Description of Module guest studies
628 Photonics
PO-Version 2020

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

Contents summary

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 **PAFMF003** 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. Schmidt
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science” or ”Optics” Required electrive module M.Sc. Photonics
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, …)	Lecutre: 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	• Electronic, dielectric, and optical properties of solids; • Mueller matrix polarimetry; • Electrooptics and magnetooptics; • Photodetectors and optical systems; • Quantum optics and quantum technologies.
Intended learning outcomes	The course covers basic and advanced topics of solid state optics, with a special focus on the relation between electronic and optical properties. An effort is made to treat electro- and magnetooptical effects and quantum optical effects as rigorous as possible through the Mueller matrix approach and through quantum mechanical approaches, respectively.
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)	Module examination written summer semester (50%) Module examination written winter semester (50%)
Language of instruction	English

Modul **PAFMF009** Optoelectronics	
Module code	PAFMF009
Module title (German)	Optoelektronik
Module title (English)	Optoelectronics
Person responsible for the module	Apl. Prof. Dr. F. Schmidl
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science” and ”Optics” Required elective module M.Sc. Photonics
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	• Semiconductors • Optoelectronic devices • Photodiodes • Light emitting diodes • Semiconductor optical amplifier
Intended learning outcomes	In this course the student will learn the fundamentals of semiconductor optical devices such as photodiodes, solar cells, LEDs, laser diodes and semiconductor optical amplifiers.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Language of instruction	English

Modul **PAFMF018** Quantum Information Theory	
Module code	PAFMF018
Module title (German)	Quanteninformationstheorie
Module title (English)	Quantum Information Theory
Person responsible for the module	Prof. A. Tünnermann Dr. F. Steinlechner Dr. F. Eilenberger (PD Dr. W. Krech)
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Solid state physics / Material science" or " Gravitation and Quantum Theory" Required elective module B.Sc. Physics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Lecture of Drs. Eilenberger, Steinlechner • Basic introduction to quantum optics; • Quantum light sources; • Encoding, • transmission and detection of information with quantum light; • Quantum communication and cryptography; • Quantum communication networks; • Outlook on Quantum metrology and Quantum imaging; Lecture of PD Krech • Qubit • Quantum entropy of information • Quantum data compression • Hidden quantum information / non-locality • Bell's inequalities

Intended learning outcomes	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, rangingfrom fundamental concepts and experiments to state of the artimplementations for secure communication networks. The course willalso give an outlook to aspects of Quantum metrology and imaging.Afteractive participation in the course, the students will be familiarwith the basic concepts and phenomena of quantum information exchangeand some aspects related to the practical implementation thereof.They will be able to apply their knowledge in the assessment andsetup of experiments and devices for applications of quantuminformation processing.
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 or presenation (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	• Grynberg / Aspect / Fabre "Introduction to Quantum Optics"; • Body ”Nonlinear Optics”;Kok / Lovett ”Introduction to Optical Quantum Information Processing”; • Leuchs ”Lectures on Quantum Information”;Sergienko ”Quantum Communications and Cryptograhy”; • Ou / Jeff ”Multi-Photon Quantum Interference”;
Language of instruction	English (Drs. Eilenberger, Steinlechner) Geman (PD Krech)

Modul **PAFMF021** 2D materials	
Module code	PAFMF021
Module title (German)	Zweidimensionale Materialien
Module title (English)	2D materials
Person responsible for the module	Jun.-Prof. Giancarlo Soavi
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus Solid-state physics Required elective module M.Sc. Photonics
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	• Graphene: electrical and optical properties. Applications in electronic and optoelectronic. • Semiconducting 2D materials: Coulomb screening and the concept of excitons. Optical spectroscopy of excitons. Optoelectronic applications. • Heterostructures: electron and exciton interactions in layered heterostructures
Intended learning outcomes	• Mastering the basics and methods of two-dimensional materials • Ability to work independently on problems in the field of two-dimensional materials
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	M. I. Katsnelsons, Graphene Carbon in Two Dimensions C. F. Klingshirn, Semiconductor Optics Additional references (journal articles) will be provided during the course
Language of instruction	English

Modul **PAFMO001** Fundamentals of Modern Optics	
Module code	PAFMO001
Module title (German)	Fundamentals of Modern Optics
Module title (English)	Fundamentals of Modern Optics
Person responsible for the module	Prof. Dr. Thomas Pertsch
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	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: 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	• Basic concepts pf wave optics • Dielectric function to describe light-matter interaction • Propagation of beams and pulses • Diffraction theory • Elements of Fourier optics • Polarization of light • Light in structured media • Optics in crystals
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 beauty of optics in nature and in technology will be taught. This will enable students to follow more specialized courses in photonics.
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 examination (100%)

Recommended reading	• B.E.A. Saleh and M.C. Teich, ”Fundamentals of Photonics,” Wiley (2007). • H. Lipson, D.S. Tannhauser, S.G. Lipson, ”Optical Physics,” Cambridge (2010). • E. Hecht and A. Zajac, ”Optics,” Addison-Wesley Longman (2003). • F.L. Pedrotti, L.S. Pedrotti, L.M. Pedrotti, ”Introduction to Optics,” Pearson (2006) • G. Brooker, ”Modern Classical Optics,” Oxford (2002).
Language of instruction	English

Modul **PAFMO002** 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, Dr. O. Stenzel
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Compulsory Module M.Sc. Photonics
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	• Classical interaction of light with matter • Basic knowledge on quantum mechanics • Einstein coefficients and Plancks formula • Selection rules • Hydrogen atom and helium atom • Introduction to molecular spectroscopy • Dielectric function and linear optical constants • Kramers-Kronig-Relations • Linear optical properties of crystalline and amorphous solids • Basic nonlinear optical effects
Intended learning outcomes	The course is an introduction to the principles of the optical response of materials.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Recommended reading	• Demtröder, "Experimental physics II" • Demtröder, "Experimental physics III – atoms, molecules and solids" • R. Feynman, "Feynman lectures on physics III quantum mechanics" • Jackson, "Classical Electrodynamics • E. Hecht, "Optics"
Language of instruction	English

Modul **PAFMO004** Laser Physics	
Module code	PAFMO004
Module title (German)	Laser Physics
Module title (English)	Laser Physics
Person responsible for the module	Prof. Dr. J. Limpert, Prof. Dr. S. Nolte
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Compulsory Module M.Sc. Photonics
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 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	• Introduction to laser physics (stimulated emission, atomic rate equations, laser pumping and population inversion); • Optical beams and laser resonators; • Laser dynamics; • Q-switching; • Mode locking; • Wavelength tuning and single frequency operation; • Laser systems; • Selected industrial and scientific applications.
Intended learning outcomes	This course provides an introduction to the basic ideas of laser physics. The first part presents the fundamental equations and concepts of laser theory, while the second part is devoted to a detailed discussion of selected laser applications. The students are introduced to the different types of lasers including classical gas or ruby lasers as well as modern high-power diode pumped solid-state concepts and their applications.
Requirements for awarding credit points (type of examination)	Written examination (100%)

