
Module code	PAFMO099
Module title (German)	Masterarbeit Photonics
Module title (English)	Master thesis
Person responsible for the module	Prof. Dr. Thomas Pertsch
Prerequisites for admission to the module	72 ECTS
Recommended or expected prior knowledge	-
Prerequisite for what other modules	-
Type of module (compulsory module, required elective module, elective module)	628 M.Sc. Photonics: Compulsory Module
Frequency of offer (how often is the module offered?)	Every semester
Duration of module	1 semester
Module Components/Types of courses (lecture, practical course, lab, tutorial, exercise, seminar, internship, ...)	Practical course
ECTS credits	30 CP
Work load:	900 h
- In-class studying	0 h
- Independent studying (incl. preparations for examination)	900 h
Content	<p>total workload:</p> <p>900 h depending on the topic this total workload should be distributed approximately as:</p> <ul style="list-style-type: none"> <li>•225 h introduction to the research topic (study of relevant literature, ...)</li> <li>•450 h research work (in the lab for experimental topics and at computer etc. for theoretical topics)</li> <li>•200 h preparation of the final report</li> <li>•25 h preparation and carrying out presentation of the results Internship in a research laboratory</li> </ul>
Intended learning outcomes	<p>The students will acquire the knowledge for:</p> <ul style="list-style-type: none"> <li>•Carrying out advanced scientific labwork in optics together with a research team</li> <li>•Preparation of the work flow and analysis of the results</li> <li>•Preparation of a scientific report</li> <li>•Presentation of the results in a Master's Thesis and presentation</li> </ul>

Prerequisites for admission to the module examination	-
Requirements for awarding credit points (type of examination)	The mark consists of a written report – Master's Thesis (66%), presentation (33%) Specifically defined by the instructor of the research team
Additional information on the module	The Master's Thesis should contain approximately 40-60 pages. The results of the Master's Thesis are presented by the candidate in a 20-30 minute talk, and then discussed. The final grade is determined according to the Rules of Examination (in German: "Prüfungsordnung").
Recommended reading	A list of Literature and materials will be provided at the beginning of the semester.
Language of instruction	English

# Abbreviations:

## Abbreviations of lectures

IL....	Inaugural lecture
WG....	Working group
AM....	Advanced module
Exh....	Exhibition
BM....	Basic module
BzPS....	Begleitveranstaltung zum Praxissemester
C....	Consulting
To....	Tour
M....	Meeting
Blo....	Blockage
BC....	Block course
DV....	Slide show
IN....	Introductory session
RS....	Registrations
EC....	Exam course
EX....	Excursion
Exp....	Experiment/survey
FE....	Celebration/festivity
MS....	Movie screening
FEx....	Field exercise
BC....	Basic course
MaS....	Main seminar
MS/ BC....	Main seminar/block course
MaS/ Ex....	Main seminar/exercise
Inf....	Information session
IDS/E....	Interdisciplinary main seminar/ exercise
E....	Exam
KS/ PR....	Klausur/Prüfung
C....	Colloquium
C/I....	Colloquium/practical work
CS....	Conference/symposium
kV....	Kulturelle Veranstaltung

## Abbreviations of lectures

Cu....	Course
Co....	Course
Lag....	Lagerung
TRP....	Training research project
RC....	Reading course
M....	Module
ME....	Musical event
AS....	Advanced seminar
OnS....	Online seminar
OnL....	Online lecture
P....	Practical work
I/S....	Practical work/seminar
PM....	Practice module
Sa....	Sample
PJ....	Project
PPD....	Propaedeutic
PS....	Proseminar
E/T....	Exam/test
EPr....	Exam preparation
CSA....	Cross-sectional area
RE....	Revision course
LS....	Lecture Series
TC....	Training course
S....	Seminar
S/E....	Seminar/Excursion
S/E....	Seminar/Exercise
ST....	Service time
Sl....	Conference
SuSch....	Summer school
MISC....	Miscellaneous
OE....	Other event
LC....	Language course
Con....	Convention
TT....	Teleteaching
MN....	Meeting
Tu....	Tutorial
T....	Tutorial
E....	Exercise
E/BC....	Exercise/block course
E....	Exercises

Abbreviations of lectures

E/I....	Exercise/interdisciplinary
E/I....	Exercise/practical work
E/T....	Exercise/tutorial
Conf....	Conference
ViCo....	Video conference
L....	Lecture
L/C....	Lecture with colloquium
L/I....	Lecture/practical work
L/S....	Lecture/seminar
L/E....	Lecture/exercise
Sp....	Speech
TK....	Talk
OS....	Optional seminar
OL....	Optional lecture
Tr....	Training
Wo....	Workshop
WOS....	Workshop
CAC....	Certificate award ceremony

Other Abbreviations

Anm.....	Anmerkung
ASQ....	Allgemeine Schlüsselqualifikationen
AT....	Altes Testament
E....	Essay
FSQ....	Fachspezifische Schlüsselqualifikationen
FSV....	Fakultät für Sozial- und Verhaltenswissenschaften
GK....	Grundkurs
IAW....	Institut für Altertumswissenschaften
LP....	Leistungspunkte
NT....	Neues Testament
SQ....	Schlüsselqualifikationen
SS....	Sommersemester
SWS....	Semesterwochenstunden
TE....	Teilnahme
TP....	Thesenpublikation
ThULB....	Thüringer Universitäts- und Landesbibliothek
VVZ....	Vorlesungsverzeichnis
WS....	Wintersemester