Recommended reading	• Siegman, Lasers; • W. Koechner, Solid-State Laser Engineering; • W. Demtröder, Laser Spectroscopy; • D. Bäuerle, Laser Processing and Chemistry; • H.-G. Rubahn, Laser Applications in Surface Science and Technology.
Language of instruction	English

Modul **PAFMO005** 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. Herbert Gross
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Compulsory Module M.Sc. Photonics
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	• Basic principles • Wave optical fundamentals • Sensors • Fringe projection, triangulation • Interferometry and wave front sensing • Holography • Speckle methods and OCT • Phase retrieval • Metrology of aspheres and freeform surfaces • Confocal methods
Intended learning outcomes	This course covers the main principles of optical measurements and surface metrology.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Language of instruction	English

Modul **PAFMO006** Introduction to Optical Modeling	
Module code	PAFMO006
Module title (German)	Introduction to Optical Modeling
Module title (English)	Introduction to Optical Modeling
Person responsible for the module	Prof. Dr. F. Wyrowski, apl. Prof. Dr. U. W. Zeitner
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics" Compulsory Module M.Sc. Photonics
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	• 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 aims to show how linear optics is applied for 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.
Requirements for awarding credit points (type of examination)	Written examination (100%)

Additional information on the module	
Recommended reading	• H. Gross, Handbook of Optical Systems Vol.1: Fundamentals of Technical Optics, Wiley-VCH; • L. Mandel and E. Wolf, Optical Coherence and Quantum Optics; • L. Novotny and B. Hecht, Principles of Nano-Optics.
Language of instruction	English

Modul **PAFMO007** 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	None
Type of module (compulsory module, required elective module, elective module)	Compulsory Module M.Sc. Photonics
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	• Introduction to experimental techniques in optics. • Planning and preparation of a scientific measuring task. • Carrying out scientific labwork in optics together with a research team. • Preparation of a scientific report.
Requirements for awarding credit points (type of examination)	Lab Work mark (100%) Consists of acceptance tests and written reports
Recommended reading	prepared electronic material describing the different labs which can be downloaded from www.asp.uni-jena.de/optics_labs
Language of instruction	English

Modul **PAFMO008** 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	Practical Module Experimental Optics
Type of module (compulsory module, required elective module, elective module)	Compulsory Module M.Sc. Photonics
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, …)	Practical course 300 h depending on the topic this total workload should be distributed approximately as: • 50 h introduction to the research topic (study of relevant literature, …) • 190 h research work (in the lab for experimental topics and at computer etc. for theoretical topics) • 50 h preparation of the final report • 10 h preparation and carrying out presentation of the results
ECTS credits	10 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	300 h - h - h
Content	Internship in industry or a research laboratory
Intended learning outcomes	• Carrying out scientific labwork in optics together with a research team. • Preparation of a written scientific report. • Presentation and defense of the results in an oral presentation.
Requirements for awarding credit points (type of examination)	Lab Work mark (100%) Consists of a written report (approximately 15-20 pages) and a final presentation (10-20 minutes) with subsequent discussion The final grade will be determined based on the research performance, the final report, and the presentation.
Recommended reading	specifically defined by the instructor of the internship
Language of instruction	English

Modul **PAFMO009** 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	Completion of the 2 practical Modules Experimental Optics and Internship
Type of module (compulsory module, required elective module, elective module)	Compulsory Module M.Sc. Photonics
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 total workload: 540 h depending on the topic this total workload should be distributed approximately as: • 150 h introduction to the research topic (study of relevant literature, …) • 270 h research work (in the lab for experimental topics and at computer etc. for theoretical topics) • 100 h preparation of the final report • 20 h preparation and carrying out presentation of the resultsh
ECTS credits	18 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	540 h - h - h
Content	Internship in a research laboratory
Intended learning outcomes	• Carrying out scientific labwork in optics together with a research team • Preparation of a scientific report • Presentation of the results in a written report
Requirements for awarding credit points (type of examination)	Lab Work mark (100%) Consists of a written report (approximately 20-30 pages) and a final presentation (15-25 minutes) with subsequent discussion The final grade will be determined based on the research performance, the final report, and the presentation.
Recommended reading	specifically defined by the instructor of the research team
Language of instruction	English

Modul **PAFMO100** 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. Th. Stöhlker
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Grundlagen der Atomphysik, Grundlagen der Elektrodynamik
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" and "Solid State Physics/Material Science" Required elective module M.Sc. Photonics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	Basic concepts of particle accelerators, application of accelerators in basic science and medicine, landmark experiments
Intended learning outcomes	Gaining an overview of the various applications of particle accelerators, in particular for basic science, ability to solve exercise 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%)
Recommended reading	• J. Eichler, • Lectures on Ion-Atom Collisions (Elsevier Science); • W. R. Leo, Techniques for Nuclear and Particle Physics Experiments (Springer)
Language of instruction	English (German on request)

Modul **PAFMO101** Active Photonic Devices	
Module code	PAFMO101
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	none
Recommended or expected prior knowledge	Basic knowledge in electrodynamics
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Introduction; • Electro-optical modulation; • Acousto-optical devices; • Magneto-optics and optical isolation; • Integrated lasers; • Non-Linear devices for light generation;
Intended learning outcomes	The aim of this course is to give a comprehensive overview about active photonic devices such as switches or modulators. The course starts by a crisp 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 we will discuss the fundamental principles as well as devices currently employed in photonics. This Lecture will provide the students a base for their Master's thesis.
Requirements for awarding credit points (type of examination)	Written examination (100%)

Recommended reading	• J. D. Jackson: Electrodynamics; • Yariv: Optical Electronics in Modern Communications; • Born/Wolf: Principles of Optics.
Language of instruction	English

Modul **PAFMO102** Analytical Instrumentations	
Module code	PAFMO102
Module title (German)	Analytical Instrumentations
Module title (English)	Analytical Instrumentations
Person responsible for the module	Dr. Adriana Szeghalmi, Prof. Dr. Andreas Tünnermann
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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 learn about analytical methods to investigate 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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.

Recommended reading	• Atkins: Physical Chemistry (partial) • Lakowicz: Principles of fluorescence spectroscopy (partial) • Selected research publications and technical notes
Language of instruction	English

Modul **PAFMO103** Applied Laser Technology I	
Module code	PAFMO103
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 and Prof. Dr. H. Stafast
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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	• 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. • Learning 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%)
Recommended reading	• Laser Spectroscopy, W. Demtröder, Springer • Molekülphysik und Quantenchemie, H. Haken u H. C. Wolf, Springer • Lasers in Chemistry, M. Lackner edit., Wiley-VCH 2008

Language of instruction	English

Modul **PAFMO104** Applied Laser Technology II	
Module code	PAFMO104
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, Prof. Dr. H. Stafast
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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 should acquire knowledge of 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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	R. Paschotta, Encyclopedia of Laser Physics and Technology, Wiley-VCH
Language of instruction	English

Modul **PAFMO106** Atomic Physics at High Field Strengths	
Module code	PAFMO106
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. Th. Stöhlker
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in atomic physics and electrodynamics
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics”, ”Solid State Physics/Material Science” Required elective module M.Sc. Photonics
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	• Strong field effects on the atomic structure • Relativistic and QED effects on the structure of heavy ions • X-ray spectroscopy of high-Z ions • Application in x-ray astronomy • Penetration of charged particles through matter • Particle dynamics in of atoms and ions in strong laser fields • Relativistic ion-atom and ion-electron collisions • Fundamental interaction processes • Scattering, absorption and energy loss • Detection methods • Particle creation
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%)
Recommended reading	• J. Eichler, Lectures on Ion-Atom Collisions (Elsevier Science); • W. R. Leo, Techniques for Nuclear and Particle Physics Experiments (Springer)
Language of instruction	English (German on request)

Modul **PAFMO107** Attosecond Laser Physics	
Module code	PAFMO107
Module title (German)	Attosecond Laser Physics
Module title (English)	Attosecond Laser Physics
Person responsible for the module	Jun.-Prof. Dr. A. Pfeiffer
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Module Strong-Field Laser Physics or equivalent
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	Zenghu Chang, Fundamentals of Attosecond Optics.
Language of instruction	English

Modul **PAFMO120** Biomedical Imaging - Ionizing Radiation

Module code	PAFMO120
Module title (German)	Biomedical Imaging - Ionizing Radiation
Module title (English)	Biomedical Imaging - Ionizing Radiation
Person responsible for the module	Prof. Dr. J. R. Reichenbach, Prof. Dr. E. Förster
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• 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.
Requirements for awarding credit points (type of examination)	Oral examination (100%)

Recommended reading	• Oppelt, Imaging Systems for Medical Diagnostics: Fundamentals, Technical Solutions and Applications for Systems Applying Ionizing Radiation, Nuclear Magnetic Resonance and Ultrasound, Publicis, 2nd edition, 2006; • P. Suetens, Fundamentals of Medical Imaging, Cambridge University Press; 2nd edition, 2009; • W.R. Hendee, E.R. Ritenour, Medical Imaging Physics, Wiley-Liss, 4th edition, 2002.
Language of instruction	English

Modul **PAFMO121** Biomedical Imaging - Non Ionizing Radiation	
Module code	PAFMO121
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, Prof. Dr. E. Förster
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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 30 h 90 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.
Requirements for awarding credit points (type of examination)	Oral examination (100%)

Recommended reading	• Oppelt. Imaging Systems for Medical Diagnostics: Fundamentals, Technical Solutions and Applications for Systems Applying Ionizing Radiation, Nuclear Magnetic Resonance and Ultrasound, Publicis, 2nd edition, 2006; • J.T. Bushberg et al., The Essential Physics of Medical Imaging, Lippincott Raven, 3rd edition, 2011; • R.W. Brown, Y.-C. N. Cheng, E. M. Haacke, M.R. Thompson, R. Venkatesan, Magnetic Resonance Imaging: Physical Principles and Sequence Design, Wiley, 2nd edition, 2014.
Language of instruction	English

Modul **PAFMO122** Biophotonics	
Module code	PAFMO122
Module title (German)	Biophotonics
Module title (English)	Biophotonics
Person responsible for the module	Prof. Dr. Rainer Heintzmann, Prof. Dr. Ralf Ehricht
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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 60 h 60 h

Content	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.
Intended learning outcomes	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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	• Paras N. Prasad, Introduction to Biophotonics • Textbooks on laser spectroscopy, e.g. Demtröder; on quantum mechanics, e.g. Atkins and on optics, e.g. Zinth/Zinth • Jerome Mertz: Introduction to Optical Microscopy, Roberts & Company Publishers, 2010 • Selected chapters of Handbook of Biophotonics (Ed. J. Popp) WILEY
Language of instruction	English

Modul **PAFMO130** Computational Photonics	
Module code	PAFMO130
Module title (German)	Computational Photonics
Module title (English)	Computational Photonics
Person responsible for the module	Prof. Dr. T. Pertsch
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics as well as basic knowledge of a computer programming language and computational physics
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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 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.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Recommended reading	• Taflove and S.C. Hagness, Computational Electrodynamics; • list of selected journal publications given during the lecture.
Language of instruction	English

Modul **PAFMO131** Fundamental Atomic and Nuclear Processes in Highly Ionized Matter	
Module code	PAFMO131
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. Th. Stöhlker
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in atomic an nuclear physics
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” , ”Solid State Physics/Material Science” Required elective module M.Sc. Photonics
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, Excercise: 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	Gaining an overview of experiments addressing astrophysical topics, in particular concerning ionized matter

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.
Language of instruction	English (German on request)

Modul **PAFMO132** Design and Correction of Optical Systems	
Module code	PAFMO132
Module title (German)	Design and Correction of Optical Systems
Module title (English)	Design and Correction of Optical Systems
Person responsible for the module	Prof. Dr. H. Gross
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in geometrical and physical optics.
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Basic technical optics; • Paraxial optics; • Imaging systems; • Aberrations; • Performance evaluation of optical systems; • Correction of optical systems; • Optical system classification; • Special system considerations.
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.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Language of instruction	English

Modul **PAFMO140** Diffractive Optics	
Module code	PAFMO140
Module title (German)	Diffractive Optics
Module title (English)	Diffractive Optics
Person responsible for the module	Prof. Dr. Frank Wyrowski
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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	• Modeling diffraction of light fields • Diffraction vs. scattering • Diffraction at gratings • Diffractive and Fresnel lens modeling and design • Modeling and design of diffractive beam splitters and diffusers • Modeling of microlens arrays • Modeling and design of cell-oriented diffractive elements • Application and modeling of Spatial Light Moduleators (SLM)
Intended learning outcomes	Diffractive optics is widely recognized as an important enabling technology in modern optics. The control of light fields by microstructured media, which is the essence of diffractive optics, opens a large number of avenues in optical research and engineering. In this Lecture, the basic modeling and design principles of diffractive optics are considered. Various scenarios from different applications are investigated.
Requirements for awarding credit points (type of examination)	written examination (100%)
Recommended reading	• E. Hecht and A. Zajac, Optics • M. Born and E. Wolf, Principles of Optics • J. Turunen and F. Wyrowski, Diffractive Optics for industrial and commercial applications, Akademie Verlag, 1997

Language of instruction	English

Modul **PAFMO150** Renewable Energies	
Module code	PAFMO150
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	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics Required elective module LA Physik
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	Teaching of knowledge on the fundamentals of renewable energies. Development of 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 form of the exam will be announced at the beginning of the semester.
Recommended reading	• Gasch, Twele: Windkraftanlagen; • De Vos: Thermodynamics of Solar Energy Conversion.
Language of instruction	English or German depending on audience

Modul **PAFMO151** Experimental Nonlinear Optics	
Module code	PAFMO151
Module title (German)	Experimental Nonlinear Optics
Module title (English)	Experimental Nonlinear Optics
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Propagation of light in crystals; • Properties of the non-linear susceptibility tensor; • Description of light propagation in non-linear media; • Parametric effects; • Second harmonic generation; • Phase-matching; • Propagation of ultrashort pulses; • High-harmonic generation; • Solitons
Intended learning outcomes	This course gives an introduction to optics in non-linear media and discusses the main non-linear effects.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Recommended reading	• Boyd, Non-Linear optics; • Zernike/Midwinter, Applied non-linear optics; • Sauter, Non-Linear optics.
Language of instruction	English

Modul **PAFMO160** Fiber Optics	
Module code	PAFMO160
Module title (German)	Fiber Optics
Module title (English)	Fiber Optics
Person responsible for the module	Prof. Dr. M. Schmidt
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge on modern optics and condensed matter physics.
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Properties of optical fibers; • Light propagation in optical fibers; • Technology and characterization techniques; • Special fiber types (photonic crystal fibers, hollow fibers, polarization maintaining fibers; • Fiber devices (e.g. fiber amplifiers and lasers); • Applications
Intended learning outcomes	This course introduces properties of different types of optical fiber waveguides. Applications of optical fibers and optical sensing will be discussed.
Prerequisites for admission to the module examination	none
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	• Snyder/Love, Optical Waveguide Theory; • Okamoto, Fundamentals of Optical Waveguides.

Language of instruction	English

Modul **PAFMO170** High-Intensity/Relativistic Optics	
Module code	PAFMO170
Module title (German)	High-Intensity/Relativistic Optics
Module title (English)	High-Intensity/Relativistic Optics
Person responsible for the module	Prof. Dr. M. Kaluza
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• High-intensity laser technology; • Laser plasma physics; • Laser accelerated particles and applications.
Intended learning outcomes	The interaction of high intensity light fields with matter is the subject of this course. The students should learn the basic ideas of high intensity laser technology and its applications.
Prerequisites for admission to the module examination	none
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	• W. L. Kruer, The Physics of Laser Plasma Interactions, Westview press (2003), Boulder Colorado; • P. Gibbon, Short Pulse Laser Interactions with Matter, Imperial College Press (2005), London; • F. F. Chen, Introduction to Plasma Physics and Controlled Fusion, Vol. 1: Plasma Physics, Springer (1984).
Language of instruction	English

Modul **PAFMO171** History of Optics	
Module code	PAFMO171
Module title (German)	Geschichte der Optik
Module title (English)	History of Optics
Person responsible for the module	Prof. Dr. C. Spielman, Dr. C. Forstner
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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 heories of vision and ending with quantum optics. A strong focus will be given on the development of concepts and experiments that influenced todays thinking about light and optics, such as wave particle dualism or the Abbe diffraction limit. An excursion 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.
Requirements for awarding credit points (type of examination)	Scientific Talk (100%)
Recommended reading	• David C. Lindberg, Theories of Vision from al Kindi to Kepler. Chicago: University of Chicago Press, 1976. • Olivier Darrigol, A History of Optics: From Greek Antiquity to the Nineteenth Century. Oxford: Oxford University Press, 2012. • Helge Kragh, Quantum Generations: A History of Physics of the Twentieth Century. Princeton: Princeton University Press, 1999.
Language of instruction	German, English

Modul **PAFMO180** Image Processing	
Module code	PAFMO180
Module title (German)	Image Processing
Module title (English)	Image Processing
Person responsible for the module	Prof. Dr. Joachim Denzler
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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	• Digital image fundamentals (Image Sensing and Acquisition, Image Sampling and Quantization) • Image Enhancement in the Spatial Domain (Basic Gray Level Transformations, Histogram Processing, Spatial Filtering) • Image Enhancement in the Frequency Domain (Introduction to the Fourier-Transform and the Frequency Domain, Frequency Domain Filtering, Homomorphic Filtering) • Image Restoration (Noise Models, Inverse Filtering, Geometric Distortion) • Color Image Processing Image Segmentation (Detection of Discontinuities, Edge Linking and Boundary Detection, Thresholding, Region-Based Segmentation) • Representation and Description Applications
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)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	Gonzalez, Woods, Digital Image Processing, Prentice Hall, 2001
Language of instruction	English

Modul **PAFMO181** Image Processing in Microscopy	
Module code	PAFMO181
Module title (German)	Image Processing in Microscopy
Module title (English)	Image Processing in Microscopy
Person responsible for the module	Prof. Dr. Rainer Heintzmann
Prerequisites for admission to the module	none
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 (www.diplib.org). 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	All the image processing and simulations will be practiced in exercises. The student needs to be familiar with programming 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.
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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).
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Recommended reading	
Language of instruction	English, German if requested

Modul **PAFMO182** Imaging and Aberration Theory	
Module code	PAFMO182
Module title (German)	Imaging and Aberration Theory
Module title (English)	Imaging and Aberration Theory
Person responsible for the module	Prof. Dr. H. Gross
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in geometrical and physical optics.
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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	• Paraxial imaging; • Basics of optical systems; • Eikonal theory; • Geometrical aberrations, representations, expansion; • Detailed discussion of primary aberrations; • Sine condition, isoplanatism, afocal cases; • Wave aberrations and Zernike representation; • Miscellaneous aspects of aberration theory.
Intended learning outcomes	This course covers the fundamental principles of classical optical imaging and aberration theory of optical systems.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Language of instruction	English

Modul **PAFMO183** Introduction to Nanooptics	
Module code	PAFMO183
Module title (German)	Introduction to Nanooptics
Module title (English)	Introduction to Nanooptics
Person responsible for the module	Jun.-Prof. Dr. I. Staude, Prof. Dr. T. Pertsch
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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	• Surface-plasmon-polaritons; • Plasmonics; • Photonic crystals; • Fabrication and optical characterization of nanostructures; • Photonic nanomaterials / metamaterials / metasurfaces; • Optical nanoemitters; • Optical nanoantennas.
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	none

Requirements for awarding credit points (type of examination)	Module mark (100%) Consists of a written examination and an oral presentation on a current research topic.
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 **PAFMO200** 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. Matt Zepf
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in electrodynamics and plasma physics
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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	• Laser Plasma Interactions • Principles of Plasma Accelerators • Ultrafast Photon Sources • Scattering of photons from particle beams
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.
Requirements for awarding credit points (type of examination)	presentation and/or oral examination (100%)
Recommended reading	Gibbon, Short Pulse Laser Interactions with Matter
Language of instruction	English/German depending on participants

Modul **PAFMO201** Laser Engineering	
Module code	PAFMO201
Module title (German)	Laser Engineering
Module title (English)	Laser Engineering
Person responsible for the module	Prof. Dr. Malte Kaluza
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Prior knowledge in electrodynamics and laser physics is strongly recommended.
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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 per week
ECTS credits	4 CP
Work load: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• origin and dependencies of absorption and emission cross sections • Ytterbium based laser media • design of laser diode pump engines, • special topics in geometrical optics for amplifier design • basic calculations for layout of diode pumped high energy amplifiers • Ytterbium based laser materials and cryogenic cooling • limitations and special topics (laser induced damage threshold (LIDT), amplified spontaneous emission (ASE) …)
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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.

Recommended reading	• Koechner, W. (2013). Solid-state laser engineering (Vol. 1). Springer. • Träger, F. (Ed.). (2012). Springer handbook of lasers and optics. Springer Science & Business Media. • Wood, R. M. (2003). Laser-induced damage of optical materials. CRC Press.
Language of instruction	English

Modul **PAFMO203** 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. H. Gross
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in geometrical and physical optics.
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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 and user interface; • Description and properties of optical systems; • Geometrical and wave optical aberrations; • Optimization; • Imaging simulation; • Introduction into illumination systems; • Correction of simple systems; • More advanced handling and correction methods.
Intended learning outcomes	This course gives an introduction in layout, performance analysis and optimization of optical systems with the software Zemax.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Language of instruction	English

Modul **PAFMO204** 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. H. Gross
Prerequisites for admission to the module	none
Recommended or expected prior knowledge	Basic knowledge in aberration theory and optical design.
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Paraxial imaging and basic properties of optical systems; • Initial systems and structural modifications; • Chromatical correction; • Aspheres and freeform surfaces; • Optimization strategy and constraints; • Special correction features and methods; • Tolerancing and adjustment.
Intended learning outcomes	This course covers the advanced principles of the development of optical systems.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Language of instruction	English

Modul **PAFMO205** Light Microscopy	
Module code	PAFMO205
Module title (German)	Light Microscopy
Module title (English)	Light Microscopy
Person responsible for the module	Prof. Dr. Rainer Heintzmann
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	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. The working principles of light-detectors are discussed and the requirements for appropriate sampling of images. Finally various modes of fluorescence microscopy and high-resolution microscopy will be covered. The exercises will be calculating examples, also involving hands-on computer based modeling using Matlab and other tools.
Intended learning outcomes	Understanding of the working principles of modern light microscopes and microscopic methods ranging from standard methods to modern superresolution techniques.

Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul **PAFMO206** Light Source Modeling	
Module code	PAFMO206
Module title (German)	Light Source Modeling
Module title (English)	Light Source Modeling
Person responsible for the module	Prof. Dr. Frank Wyrowski
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Special cases of monochromatic fields • Gaussian beams and its propagation • Electromagnetic coherence theory; cross spectral density • Cross spectral density and polarization matrices • Stokes vectors and Mueller matrix • Mode decomposition of general source fields • Elementary mode decomposition • System modeling with partially coherent source fields • System modeling with ultrashort pulses • All techniques are demonstrated at hands-on examples
Intended learning outcomes	The application and usage of optical technologies benefit significantly from the ever growing variety of light sources with different characteristics and reasonable prices. LEDs, lasers and laser diodes have become indispensable in numerous applications and devices. Ultrashort pulses are on the way to industrial and medical applications. X-ray sources are of increasing importance. All those sources require a suitable approach in optical modeling and design. The students will get a comprehensive overview of different source modeling techniques of practical importance in optical modeling and design.
Requirements for awarding credit points (type of examination)	Written examination (100%)

Recommended reading	• E. Hecht and A. Zajac, Optics • M. Born and E. Wolf, Principles of Optics • L. Mandel and E. Wolf, Optical Coherence and Quantum Optics • B.E.A. Saleh and M.C. Teich, Fundamentals of Photonics
Language of instruction	English

Modul **PAFMO220** Micro/Nanotechnology	
Module code	PAFMO220
Module title (German)	Micro/Nanotechnology
Module title (English)	Micro/Nanotechnology
Person responsible for the module	Dr. habil. Uwe Zeitner
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• demands of micro- and nano-optics on fabrication technology • basic optical effects of micro- and nano-structures and their description • typical structure geometries in micro- and nano-optics • coating technologies • lithography (photo-, laser-, electron-beam) and its basic physical principles • sputtering and dry etching • special technologies (melting, reflow, …) • applications and examples
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.
Requirements for awarding credit points (type of examination)	Written examination (100%)
Language of instruction	English

Modul **PAFMO221** Microscopy	
Module code	PAFMO221
Module title (German)	Microscopy
Module title (English)	Microscopy
Person responsible for the module	Prof. Dr. R. Heintzmann, Prof. Dr. C. Eggeling
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Optical microscopy • Circumventing the resolution limit • Electron microscopy • Atomic force microscopy
Intended learning outcomes	This Module provides an introduction into the fundamentals of modern light and electron microscopy.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul **PAFMO222** Modern Methods of Spectroscopy	
Module code	PAFMO222
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	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics”
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	• Fundamentals of light-matter interaction; • Experimental tools of spectroscopy; • laser spectroscopy; • Time-resolved spectroscopy; • Laser cooling; • THz and X-ray spectroscopy; • photoelectron spectroscopy; • Applications of laser spectroscopy in physics, chemistry, medicine.
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	Active participation in the discussions in the seminar.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%) The form of the exam will be announced at the beginning of the semester.
Language of instruction	German, English

Modul **PAFMO230** Nano Engineering	
Module code	PAFMO230
Module title (German)	Nano Engineering
Module title (English)	Nano Engineering
Person responsible for the module	Dr. Stephanie Höppener, Prof. Dr. Ulrich S. Schubert
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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	• Building with Molecules • Self-organization and self-assembled coatings • Chemically sensitive characterization methods • Nanomaterials for optical applications • Nanowires and nanoparticles • Nanomaterials in optoelectronics • Bottom-up synthesis strategies and nanolithography • Polymers and self-healing coatings • Molecular motors • Controlled polymerization techniques

Intended learning outcomes	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. 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.
Prerequisites for admission to the module examination	Assignments
Requirements for awarding credit points (type of examination)	Oral examination (100%)
Recommended reading	• G. Cao, Nanostructures & Nanomaterials: Synthesis, Properties & Applications, Imperial College Press, 2004 • G.A. Ozin, A.C. Arsenault, L. Cademartiri, A Chemical Approach to Nanomaterials, Royal Soc. Of Chemistry, 2nd Ed., 2009 • L.F. Chi, Nanotechnology Vol. 8 Nanostructured Surfaces, Wiley-VCH, 2010
Language of instruction	English

Modul **PAFMO231** Nonlinear Dynamics in Optical Systems	
Module code	PAFMO231
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	none
Recommended or expected prior knowledge	Basic knowledge in electrodynamics
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics" Required elective module M.Sc. Photonics
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	• Non-Linear dynamics in optical fibers and waveguides • Solution of non-linear partial differential equations • Solitons and collapse in optical systems • Super continuum generation
Intended learning outcomes	Understanding the theoretical fundamentals of non-linear dynamics in optical systems
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%)
Recommended reading	• Agrawal, Govind P. Non-Linear optics • Moloney, Jerome V., Newell Alan C., Non-Linear Optics • Y.S.Kivshar and G.Agrawal, Optical Solitons: From Fibers to Photonic Crystals
Language of instruction	German or English on request

Modul **PAFMO242** Optics for Spectroscopists: Optical Waves in Solids	
Module code	PAFMO242
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. Thomas Mayerhöfer
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Limitations and non-linearities of the (Bouguer-)Beer-Lambert law derived from wave-optics based approaches. • Reflection and Refraction at isotropic and anisotropic interfaces (Yeh's formalism, Berreman formalism, special cases, Euler orientation representations, example spectra etc.) • 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.) • 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.
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.
Requirements for awarding credit points (type of examination)	Oral examination (100%)

Recommended reading	• Wave optics in infrared spectroscopy, lecture notes, Thomas Mayerhöfer (https://www.researchgate.net/project/Book-Project-Wave-Optics-in-Infrared-Spectroscopy) • Optical Waves in Layered Media, Pochi Yeh,Wiley, 2005 • Absorption and Scattering of Light by Small Particles Craig F. Bohren, Donald R. Huffman, 1998 • The Infrared spectra of minerals, Victor Colin Farmer, Mineralogical Society, 1974
Language of instruction	English

Modul **PAFMO250** Particles in Strong Electromagnetic Fields	
Module code	PAFMO250
Module title (German)	Particles in Strong Electromagnetic Fields
Module title (English)	Particles in Strong Electromagnetic Fields
Person responsible for the module	Prof. Dr. Matt Zepf, Dr. Sergey Rykavanov
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	<p>Fundamental knowledge on electrodynamics und special theory of relativity <pre id="tw-target-text" class="tw-data-text tw-ta tw-text-medium" dir="ltr" style="text-align: left;" data-placeholder="Übersetzung"> </pre>
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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	• Electrons in constant fields • Electrons in electromagnetic pulses • Radiation produced by particles in extreme motion • Radiation reaction • QED effects in strong laser fields
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.

Requirements for awarding credit points (type of examination)	Presentation or oral Exam (100%)
Recommended reading	• J.D. Jackson, Classical Electrodynamics • L.D. Landau and E.M. Lifshitz, Classical Theory of Fields • P. Gibbon, Short Pulse Laser Interactions with Matter • G.A. Mourou, T. Tajima, and S.V. Bulanov, Optics in the relativistic regime, Reviews of Modern Physics, 78, 309 (2006)
Language of instruction	Englisch

Modul **PAFMO251** Physical Optics Design	
Module code	PAFMO251
Module title (German)	Physical Optics Design
Module title (English)	Physical Optics Design
Person responsible for the module	Prof. Dr. Frank Wyrowski
Recommended or expected prior knowledge	Module Fundamentals of Modern Optics and Introduction to Optical Modeling and Design oder äquivalent
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics" Required elective Module M.Sc. Photonics
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	• Concept of physical optics modeling by field tracing • Geometric field tracing by smart rays. • Design as an inverse field propagation problem • System design in the functional embodiment • Design of lens systems for laser sources • Design of systems for light shaping by holographic optical elements and freeform surfaces • Inclusion of partially coherent and polychromatic light; multiplexing • Optimization of coatings and gratings in structure design • Applications in laser optics, wavefront engineering, and lighting
Intended learning outcomes	Optical design is typically based on ray optics. It is discussed when the ray approach fails and a physical optics based concept can be used to tackle such situations. Moreover, physical optics provides very powerful concepts in system design, since the design tasks are formulated in terms of fields which enables access to all parameters of concern in design. Various examples from different applications are investigated to illustrate and demonstrate theoretical results.
Requirements for awarding credit points (type of examination)	Exam(100%)

Recommended reading	• E. Hecht and A. Zajac, Optics • M. Born and E. Wolf, Principles of Optics • R.E. Fischer and B. Tadic-Galeb, Optical System Design • J. Turunen and F. Wyrowski, Diffractive Optics for industrial and commercial applications, Akademie Verlag, 1997
Language of instruction	English

Modul **PAFMO252** Physical Optics Modeling	
Module code	PAFMO252
Module title (German)	Physical Optics Modeling
Module title (English)	Physical Optics Modeling
Person responsible for the module	Prof. Dr. F. Wyrowski
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	Fundamental knowledge on optical modeling and design
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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 field tracing; • Diffraction integrals, free space propagation; • Propagation through plane interfaces and stratified media; • Propagation through gratings; • Mie theory; • Geometric field tracing; • Thin element approximation; • Propagation through lenses and refractive freeform surfaces; • Propagation through diffractive lenses and computer-generated holograms; • Modeling combined surfaces (refractive + microstructures); • All techniques are demonstrated at hands-on examples.
Intended learning outcomes	Physical optics modeling deals with the solution of Maxwell’s equations for different types of optical components. On its basis, a source field can be propagated through a system by the concept of field tracing. The students will get an introduction to field tracing and a comprehensive overview of different modeling techniques of practical importance in optical modeling and design.

Prerequisites for admission to the module examination	None
Requirements for awarding credit points (type of examination)	written Exam (100%)
Recommended reading	• E. Hecht and A. Zajac, Optics; • M. Born and E. Wolf, Principles of Optics; • L. Novotny and B. Hecht, Principles of Nano-Optics.
Language of instruction	English

Modul **PAFMO253** Physics of Free-Electron Laser	
Module code	PAFMO253
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	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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	• physical foundations of X-ray lasers • undulators • FEL differential equation • Instrumentation • selected applications
Intended learning outcomes	The student understands the physical foundations, instrumentation, and selected applications of FELs. Acquisition of the competence to judge the applicapility and significance of FELs to address problems in X-ray physics.
Requirements for awarding credit points (type of examination)	Oral examination (100%).
Recommended reading	Schmüser et al.: Ultra-violet and Soft X-ray Free-Electron Lasers
Language of instruction	English

Modul **PAFMO254** Physics of Ultrafast Optical Discharge and Filamentation	
Module code	PAFMO254
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. Christian Spielmann, Dr. Daniil Kartashov
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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	• physics of photoionization • optical breakdown • basics of plasma kinetics • LIBS Laser induced breakdown spectroscopy • physics of filamentation • applications: LIDAR, lightning discharge, supercontinuum generation
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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul **PAFMO255** Plasma Physics	
Module code	PAFMO255
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	None
Recommended or expected prior knowledge	Fundamental knowledge on electrodynamics und laser physics
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics" Required elective Module M.Sc. Photonics
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	• Fundamentals of plasma physics; • Single particle and fluid description of plasmas; • Waves in plasmas; • Interaction of electromagnetic radiation with plasmas; • Plasma instabilities; • Non-linear effects (shock waves, parametric instabilities, ponderomotive effects, ...).
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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The form of the exam will be announced at the beginning of the semester.

Recommended reading	• F. Chen: Plasma Physics and Controlled Fusion, Plenum Publishing Corporation, New York (1984); • J. A. Bittencourt: Fundamentals of Plasma Physics, Springer, New York (2004); • U. Schumacher: Fusionsforschung, Wissenschaftliche Buchgesellschaft, Darmstadt (1993).
Language of instruction	English

Modul **PAFMO256** Physics of Photovoltaics	
Module code	PAFMO256
Module title (German)	Photovoltaik
Module title (English)	Physics of Photovoltaics
Person responsible for the module	Prof. Dr. Gerhard G. Paulus
Prerequisites for admission to the module	none
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus Optics, Solid-state Physics Required elective Module M.Sc. Photonics
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	• Pertinent elements of thermodynamics and statistical mechanics (diffusion, Boltzmann factor, free energy) • Fundamental concepts of solid state physics • Semiconductors and pn-junction • Diode equation • Shockley-Queisser limit • Design criteria for solar cells
Intended learning outcomes	• Profound understanding of the physics underlying the performance of solar cells • Development of an understanding of the role of photovoltaics for covering the energy demand of modern societies. • Capability to solve complex problems pertinent to solar cells
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 form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul **PAFMO257** Physical Optics	
Module code	PAFMO257
Module title (German)	Physical Optics
Module title (English)	Physical Optics
Person responsible for the module	Prof. Dr. H. Gross
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus "Optics" Required elective Module M.Sc. Photonics Compulsory Module M.Sc. Medical Photonics
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: 2 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	• Wave optics, light propagation • Diffraction, slit, PSF, aberrations • Coherence, temporal and spatial, OCT, speckle • Laser, resonators, laser beams, pulses • Gaussian beams, propagation, generalizations, Schell beams • Fourier optics, resolution, image formation, OTF, criteria • Quality criteria of imaging • PSF engineering, superresolution, extended depth of focus • Confocal methods, laser scanning, metrology • Polarization, fundamentals, Jones vectors, birefringence • Photon optics, uncertainty, statistics • Scattering, surfaces, volume models, tissue optics • Miscellaneous, coatings, non-linear optics, short pulses
Intended learning outcomes	The course covers the basic understanding of physical optical subjects in the context of optical systems.
Requirements for awarding credit points (type of examination)	written examination (100%)
Additional information on the module	Parts of the lectures are given by a Dr. B. Böhme / C. Zeiss and M. Dienerowitz / Medical Faculty to include industrial and practical viewpoints.

Recommended reading	Lecture materials • B. Saleh, M. Teich, Fundamentals of Photonics, Wiley, 2007 • W. Singer, M. Totzeck, H. Gross, Handbook of optical systems, Vol 2, Wiley, 2005 • J. Goodman, Introduction to Fourier Optics, Wiley, 2005 • A. Lipson / S. Lipson, Optical Physics, Cambridge 2011 • G. Reynolds / J. deVlies, The Physical Optics Notebook, SPIE Press, 2000 • J. Goodman, Statistical Optics, Wiley, 1985 • E. Hecht, Optics, deGruyter, 2014 • C. Brosseau, Polarized Light, Wiley, 1998 • J. Stover, Optical Scattering, McGrawHill, 1990 • M. Nieto-Vesperinas, Scattering and Diffraction in Physical Optics, World Scientific, 2016 • A. Siegman, Lasers, Oxford University, 1986 • F. Trager, Handbook of Lasers and Optics, Springer, 2007
Language of instruction	English

Modul **PAFMO260** Quantum Optics	
Module code	PAFMO260
Module title (German)	Quantum Optics
Module title (English)	Quantum Optics
Person responsible for the module	Prof. Dr. T. Pertsch, Dr. F. Setzpfandt
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	Fundamental knowledge on quantum theory, electrodynamics, theoretical optics
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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	• Basic introduction to quantum mechanics; • Quantization of the free electromagnetic field; • Non-classical states of light and their statistics; • Experiments in quantum optics; • Semi-classical and fully quantized light-matter interaction; • Non-Linear optics.
Intended learning outcomes	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. 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.
Requirements for awarding credit points (type of examination)	Written or oral examination (100%). The form of the exam will be announced at the beginning of the semester.

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 **PAFMO265** Semiconductor Nanomaterials	
Module code	PAFMO265
Module title (German)	Semiconductor Nanomaterials
Module title (English)	Semiconductor Nanomaterials
Person responsible for the module	Jun.-Prof. Dr. Isabelle Staude
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	Fundamental knowledge on modern optics and condensed matter physics
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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: • Review of fundamentals of semiconductors • Optical and optoelectronic properties of semiconductors • Effects of quantum confinement • Photonic effects in semiconductor nanomaterials • Physical implementations of semiconductor nanomaterials, including epitaxial structures, semiconductor quantum dots and quantum wires • Advanced topics of current research, including 2D semiconductors and hybrid nanosystems

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.
Requirements for awarding credit points (type of examination)	written examination at the end of the semester and oral presentation on a current research topic
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 **PAFMO266** Strong-Field Laser Physics	
Module code	PAFMO266
Module title (German)	Strong-Field Laser Physics
Module title (English)	Strong-Field Laser Physics
Person responsible for the module	Prof. Dr. G. G. Paulus
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics specialisation Optics Required elective module M.Sc. Photonics
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	• characteristic quantities in attosecond laser physics • characteristic effects (above-threshold generation, high-harmonic generation, non-sequential double ionization) • experimental techniques • theoretical description of strong-field electron dynamics • recollision as a fundamental process in strong-field and • attosecond laser physics • generation and measurement of attosecond pulses
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.
Requirements for awarding credit points (type of examination)	oral examination (100%)
Recommended reading	Review-Artikel Z. Chang: Fundamentals of Attosecond Optics
Language of instruction	English

Modul **PAFMO270** Theory of Nonlinear Optics	
Module code	PAFMO270
Module title (German)	Theory of Nonlinear Optics
Module title (English)	Theory of Nonlinear Optics
Person responsible for the module	Prof. Dr. U. Peschel
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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	• Types and symmetries of non-linear polarization; • Non-Linear optics in waveguides; • Solutions of non-linear evolution equations; • Temporal and spatial solitons; • Super continuum generation.
Intended learning outcomes	The course provides the theoretical background of non-linear optics and quantum optics.
Requirements for awarding credit points (type of examination)	Exam (100%)
Additional information on the module	Die Modulnote setzt sich aus der Übungleistung (25%) und einer mündlichen Prüfung zusammen (75%).
Recommended reading	• Agrawal, Govind P.: Contemporary non-linear optics; • Moloney, Jerome V., Newell Alan C.: Non-Linear Optics ; • Sutherland, Richard Lee: Handbook of non-linear optics.
Language of instruction	English

Modul **PAFMO271** Thin Film Optics	
Module code	PAFMO271
Module title (German)	Thin Film Optics
Module title (English)	Thin Film Optics
Person responsible for the module	Prof. Dr. A. Tünnermann, Dr. O. Stenzel
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	Fundamental knowledge on optics and elektrodynamics in continuums
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics" Required elective Module M.Sc. Photonics
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	• Basic dispersion models in Thin Film Optics • Optical properties of material mixtures • Interfaces: Fresnels equations • Multiple internal reflections in layered systems • Optical spectra of single thin films • Wave propagation in stratified media • Matrix formalism • Multilayer systems: Quarterwave-stacks and derived systems • Coatings for ultrashort light pulses • Remarks on coating design
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.
Requirements for awarding credit points (type of examination)	Written examination (100%).

Recommended reading	• Born/Wolf: Introduction to optics; • H. A. Macleod, Thin Film Optical Filters, Adam Hilger Ltd. 2001; • R. Willey, Practical Design and Productions of Optical Thin Films, Marcel Dekker Inc. 2003; • N. Kaiser, H. K. Pulker (Eds.), Optical Interference Coatings, Springer Series in Optical Sciences, Vol. 88, 2003; • O. Stenzel, The Physics of Thin Film Optical Spectra. An Introduction, Springer Series in Surface Sciences, Vol. 44, 2005.
Language of instruction	English

Modul **PAFMO272** Terahertz Technology	
Module code	PAFMO272
Module title (German)	Terahertz Technology
Module title (English)	Terahertz Technology
Person responsible for the module	Prof. Dr. G. Paulus
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	The course will provide an introduction to the fundamentals of THz technology and science to master students. The course begins with an introduction to THz radiation and current status of terahertz research. A review on the interaction of electromagnetic waves with matter will be discussed followed by the elementary excitation in matter during interaction with THz. Various techniques to generate THz radiation will be presented with an emphasis on pulsed power sources. Detection techniques are equally important in studying the terahertz radiation. We will look at the detection schemes based on electronics and photonics and compare them. Attention will also be paid to selecting suitable optics for THz and materials suitable for THz transmission. Finally, we will also look at some potential applications of THz in the field of imaging, spectroscopy, etc.
Prerequisites for admission to the module examination	Abgabe von Übungsaufgaben (Art und Umfang wird zu Semesterbeginn bekannt gegeben)
Requirements for awarding credit points (type of examination)	exam (100%)
Additional information on the module	Die Modulnote besteht aus bewerteten Übungsaufgaben und einer schriftlichen Prüfung oder mündlichen Präsentation.

Recommended reading	• Principles of terahertz Science and Technology, Lee, Yun-Shik , Springer ,ISBN 978-0-387-09540-0 • Terahertz techniques, Bründermann, Hubers,Kimmit, Springer, ISBN 978-3-642-02592-1 • Introduction to THz wave photonics, Zhang, Xu,Springer, ISBN 978-1-4419-0978-7 • Journals: Journal of Infrared, Millimeter and Terahertz waves, IEEE transactions on Terahertz technology, OSA and Nature publications
Language of instruction	English

Modul **PAFMO280** Ultrafast Optics	
Module code	PAFMO280
Module title (German)	Ultrafast Optics
Module title (English)	Ultrafast Optics
Person responsible for the module	Prof. Dr. S. Nolte
Prerequisites for admission to the module	None
Recommended or expected prior knowledge	Basic knowledge in laser physics and modern optics.
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics" Required elective Module M.Sc. Photonics
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	• Introduction to ultrafast optics; • Fundamentals; • Ultrashort pulse generation; • Amplification of ultrashort pulses; • Measurement of ultrashort pulses; • Applications; • Generation of attosecond pulses.
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%).

Recommended reading	• Weiner, Ultrafast Optics; • Diels/Rudolph, Ultrashort Laser Pulse Phenomena; • Rulliere, Femtosecond laser pulses; • W. Koechner, Solid-state Laser engineering; • A. Siegman, Lasers.
Language of instruction	English

Modul **PAFMO290** 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, Dr. D. Kartashov
Prerequisites for admission to the module	None
Type of module (compulsory module, required elective module, elective module)	Required elective Module M.Sc. Physics focus „Optics” Required elective Module M.Sc. Photonics
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	• Complex refractive index in the XUV and X-ray range; • Refractive and grazing incidence optics; • Zone plate optics; • Thomson and Compton scattering; • X-ray diffraction by crystals and synthetic multilayers; • VUV and X-ray optics for plasma diagnostics; • Time-resolved X-ray diffraction; • EUV lithography.
Intended learning outcomes	This course covers the fundamentals of modern optics at short wavelengths as they are necessary for the design of EUV and X-ray optical elements. Based on this the students will learn essentials of several challenging applications of short-wavelength optics, being actual in modern science and technology.
Requirements for awarding credit points (type of examination)	written exam (100%)
Language of instruction	English

Modul **PAFMO901** Topics of Current Research 1	
Module code	PAFMO901
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	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Advanced topics of current research in optics and photonics
Intended learning outcomes	• Introduction into a field of current ressearch as a basis for further study and research in this field; • Independent solution of Exercise problems; • Ability to acquire further knowledge by independent literature studies.
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 form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul **PAFMO902** Topics of Current Research 2	
Module code	PAFMO902
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	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Advanced topics of current research in optics and photonics
Intended learning outcomes	• Introduction into a field of current ressearch as a basis for further study and research in this field; • Independent solution of exercise problems; • Ability to acquire further knowledge by independent literature studies.
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 form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul **PAFMO903** Topics of Current Research 3	
Module code	PAFMO903
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	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Advanced topics of current research in optics and photonics
Intended learning outcomes	• Introduction into a field of current ressearch as a basis for further study and research in this field; • Independent solution of Exercise problems; • Ability to acquire further knowledge by independent literature studies.
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 form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Modul **PAFMO904** Topics of Current Research 4	
Module code	PAFMO904
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	none
Type of module (compulsory module, required elective module, elective module)	Required elective module M.Sc. Physics focus „Optics” Required elective module M.Sc. Photonics
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: - In-class studying - Independent studying (incl. preparations for examination)	120 h 45 h 75 h
Content	• Advanced topics of current research in optics and photonics.
Intended learning outcomes	• Introduction into a field of current ressearch as a basis for further study and research in this field; • Independent solution of Exercise problems; • Ability to acquire further knowledge by independent literature studies.
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 form of the exam will be announced at the beginning of the semester.
Language of instruction	English

Abbrevations:

Abbrevations 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
E/T....	Exam/test
C....	Colloquium
C/I....	Colloquium/practical work
CS....	Conference/symposium
kV....	Kulturelle Veranstaltung
Co....	Course
Cu....	Course

Abbrevations of lectures

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
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
SI....	Conference
SuSch....	Summer school
MISC....	Miscellaneous
OE....	Other event
LC....	Language course
Con....	Convention
TT....	Teleteaching
MN....	Meeting
T....	Tutorial
Tu....	Tutorial
E....	Exercise
E/BC....	Exercise/block course
E....	Exercises
E/I....	Exercise/interdisciplinary
E/I....	Exercise/practical work
E/T....	Exercise/tutorial

Abbrevations of lectures

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
TK....	Talk
Sp....	Speech
OS....	Optional seminar
OL....	Optional lecture
Tr....	Training
WOS....	Workshop
Wo....	Workshop
CAC....	Certificate award ceremony

Other Abbrevations

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